The potential for, and costs of, reducing greenhouse gas emissions from non-energy sources in South Africa

R TAVIV*, R WISE*, M VAN DER MERWE* AND H WINKLER**
*NRE, CSIR; South Africa
** ERC University of Cape Town, South Africa
Email: rtaviv@csir.co.za

Abstract

The South African Government commissioned a detailed study entitled Long-Term Mitigation Scenarios (LTMS). This study defined and quantified the mitigation options and associated costs available under several energy and economic futures. Following a high-level process based on the outcomes of the LTMS, Cabinet adopted a vision, strategic direction and framework for policy on climate change mitigation.

Most of the studies on mitigation costs focus on the energy sector, but less is known about the costs of mitigation in non-energy sectors. This is of particular importance in many developing countries where non-energy sectors are substantial contributors to national emissions. The non-energy sectors include waste management and several forms of land use: forestry, crop agriculture, animal management. The options for mitigation were assessed and prioritized. The following six options were selected for more detailed analysis:
1) increasing afforestation; 2) shifting to low or non-till farming practices; 3) changes in livestock management to reduce emissions from enteric fermentation; 4) improvements in manure management options; 5) fire control and 6) improved waste management.

A spreadsheet-based financial model was developed to analyse annual and cumulative mitigation potential and costs of the mitigation options, compared to baseline scenario costs. Only CO_2 and CH_4 emissions were considered. Levelised annual costs, expressed as a marginal cost of CO_2-eq reduction were calculated. The results showed that fire control is the most cost-effective option per unit of avoided emission and has the highest mitigation potential. Fire control has a negative mitigation cost because of the co-benefits from reducing fire damage. Its mitigation potential is further enhanced by the concurrent process of bush encroachment, which provides a CO_2 sink lasting several decades in the affected areas.

Many recent studies have shown that actual levels of greenhouse gases (GHG) mitigation are far below the technical potential for existing mitigation options. The gap is caused by mitigation costs and other barriers. This study improved understanding of the mitigation potential and provided some quantitative assessment of the costs for the non-energy sector for South Africa. The study limitations were also described and areas of further research recommended.

1. Introduction

The IPCC 4th assessment report (IPCC, 2007) concluded that human activities unequivocally contribute to global climate change. The Stern Review demonstrated that overall, mitigation is cheaper than adaptation and needs to be implemented without further delay (Stern Review, 2006). A large amount of work has been done on the cost of the mitigation in various sectors, countries and using a range of technologies. However most of the work has focused on the energy sector, and less is known about the costs of mitigation in the non-energy sectors. Furthermore, most of the research has been conducted on mitigation in developed counties as many of them undertook a commitment under the Kyoto protocol to reduce their greenhouse gas (GHG) emissions.

Although South Africa emits only about 1% of the global annual CO_2 emissions (Scenario Building Team (SBT), 2007), it has an energy intensive economy. Both its GHG emissions per capita and GHG emissions per unit of GDP are nearly double that of the world average. This means that, even as a developing country, South Africa has some responsibility for mitigation. The South African Government, through the Department of Environmental Affairs and Tourism (DEAT) commissioned a process to examine long-term mitigation scenarios (LTMS) for South Africa. Strategic thinkers from a range of stakeholders participated in the SBT that considered the potential of mitigation options in terms of emission reductions and associated costs (or savings). The SBT considered several energy and economic futures. A Scenario Document was approved in October 2007 (SBT, 2007). Following a high-level process, Cabinet adopted a vision, strategic direction and framework for policy on climate change mitigation (Van Schalkwyk, 2008). This paper is based on technical work done as part of the LTMS study (Taviv et al., 2007).

2. Main findings of the LTMS study

The LTMS study is the first study of its kind in the developing world. The combination of research-based scenarios with an intensive stakeholder consultation process was a pioneering effort to provide high-quality information for decision making on climate change response strategies in South Africa. The methodologies used in the research were consistent with international best practice and the results are robust.

The LTMS study considered two main scenarios: Growth Without Constraints (GWC), in which emissions would grow in the absence of any policy constraint on carbon emissions; and Required By Science (RBS), in which emissions peak soon, and then decline to -30% to -40% from the base year levels by 2050. In attempting to close the large gap between GWC and RBS, three strategic options were modelled and discussed with stakeholders: Start Now, Scale Up and Use the Market. When it became clear that with known technologies and assuming known costs it would not be possible to fully bridge the gap between GWC and RBS for the full 48 years, a fourth strategic option - ‘Reach for the Goal’ - was added. This option focuses on R&D for new technologies, identifying new resources, fully including people-centred measures and addressing a transition to low-carbon economy – see Figure 1.

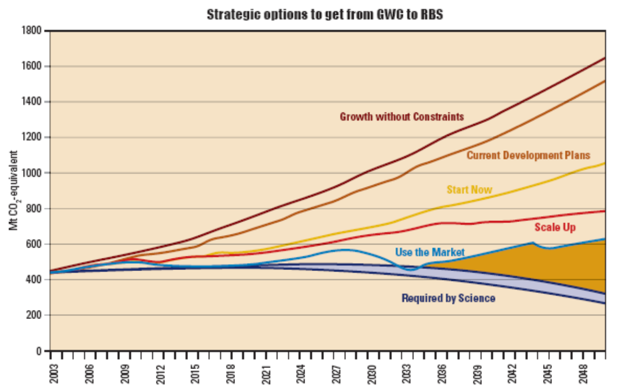

Figure 1: LTMS scenarios (source: SBT, 2007)

According to Van Schalkwyk, 2008 “*it is clear that without constraints our emissions might quadruple by 2050. This is, in the most literal sense, not sustainable: If we continue with business-as-usual, we will go out of business. The alternative is a very challenging scenario – to make it our goal to achieve what is required by science of a developing country.”*

The LTMS (SBT, 2007) showed that a massive effort by South Africa would be required to achieve emissions reduction sufficient to meet the RBS target. The modelled scenarios were based on different combinations of mitigation options. The mitigation options quantified by the LTMS included energy efficiency, in industry and other sectors; electricity supply options; carbon capture and storage; transport efficiency and shifts; mitigation by changes in industrial processes, agriculture, land use and afforestation. Mitigation potential and costs were calculated for 36 options. The costs to the economy for implementation of these options range from affordable to very substantial. It was shown that a number of options have negative costs (i.e. savings), which means that their implementation has initial costs, but saves much more money over time and hence brings long-term net benefits.

When considering the options, the South African government would be well advised to implement the ‘Start Now’ scenario and at the same time initiate the R&D programme required for the ‘Reach for the Goal’ option. To more fully close the gap between the GWC and RBS scenarios, South Africa can choose both regulatory and economic instruments. However, even the combination of approaches would close the gap only up to about

2035 (see Figure 1). After that, the new strategies developed under 'Reach for the Goal' would be needed to help close the gap.

The framework for Climate change policy (Van Schalkwyk, 2008) focused on energy and industrial sectors. In this paper the mitigation potential and the costs of non-energy related mitigation options are described and their importance for developing countries is explained. The non-energy sectors are: forestry, agriculture and other land uses as well as waste. The full details of the study are available in the report downloadable from the LTMS web-site: (http://www.erc.uct.ac.za/Research/LTMS/LTMS-intro.htm) (Taviv et al., 2007).

3. Global emissions in non-energy sector

Global GHG emissions per sector prepared by the IPCC (Barker *et al*, 2007) are presented below.

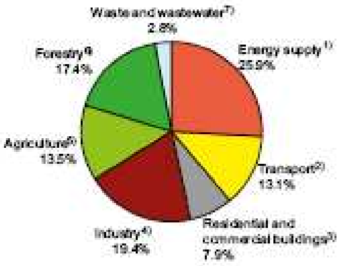

Figure 2: GHG emissions in 2004 (source: Barker *et al.*, 2007)

The emissions from non-energy sectors are roughly 33 % of the total. Similar values were estimated by USEPA, 2006, which calculated that agriculture and waste contributed 35% of the global total in 2000. The emissions for these two sectors and the global total are summarised in Table 1.

The slight difference in estimations for the non-energy sectors between two reputable sources of information (IPCC and USEPA) is explained by the fact that they may include or exclude different sub-sectors. Non-energy sectors are thought to have higher error margins than those of the energy and industry sectors.

The projected growth in emissions is even more uncertain than the variation in historical emission estimates. The IPCC 4th Assessment report (Barker *et al.*, 2007) projected emissions up to 2100. The range of total baseline emissions for 2100 varies, from 17 000 to 135 000 Mt CO_2-eq. Most of this range is because of uncertainty about the political and economic responses to the emerging climate change problem – will the world continue with Business as Usual, or will it collectively adopt a strong climate change avoidance strategy?

Table 1: Global emissions for agriculture and waste sectors for 2000 (Mt CO_2-eq)*

Sectors	CO_2	CH_4	N_2O	Global total	% Global
Agriculture	7631	3113	2616	13360	32
Waste	0	1255	106	1361	3
Other sectors	24237	1653	392	26661	64
Global total	**31868**	**6021**	**3114**	**41382**	**100**

* *source: USEPA, 2006*

In developing countries the contribution of the agricultural and waste sectors are often higher than the global average of 35% (USEPA, 2006). In South Africa, the highly developed energy intensive industry and dependency on coal in electricity production results in a much lower contribution by these two sectors, which in 2005 was estimated to be below 10% (Taviv *et al.*, 2007). Nevertheless, the potential mitigation was evaluated for all options selected by stakeholders as described in the section below.

4. Mitigation in non-energy sector

4.1 Sectors and options considered

The relevant non-energy sectors and mitigation options were selected using the procedures and processes developed in the LTMS study. It was based on an intensive literature review and a number of workshops with the Scenario Building Team (SBT). The SBT operated for about 18 months and was closely involved in every step of the process.

The selected non-energy sectors correspond with the sectors included in the South African GHG inventory (DEAT, 2004) and include: forestry, agriculture and other land uses as well as waste. The options for mitigation in these sectors were assessed and prioritized based on numerous criteria, the most critical one being the potential mitigation value. The following six mitigation options were selected:

1) increasing afforestation;
2) shifting to low or no-till farming practices;
3) changes in livestock management to reduce emissions from enteric fermentation;
4) improvements in manure management options;
5) fire control, and
6) improved waste management.

4.2 Methodology for calculation of mitigation potential

First, long-term baseline emission scenarios were developed based on the key drivers of GHG emissions such as population, GDP growth and technological changes. The same assumptions for population and GDP growth were used for all the sectors in the LTMS study. Baseline emission projections from 2003 to 2050 were developed and agreed to by the SBT.

The second step involved determining the mitigation potential for each of the six selected mitigation options. These estimates were calculated using sector-specific, spreadsheet–based models. For this study, the models for afforestation, agriculture and land use, developed previously for the South African Country Study on Climate Change (Scholes *et al*., 2000), were updated and extended and a new model was developed for the waste sector. An extensive data collection process supported by the SBT was undertaken to populate the models and to define sector-specific assumptions.

Two GHGs were considered - carbon dioxide (CO_2) and methane (CH_4) as these make up 92% of global emissions. The emissions of nitrous oxide (N_2O) were ignored as the mitigation potential for the options considered in this study was very small. To calculate the contribution of CH_4 emissions to an increase in radiative forcing, the total amount of this gas emitted annually was converted to CO_2 equivalents (CO_2-eq) using the relevant Global Warming Potentials calculated over 100 years (IPCC, 1996). In the short term, the mitigation of the non-CO_2 emissions has an advantage because CH_4 is about 21 times more powerful at warming the atmosphere than CO_2 over a 100-year period.

4.3 Description of mitigation options

Increased afforestation

Forestry plays a major role in the first and second economy in South Africa. About 15% of the land surface of South Africa is climatically suitable for afforestation and only about a tenth of this area is actually planted to forests. Strong justification for additional afforestation based on economic growth needs has been provided by the Minister of Water Affairs and Forestry (Hendriks, 2006), but constraints are imposed by the impact on water supplies, biodiversity, and the needs of competing land uses.

When tree plantations replace grasslands the amount of carbon stored per unit ground area increases as the trees mature. It is temporarily and partially (most of the below ground biomass is retained) reduced again at the time of tree harvest. The time-averaged carbon density for plantations is higher than for grasslands (Scholes, *et al.,* 2000).

For the baseline scenario the rate of expansion of the total plantation area is assumed to be 11 000 ha per year for 48 years (based on an average value calculated from the data provided by the Forestry Industry (www.Forestry.co.za). For the mitigation option it is assumed that the net afforestation will increase by 200% from 2008 to 2030 to allow for an additional 760 000 ha (close to the value suggested in DWAF, 2004). This mitigation option is unusual because it provides the highest mitigation potential while supporting GDP growth – but the aforementioned constraints may reduce the extent to which this option can be implemented.

Shifting to low-till or no-till farming practices

Conversion of land from natural grassland, savanna or forest to cropland, through the process of tillage, causes carbon to be lost from the soil. Carbon is lost because the amount of 'below ground' carbon produced by crops is typically less than from the original grasslands, and because the physical disturbance caused by the plough accelerates the decomposition of soil carbon. A range of farming techniques called *no-till, reduced-till, returned residue or conservation tillage*, can be used to grow crops with less soil disruption and a greater return of crop residues to the soil. There are many co-benefits of this practice, including reduction in soil erosion and increased soil fertility. The main barriers to the adoption are the lack of access to information; the need for intensive management and the high capital cost of the specialized equipment.

Two mitigation scenarios were considered. For the 'Start now' scenario, the average adoption of reduced tillage is assumed to be 30%, (much higher for wheat, and much lower for maize). For the 'Required by Science' scenario the adoption of reduced tillage is assumed to be 80%.

Changes in livestock management to reduce emissions from enteric fermentation

Enteric fermentation in cattle and sheep is the largest single source of methane in the South African GHG inventory (van der Merwe and Scholes, 1998). Methane is a by-product of digestion, and represents a loss of energy to the animal, which could otherwise be used for mass gain. Therefore, reduction of emissions is in the interest of livestock farmers while also providing a mitigation benefit. Increasing the efficiency of production (meat, milk, wool and hides) per animal can decrease these emissions and may also improve the net margins in the livestock sector, which are low.

Enteric methane emissions of livestock are dependant on the type, age and weight of the animal, the quality and quantity of forage and the energy expenditure of the animal. A reduction of enteric emissions of CH_4 could be achieved if the herd composition is optimized for maximum production and the quality of the feed is improved. Moving some livestock to feedlots and improving the quality of their feed reduces their enteric fermentation emissions, but increases the emissions from manure handling (see next section). For this reason these two processes are modelled together.

The mitigation option assumes a smaller herd (reduced by 30%), but a more productive herd as a result of moving some animals from rangelands to feedlots with high-digestibility and high protein forage containing the appropriate oil content. It is assumed that 5% of free-range herd is moved to feedlots each year until 45% of the cattle are in feedlots.

*I***mprovements in manure management options**

Animal manure, when decomposed in continuously anaerobic (waterlogged) conditions, generates both methane and nitrous oxide. Emissions from this source in South Africa are 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. In feedlots, the excreta can be handled in the following ways: open lagoons, where wastes decompose anaerobically; completely closed anaerobic digestion systems, called biogas digesters, where methane can be trapped and used as a fossil fuel substitute; and dry spread, where the wastes are scraped daily and composted aerobically. The 'kraal manure' produced is applied to gardens and fields as an organic fertilizer.

To model mitigation, it was assumed that ten percent of the dairy and feedlot waste is consumed in a biogas digester. Ten percent is treated in open lagoons, and the remaining 80% is scraped and spread in dry form. Fifty percent of manure from the management of swine and poultry farms is spread in dry form, ten percent disposed in lagoons and the rest processed in digesters.

Fire control

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. It showed that investment in fire control is economically justifiable.

Improved fire control will lead to more 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. The causes are still poorly understood. Three leading reasons are: changes in the fire regime, changes in the grazing regime, and changes in the atmospheric carbon dioxide concentration. The impact of a warming climate may also be implicated in the spread of savannas into former grasslands.

Fires in the grasslands, savannas, fynbos and plantation forests in South Africa were 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. To model savanna thickening, 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 a function of fire return frequency and rainfall. For this model, mitigation by fifty percent reduction in the fire frequency is assumed.

Improved waste management.
Methane from landfills is produced in combination with other landfill gases (LFGs) through the natural process of bacterial decomposition of organic waste under anaerobic conditions. The LFG is generated over a period of several decades. 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 LFG generation within a landfill are an increased share of organic waste and increased levels of moisture.

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

The modelled mitigation options were composting and methane capture from municipal waste (with and without the use of energy). A number of simplifying assumptions were made for the calculation of emission reduction (e.g. the large landfill sites that will use LFG for energy production can use only about 70% of methane generated).

The implementation costs vary widely and need to be determined for each project. Because of the financial benefits provided through CDM, this is likely to be one of the first options to be implemented.

4.4 Methodology for calculating mitigation costs

The methodology for calculating mitigation costs was based on the approach developed for the South African Country Study (Clark and Spalding-Fecher, 1999). The approach drew on international best practice and used cost estimates reported in the national and international literature.

The approach can be summarised as follows:

- The costs of the mitigation and baseline options for the study period (2003 to 2050) were calculated by discounting all the costs of these options to a present value.
- These costs were then levelised and expressed in Rands per year. The resulting value is the same as payment for a loan (equal to present value) assuming constant payments and a constant interest rate. An interest rate of 3, 10% and 15% were used for calculations. The results presented below are based on an interest rate of 10%.
- The cost-effectiveness analysis was based on the difference in the levelised life cycle costs of the mitigation option and the baseline option (levelised annual cost), divided by the average annual reduction in emissions.

For each mitigation option the emissions reduction was calculated by adding the annual emissions over the study period (2003 to 2050), then subtracting the cumulative emissions for 48 years for the mitigation option from those of the baseline and calculating the average over the study period.

For example, the costs of the low-tillage practice were subtracted from that of conventional tillage.

5. Results

The results are presented below (see Table 2).

Table 2: Mitigation costs, cumulative emission reductions and ranking for mitigation options. Negative costs (ie net savings) are in brackets*

Mitigation action	Mitigation cost (R / t CO2-eq);	GHG emission reduction, Mt CO2-eq, 2003-2050	Rank by costs – (lowest cost is no.1)	Rank by emission reductions – (highest reduction is no.1)
Land use: fire control and bush encroachment	(R 15)	455	10	17
Waste management	R 14	432	15	20
Agriculture: enteric fermentation	R 50	313	21	24
Land use: afforestation	R 39	202	19	27
Agriculture: reduced tillage	R 24	100	18	31
Agriculture: manure management	(R 19)	47	9	34

***** *source: SBT, 2007*

The results of the modelling for non-energy options were extracted from the total summary table for all 36 options modelled in the LTMS study (Table 35 in SBT, 2007).

The mitigation costs were calculated using the methodology described above and expressed in R/t CO_2-eq mitigated. The mitigation potential was expressed as total cumulative GHG emission reduction for the study period. The 36 options modelled were ranked by costs and by emission reductions. Only the six options described in this paper are presented in the table above.

The table shows that two of the options (fire control and manure management) have negative costs, which makes them attractive for urgent implementation. Fire control has a negative mitigation cost because of the co-benefits from reducing fire damage. The negative cost of manure management is caused by the fact that mitigation through increased dry spread is cheaper than the presently used lagoon disposal. The limitations of this option are described in the section below.

The mitigation potential ranges from more than 400 Mt CO_2-eq (for fire control and waste management) to under 50 Mt CO_2-eq (for manure management). These values, although substantial, are much smaller than the mitigation potentials in the energy sector, and very much smaller than what is needed to close the gap between GWC and RBS. The highest mitigation option modelled by the LTMS overall was implementation of a Carbon tax (over 12 000 Mt CO_2-eq). There are 15 other options with greater mitigation potential than the mitigation achieved by fire control, but the contribution by fire control is nevertheless greater than some other options modelled, such as biofuels or coal methane reduction which may achieve mitigation of 154 Mt CO_2 eq and 61 Mt CO_2-eq with associated costs of 524R/t CO_2-eq and 346 R/t CO_2-eq respectively.

6. Importance of mitigation in the non-energy sector

Presently the focus of many government and sectoral activities is on the energy sector, because of the current electricity crisis and general importance of this sector for economic development. The energy sector contributes to more than eighty percent of GHG emissions and therefore most of the mitigation efforts should focus on this sector. However, the LTMS study demonstrated that in order to achieve the 'Required by Science' scenario all possible mitigation options need to be considered. This paper shows the advantages of implementing mitigation in the non-energy sector.

Firstly, these mitigation options are relatively cheap. As shown in Table 2 they rank from 9th to 21st position amongst 36 options considered and two of them have negative costs. Their cost is very low compared to the costs estimated in the IPCC report (Barker *et al*, 2007), where cost of under 20$/t CO_2-eq (which is equal to about R150/ t CO_2-eq) is considered as low.

Secondly, most of these options have co-benefits which have positive implications for sustainable development. In particular, afforestation supports GDP growth; waste management provides clean energy; livestock management reduces costs of meat and dairy and helps to control overgrazing. Low tillage helps with soil fertility and reduces soil erosion. The increased productivity of soils is an important benefit as global food demands increase. Low tillage also helps with water conservation and therefore the better use of dwindling water resources. Manure management helps to reduce water pollution and odour nuisance. However, agro-ecosystems are inherently complex and very few practices yield purely "win-win" outcomes (Smith *et al*, 2007).

Lastly, the speedy implementation of these options will place South Africa in a leading position amongst other developing countries. Since many developing countries have a low carbon footprint, the experience of South Africa in implementing these options could be transferred to and shared with other developing countries. Many recent studies have shown that actual levels of GHG mitigation are far below the technical potential for existing mitigation options. The gap is caused by mitigation costs and other barriers. This study improved understanding of the mitigation potential and provided some quantitative assessment of the costs.

7. Model limitations and further research

Although the data used and assumptions applied in this study were agreed with stakeholders, some of them require more rigorous verification or further research.

The mitigation potential and the costs for N_2O emissions need to be further researched and quantified.

The assumption that **increased afforestation** and planned extensions will be significantly higher than they were historically, needs to be verified. The cost data used should be checked with industry as it shows that, if opportunity costs are included, the total costs are higher than the income generated.

The increasing cost of diesel could play the role of a driver in the potential adoption of **reduced tillage** practices. It would therefore be useful to estimate the potential-long term savings.

The implementation of a national biofuel strategy will affect the cultivated areas. A full life cycle assessment of biofuel production is needed to determine the impacts.

The impact of erosion and the potential benefit of combating erosion through a low tillage practice, require further research as its relationship to carbon storage is very complex and not yet resolved nationally or internationally.

The calculation of mitigation costs for **improved livestock management** is very sensitive to the assumptions concerning the cost of providing high-quality food, productivity and the percentage of cattle moved to feedlots. These assumptions need to be verified. Furthermore, local research is needed to show how the improvement of productivity in the dairy sector can potentially reduce CH_4 emissions.

The calculation of mitigation costs for **improved manure management** is sensitive to the assumptions about the cost of disposal. Therefore further investigation into these costs would be beneficial. The assumption made regarding the use of a different disposal system could also be refined. In particular the feasibility and potential environmental impacts of the assumption on the increased disposal by dry spread needs to be investigated.

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

To calculate **emissions from fire,** the area burnt was determined based on the assumption of a specific percentage of area burnt for different vegetation types. New satellite data (MODIS) are available to more accurately determine the area burnt. The amount of fuel exposed to fire depends on rainfall and other factors. Subdivision of the burned area in several different environments will improve the estimates of fire emissions.

The cost calculation in this model does not include the benefits of increased wood availability and other non-timber forest products that could be harvested. Fuelwood supply and demand was evaluated as one of the ecosystem services (Shackleton *et al.*, 2004). However, more research is needed to model the long-term feedback between mitigation policies and the sustainable use of wood as a fuel.

The major limitation of the **waste sector** model is that the calculations for the annual mitigated amount are based on the amount of waste generated during that year. If decay of organic matter is modelled it will change the amount of LFG generated significantly. Furthermore, the waste minimisation impact was not modelled.

The cost of methane capture and utilisation was based on unpublished data from two sites with a large variation between both capital and maintenance costs. More accurate cost data would improve the calculation of mitigation costs. Furthermore, it was assumed that cost of composting is equal to the cost of disposal

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. In particular, the disposal of organic waste from the wine industry in the Western Cape is a problematic waste stream.

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

In general, it is recommended that trade-offs between economic and environmental aspects of different mitigation options need to be further investigated, quantified and included in decision making.

8. References

Barker, T. *et al*., (2007). Technical Summary. In: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (Eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Clark, A. & Spalding-Fecher, R. (1999). Financial protocol for South Africa's climate change mitigation assessment. Cape Town, Energy & Development Research Centre, University of Cape Town. (Unpublished)

Department of Environmental Affairs and Tourism (DEAT), (1999). National waste management strategies and action plans, South Africa. Strategy formulation phase. National Waste Management Strategy. Version D, 15 October 1999.

Department of Environmental Affairs and Tourism (DEAT) (2004) South Africa Initial National Communication under the United Nations Framework Convention on Climate Change, 2000. ISBN No.0-9584773-1-0

Department of Water Affairs and Forestry (DWAF), (2004). 'Roundwood supply and demand to 2030' Report prepared by LHA management consultants (Unpublished)

Forsyth, G.G., *et al*., (2006). Integrated veldfire management in South Africa: An assessment of the current conditions and future approaches. Report CSIR/NRE/ECO/ER/2006/0064/C, CSIR, Stellenbosch

Hendricks LB, (2006) speech by Minister of Water Affairs and Forestry at Eastern Cape Summit on Forestry and Timber Processing, Mthatha Health Resource Centre, Mthatha, Eastern Cape 26 February 2007. (Unpublished)

IPCC, (1996). Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (Online) Available from http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html (cited 15 April 2008)

IPCC, (2007). Climate Change 2007 Synthesis Report of the IPCC Fourth Assessment Report: Summary for Policy Makers. Published by Cambridge University Press

SBT (Scenario Building Team), (2007). Long Term Mitigation Scenarios: Strategic Options for South Africa. Department of Environment Affairs and Tourism. http://www.erc.uct.ac.za/Research/publications/07Scenario_team-LTMS_Scenarios.pdf (Accessed 29 August 2008).

Scholes, R. J., Van der Merwe, M. R., Kruger, A. J. & Crookes, D. (2000). Mitigation of climate change through land use practices. South African Country Studies on Climate Change. Pretoria, Council for Scientific and Industrial Research.

Shackleton, C.M., *et al.* (2004). Fuelwood and poverty alleviation in South Africa: opportunities, constraints and intervention options. Report to Dept of Water Affairs & Forestry, Pretoria.

Smith, P., Martino, D., Cai Z. et al. (2007). Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. *Agriculture, Ecosystems and Environment* Vol. 118(1-4) pp 6-28

Stern, N., 2006. Stern Review on the Economics of Climate Change. Published by HM treasury, United Kingdom

Taviv R., *et al*., (2007). Non- Energy Emissions – Agriculture, Forestry & Waste: An input into the Long Term Mitigation Scenarios process, LTMS Input Report2, Energy Research Centre, Cape Town, October 2007

Van der Merwe, M R & Scholes, R J 1998. South African Greenhouse Gas Emissions Inventory for the years 1990 and 1994. Pretoria, National Committee on Climate Change. (Unpublished)

Van Schalkwyk, (2008). 'Vision, strategic direction and framework for Climate policy' *Media statement* *by Van Schalkwyk, Minister of DEAT on 28 July 2008*, Cape Town, South Africa (Unpublished)

USEPA, (2006). Global mitigation on non-CO_2 Greenhouse gases EPA 430-R-06-005 Washington, DC 20460

9. **Endnote:** The authors wish to express gratitude to Gill Collet for editing and support in this project.