mitigation REPORT

SOUTH AFRICA'S GREENHOUSE GAS MITIGATION POTENTIAL ANALYSIS

TECHNICAL APPENDIX A – APPROACH AND METHODOLOGY

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On behalf of:
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The suite of reports that make up South Africa's Greenhouse Gas (GHG) Mitigation Potential Analysis include the following:

Technical Summary

Main Report

Technical Appendices:

Appendix A: Approach and Methodology

Appendix B: Macroeconomic Modelling

Appendix C: Energy Sector

Appendix D: Industry Sector

Appendix E: Transport Sector

Appendix F: Waste Sector

Appendix G: Agriculture, Forestry and Other Land Use Sector

List of Abbreviations

Acronym	Definition
AFOLU	agriculture, forestry and other land use
BAT	best available technology
BAU	business as usual
BOF	basic oxygen furnace
CDM	Clean Development Mechanism
CGE	computable general equilibrium
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DBSA	Development Bank of Southern Africa
DEA	Department of Environmental Affairs
DoT	Department of Transport
DERO	desired emission reduction outcome
DoE	Department of Energy
Dti	Department of Trade and Industry
EAF	electric arc furnace
ERC	Energy Research Centre
GDP	gross domestic product
GHG	greenhouse gas
GHGI	National Greenhouse Gas Inventory
GVA	gross value added
GW	gigawatt
GWh	gigawatt hour
GWP	global warming potential
IEP	Integrated Energy Plan
INFORUM	Inter-Industry Forecasting Model
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
$ktCO_2e$	kilo tonnes of carbon dioxide equivalent
MAC	marginal abatement cost
MACC	marginal abatement cost curve
MANB	marginal abatement net benefit
MANBC	Marginal abatement net benefit curve
MCA	multi-criteria (decision) analysis

Acronym	Definition
MIA	macroeconomic impact
MW	megawatt
MWh	megawatt hour
Mt	million tonnes
$MtCO_2e$	million tonnes of carbon dioxide equivalent
N_2O	nitrous Oxide
NAC	net annualised cost
NCCRP	National Climate Change Response Policy
NPC	National Planning Commission
NPV	net present value
NT	National Treasury
OECD	Organisation for Economic Co-operation and Development
PRASA	Passenger Rail Association of South Africa
SAM	social accounting matrix
SARB	South African Reserve Bank
SATIM	South African TIMES model
StatsSA	Statistics South Africa
SULTAN	Sustainable Transport Illustrative Scenario Accounting Tool
TWG-M	Technical Working Group on Mitigation
UNFCCC	United Nations Framework Convention on Climate Change
WAM	With Additional Measures scenario
WEM	With Existing Measures scenario
WOM	Without Measures scenario
WTO	World Trade Organization
ZAR/R	South African Rand

Acknowledgements

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1. Development of a Reference Case National Emissions Projection

1.1. Projections

This study has produced projections for greenhouse gas (GHG) emissions to 2050. The approach to projecting emissions follows the United Nations Framework Convention on Climate Change (UNFCCC) reporting guidance (UNFCCC, 2000). This guidance is summarised in Box 1.

Two projections have been produced:

- **A 'reference case' projection:** This is a projection of emissions from 2000 to 2050 assuming that no climate change mitigation actions have taken place since 2000. Thus for the period from 2000 to 2010, it does not follow the actual observed path of emissions but the path that emissions would have taken if none of the climate change mitigation actions implemented in this period had taken place. The UNFCCC refers to this as a 'without measures' (WOM) projection.
- **A 'with existing measures' (WEM) projection**: This projection incorporates the impacts of climate change mitigation actions including climate change policies and measures implemented to date. The projection extends from 2010 to 2050. For the period 2000 to 2010 the projections follow the actual path of observed emissions.

The projections were developed using a bottom-up methodology to produce models for each sector. Key characteristics and assumptions are summarised in Table 1 and are described fully in the appendices for each sector. Common key assumptions in the projections are:

- A moderate growth rate for the economy, with growth rates for particular economic sectors as defined in the macroeconomic modelling (see Section 3). The governing assumptions for macroeconomic growth are based on the moderate growth target defined by National Treasury.
- The growth rate for an industrial sector is used as the production growth rate for the sector, which in turn drives projected fuel use and hence emissions. The only exception to this is modelling in the refinery and other energy industries subsectors where increases in production are linked to the demand for liquid fuel, and in the upstream oil and gas subsector where growth is related to expected development of gas fields.
- Emissions factors for fuels and processes are taken from the latest (draft) version of the South African Greenhouse Gas Inventory (GHGI) (DEA, 2013).
- Historic emissions in the period from 2000 to 2010 are taken from the latest (draft) version of the GHGI for the WEM projection, unless more recent data was available from industry. The main revision is in the power sector, where historical fuel consumption (and hence emissions) is calculated based on the net calorific value of coal provided by Eskom, rather than the net calorific value used in the GHGI. The resulting estimates of historic emissions from the power sector are approximately 20% lower than estimates in the draft GHGI.
- Emissions sources which are not included in the current GHGI were not included in projections due to a lack of data on which to base projections. An exception is upstream oil and gas activities where information from industry allowed this to be estimated.
- Estimates of GHG abatement resulting from actions specifically identified as being undertaken for the purposes of climate change mitigation are added to the WEM projection to produce the WOM projection.
- The fuel activity data used in the GHGI was used as the primary source of energy data, as it is considered by the DEA to reflect sectoral consumption more accurately than data in the Energy Balance (DoE, 2013). This was supplemented with more detailed fuel consumption data provided by industry for several subsectors (e.g. other energy industries, oil refining, chemicals and mining). Electricity consumption was taken from the energy balance dataset as no other source of information was available. The energy balance was also used to provide a more detailed breakdown of fuel use in some specific industries.
- The approach taken in the study was to produce bottom-up projections for each sector. The advantage of this approach is that the assumptions made in projecting emissions for individual sectors and subsectors are transparent (these are described in Table 1). This approach imposes some limitations on the amount of feedback that can be incorporated between different sectors, however. For example, in the WOM and WEM projections, demand in the

power tool is set to the sum of electricity demands forecast in the bottom-up projections for end-use sectors. A full integration which would also take into account the impact of price elasticity (i.e. accounting for how the change in electricity price caused by the change in electricity generation would affect electricity demand) was not possible. In another example, growth rates for industry which determine the change in electricity demand are consistent with the growth projected by the macroeconomic model, although the power sector tool is not directly integrated with the macroeconomic model.

Box 1: UNFCCC guidance on projections

The UNFCCC reporting guidelines (UNFCCC, 2000) require countries to report a 'with measures' scenario, and also allows them to report a 'without measures' scenario and a 'with additional measures' scenario. The guidelines define these terms as follows:

- A 'without measures' projection excludes all policies and measures implemented, adopted or planned after the year chosen as the starting point for this projection (the base year).
- A 'with (existing) measures' projection encompasses currently implemented and adopted policies and measures.
- A 'with additional measures' projection also encompasses planned policies and measures but includes an estimate of the impact of additional mitigation measures.

The relationship between these alternative scenarios is described further in the diagram below. The same guidelines define 'implemented', 'adopted' and 'planned' as follows:

- Implemented policies and measures are those for which one or more of the following applies: (a) national legislation is in force; (b) one or more voluntary agreements have been established; (c) financial resources have been allocated; (d) human resources have been mobilized.
- Adopted policies and measures are those for which an official government decision has been made and there is a clear commitment to proceed with implementation.
- Planned policies and measures are options under discussion and having a realistic chance of being adopted and implemented in future.

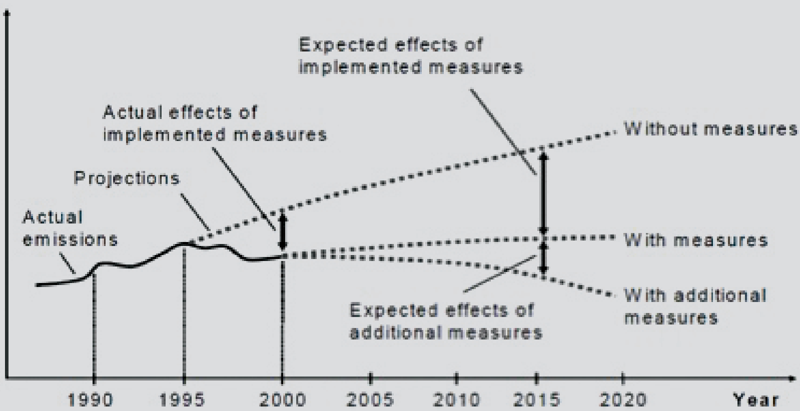


Table 1: Summary of projection methodologies

Sector	Subsector	Modelling approach	Reference case ('without measures')	'With existing measures'
Energy	Power sector	Power sector scenario tool: a bottom-up technology-based tool that allows different power generation mixes (choice of generation technology and fuel) to be modelled while ensuring that as well as meeting demand, other power system constraints such as peaking and reserve capacity are met. Contains information on fuel prices and technology costs derived mainly from the Integrated Resource Plan (IRP) (DoE, 2011).	Electricity demand from other reference case sector projections. Continuation of current generation mix, predominantly based on coal.	Electricity demand from other WEM sector projections. Generation mix to 2030 based on base case in IRP (DoE, 2011) which includes committed build. Generation mix in 2030 retained until 2050.[1]
	Fuel related emissions: oil refining, coal mining and handling, upstream oil and gas, other energy industries	Current fuel consumption projected forward based on expected growth rates in sector, and allowance for autonomous energy efficiency improvements i.e. improvements to energy consumption in the sector which occur simply as a result of replacing retired equipment with new, more efficient equipment. Emissions calculated from fuel consumption using emissions factors from GHGI.	Growth in coal mining from macro-economic modelling. Growth in oil refining, and other energy industries based on modelling of additional process capacity required to meet liquid fuel demands and the requirements for domestic fuel supply specified in the energy security plan. Impact of climate change mitigation measures notified by industry accounted for both historically and into the future.	As reference case, but as impact of existing measures included, historic emissions follow pathway of actual emissions.
	Fugitive emissions (oil refining, other energy industries and coal mining)	Fugitive emissions projected forward based on growth in sector and constant emissions factor.		

1. As the tool is a technology-based tool for the power sector only wider economic implications of structural changes e.g. switching from coal to gas are not examined.

Sector	Subsector	Modelling approach	Reference case ('without measures')	'With existing measures'
Industry	Manufacturing and construction – fuel and process related emissions	Individual industry sectors modelled separately. Current fuel consumption projected forward based on expected growth rates in sector, and allowance for autonomous energy efficiency improvements i.e. improvements to energy consumption in the sector which occur simply as a result of replacing retired equipment with new, more efficient equipment. Emissions calculated from fuel consumption using emissions factors from GHGI. Process emissions projected by applying growth rates to estimates of historic process emissions from GHGI. Some updates to GHGI estimates provided by industry incorporated.	Growth in sectors from macroeconomic modelling. Autonomous energy improvements estimated on an industry specific basis based on international data. Impact of climate change mitigation measures notified by industry accounted for both historically and into the future.	As reference case, but as impact of existing measures included, historic emissions follow pathway of actual emissions.
	Agriculture forestry and fishing – fuel related emissions	Current fuel consumption projected forward based on expected growth rates in sector. Emissions calculated from fuel consumption using emissions factors from GHGI.	Growth in sectors from macroeconomic modelling.	As reference case; no climate change mitigation measures affecting fuel consumption identified.
	Residential buildings	Current fuel consumption projected forward based on expected growth rates in residential sector and changes in income which affect energy consumption per household. Emissions calculated from fuel consumption using emissions factors from GHGI.	Growth rate based on linear regression with population as explanatory variable.	As reference case plus impact of existing measures. Thus historic emissions follow actual emissions pathway.

Sector	Subsector	Modelling approach	Reference case ('without measures')	'With existing measures'
Industry Continued	Commercial buildings	Current fuel consumption projected forward based on expected growth rates in sector. Emissions calculated from fuel consumption using emissions factors from GHGI.	Growth in sector from SBCI (2009).	As reference case plus impact of existing measures. Thus historic emissions follow actual emissions pathway.
Transport	Road	Ricardo-AEA's SULTAN model (sustainable transport illustrative scenario accounting tool) used to project fuel consumption from 2010 to 2050. Emissions calculated from fuel consumption using emissions factors from GHGI. Emissions from 2000 to 2010 based on GHGI.	Projections of transport demand based on previous detailed modelling by ERC (Merven, 2012); same study used for mix of vehicle stock and modal share (assumed to remain fixed) and load factor. Fuel efficiency of new cars assumed to increase over time.	As reference case; no historic climate change mitigation measures in road and rail sectors identified.
	Rail	Ricardo-AEA's SULTAN model used to project fuel consumption from 2010 to 2050.	Projections of passenger transport demand based on previous detailed modelling by ERC (Merven, 2012). Data on current activity levels from PRASA and Transnet used to provide estimate of energy intensity of mode, and information on investment plans used to project improvements in energy efficiency over time.	As reference case; no historic climate change mitigation measures in road and rail sectors identified.
	Aviation	Domestic aviation only modelled. Emissions projected forward from historical emissions data based on assumptions about growth in demand and underlying level of improving fuel efficiency of aircraft.	Aviation demand forecast based on Airbus market forecast (Airbus, 2012) and forecast in National Transport Master Plan (DoT, 2010). Increase in fuel efficiency of fleet of 1.5% per year.	Demand as reference case but increase in fuel efficiency of fleet rises to 2.5% per year in later years.

Sector	Subsector	Modelling approach	Reference case ('without measures')	'With existing measures'
Waste	Managed waste disposal	IPCC first order decay model as used in the GHGI used to estimate future emissions from landfill on basis of future waste generation rates, and amount of waste generated disposed of in managed landfills.	Increases in waste generation based on increases in GDP/capita and UN population forecasts (UN, 2011). Allowance for increasing urbanisation and increase in level of waste services provision.	As reference case but allowing for mitigation from existing landfill gas recovery projects.
	Waste water treatment	Same estimation methodology as used in GHGI which is based on assumed mix of treatment technologies for population in three categories, urban high income, urban low income and rural.	Projections allow for trends in urbanisation, prosperity and improvement in access to sanitation.	As reference case; no historic climate change mitigation measures in waste water sector.
Agriculture, forestry and other land use (AFOLU)	General	Analysis based on trends in key emission sectors, with natural biomes excluded due to lack of data. This is related to the assessment that production is de-linked from economic growth and dependent on supply side factors.	Production under the 'without measures' projection, with unchanged natural biomes, emissions decline somewhat, driven primarily by changes in production of agricultural products.	Small changes projected over time.
	Enteric fermentation			Decreasing trend in livestock numbers.
	Natural biomes			No change in the extent of natural biomes and therefore no changes to the sinks or sources of CO_2 from these land areas.
	Croplands and managed soils			Data on croplands is deemed too unreliable. It is therefore assumed that cropland and the related indirect emissions from managed soils are stable.
	Biomass burning			Emissions from biomass burning show a marginal decrease over time.

1.2. Sensitivity Analysis

In addition to projections based on the moderate growth scenario from the macroeconomic modelling, a sensitivity analysis was carried out. WEM projections were produced for low and high economic growth scenarios (definitions based on NPC, 2012). The approach to implementing the sensitivity analysis is outlined in Table 2 below. Further details on the assumptions governing the macroeconomic growth assumptions for the sensitivity analysis are discussed in Section 3.4.

Table 2: Methodology for macroeconomic growth sensitivity analysis

Sector	Subsector	Modelling approach
Energy	Power Sector	Electricity demand projections are determined by final electricity demand under high and low growth assumptions in end use sector. The generation mix was kept similar to that in the medium growth power sector projection subject to the build rate, which was based on the IRP (DoE, 2011), and other constraints in the power sector tool.
	Coal mining and handling	Growth rates for sector modified to reflect those in the macroeconomic modelling under the low and high growth rate scenarios.
	Upstream oil and gas	Unchanged from medium growth model as based on development of gas fields and unlikely to be affected by small changes in demand.
	Petroleum refining and other energy industries	Growth in processing capacity unchanged as change in liquid fuel demand from revised sector projections was not significant enough to change timing for introduction of new processing capacity.
Industry	Manufacturing and construction – fuel and process related emissions	Growth rates for subsectors modified to reflect those in the macroeconomic modelling under the low and high growth rate scenarios
	Agriculture forestry and fishing – fuel related emissions	Growth rate for sector modified to reflect those in the macroeconomic modelling under the low and high growth rate scenarios.
	Residential buildings	GDP growth not used explicitly in projection, which is based on population growth and transitions between household types. Growth rate in projection therefore scaled by applying the proportional difference in GDP growth under the high and medium economic growth scenarios for the high growth scenario. Similarly, the growth rate in the low scenario was derived by applying the proportional difference in GDP growth under the low and medium economic growth scenarios for the low growth scenario.

Sector	Subsector	Modelling approach
Industry (Continued)	Commercial buildings	GDP growth not used explicitly in projection. Growth rate in high projection therefore modified by multiplying the medium growth rate for commercial buildings by the proportional difference in GDP growth in the building sector under the medium and high growth macroeconomic modelling. A similar approach is used for the low growth scenario.
Transport	Road, rail and aviation	As demand forecasts for each sector were based on exogenous forecasts of demand from other studies, it was not possible to update these. High and low growth scenarios are therefore the same as the medium growth scenario.
Waste	Managed waste disposal	A relationship between waste generation per capita and GDP per capita was developed from the medium growth scenario. GDP per capita each year under the high and low growth scenarios was calculated and used to calculate the appropriate waste generation per capita value.
	Waste water treatment	The driver in the projections is population so emissions are unchanged in the high and low growth scenario.
AFOLU	All	The approach for projecting emissions in the AFOLU sector has assumed that land areas under crop production and commercial forestry are stable (supported by AFOLU Task Team discussion and sector specialists). Therefore, economic growth is not a driver of emissions in this sector: while the demand for agricultural products continues to grow, this demand is being met through more intensive production on the same area of land, complemented by growing imports. The AFOLU sector is thus excluded from the sensitivity analysis.

Chapter II. Sector Classification

2. Sector Classification

The overall objective of this study has been to present a set of viable options for reducing GHGs in key economic sectors. The Technical Working Group on Mitigation (TWG-M), in conjunction with the DEA, established a total of five task teams, to consider and provide evidence/fact based advice on specific issues in key sectors and subsectors. These sectors were defined as:

- energy
- industry
- transport
- waste
- agriculture, forestry and other land use (AFOLU)

Table 3 shows which subsectors have been included under each of these sectors when compiling projections. It also shows the IPCC classification for the subsectors (as used in the GHGI), which allows the projections to be linked to historic emissions reported in the GHGI, and whether mitigation potential analysis has been carried out.

In presenting the results of the projections and analysis in the technical appendices, emissions from the power sector, while estimated separately using the power sector tool, have been reallocated to end use sectors based on electricity demand.

Table 3: Sector and subsector classification for projecting GHG emissions, including IPCC emission categories (table also indicates sectors for which mitigation potential analysis has been provided)

Key sector	Sector	Subsector	IPCC emissions category			Mitigation potential analysis provided
			Fuel combustion (1A)	Fugitive emissions (1B)	Process emissions (2)	
Energy	Power	Electricity and heat production	1A1a			Yes
	Non-Power	Petroleum refining	1A1b	1B2		Yes
		Other energy industries	1A1c	1B3		Yes
		Coal mining and handling		1B1a		Yes
		Oil and natural gas		1B2		Yes
Industry	Metals	Iron and steel production	1A2a		2C1	Yes
		Ferroalloy production	1A2a		2C2	Yes
		Primary aluminium production	1A2b		2C3	Yes
	Chemicals	Chemicals production (including ammonia, nitric acid, carbide, titanium dioxide, petrochemical and carbon black production)	1A2c		2B (including 2B1, 2B2, 2B5, 2B6 2B8)	Yes
	Other	Pulp and paper production	1A2d			Yes

Key sector	Sector	Subsector	IPCC emissions category			Mitigation potential analysis provided
			Fuel combustion (1A)	Fugitive emissions (1B)	Process emissions (2)	
Industry Continued	Minerals	Cement production	1A2f		2A1	Yes
		Lime production	1A2f		2A2	Yes
	Buildings	Residential buildings	1A4b			Yes
		Non-residential buildings	1A4a			Yes
	Mining	Mining and quarrying excluding coal products	1A2i	1B1		Yes
	Other sectors in manufacturing and construction, not listed above (including process emissions from glass, lead and zinc production, refrigeration and air conditioning)		Remainder of 1A2 including 1A2e, 1A2g to 1A2, 1A2m		2A3, 2C5, 2C6, 2F	No (1)
	Agriculture, forestry and fishing		1A4c			No (1)
	Other		1A5			No (1)
Transport	Aviation	Civil aviation	1A3a			Yes
	Road	Road transport	1A3b			Yes
	Rail	Railway	1A3c			Yes
	Maritime	Maritime	1A3d			No (1)
Waste	Waste	Managed waste disposal sites			4A1	Yes
		Wastewater treatment and discharge			4D	No (1)
AFOLU	AFOLU	AFOLU (including: enteric fermentation, manure management, biomass burning, liming, urea, direct N_2O from managed soils, indirect N_2O from managed soils, indirect N_2O from manure management			3A (including: 3A1, 3A2, 3C1, 3C2, 3C3, 3C4, 3C5, 3C6)	Yes (2)

Notes: (1) sectors either not prioritised by TWG-M or no data available to estimate mitigation potential
(2) certain sectors (e.g. biomass burning excluded as deemed not appropriate as source of mitigation potential)

Chapter III. Projecting Economic Growth

3. Projecting Economic Growth

A detailed inter-industry economic modelling framework was used as the basis for projecting economic growth in all the subsectors of the South African economy.

Two broad modelling approaches were employed.

- Long-term forecasting of the South African economy on a detailed subsector basis using the Inter-Industry Forecasting Model (INFORUM).
- Quantification of the socioeconomic impact of various proposed GHG emission mitigation intervention options using two models:
  - The Macro-Economic Impact Assessment Model[2] based on the South African Social Accounting Matrix (SAM).
  - An associated model for assessing the impact of surpluses on the 'forward linked' economy.

The reason why it was necessary to employ a disaggregated sectoral modelling framework for analytical purposes is that the different sectors have different combinations of capital and labour inputs in their production processes and different emission intensities.

3.1. Methodology used for Forecasting the South African Economy

Forecasting the South African economy for the next 40 years is necessary to determine the reference case for the level of emissions over the period, 2000 to 2050. The impacts on GHG emissions of various possible mitigation interventions were compared to the 'with existing measures' reference case in order to calculate the socioeconomic impact of the proposed interventions.

The forecasting was done using the INFORUM model and verified by information from specialists in the private and public sectors.[3] This model combines the primary features of key macroeconomic models, simulating the behaviour of the economy as a whole, and producing projections for aggregate gross domestic product and its components.

The modelling system is dynamic from the outset and produces projections of a time path of the economy instead of only the differences between static equilibrium positions. An important feature of the modelling for the project is the bottom-up approach used to simulate the workings of the economy. Macroeconomic aggregates are built up from detailed projections at the industry and product level, as a preferred alternative to initially being estimated at the macroeconomic level and then simply distributed between sectors. A detailed description of the South African INFORUM model is provided in the next section.

3.2. The South African INFORUM Model

The INFORUM modelling system is macroeconomic, dynamic and multi-sectoral. It depicts the behaviour of the economy in its entirety i.e. It accommodates the workings of all the major markets in their interrelated, dynamic co-existence. It therefore lends itself to projecting aggregate gross domestic product (GDP) and all its components, as well as the demand categories that determine GDP, instantaneously and dynamically.

The system includes an input-output (I-O) table and accounting which shows the magnitude and diversity of intermediate consumption within the context of the current economic structure. This allows the system to integrate intermediate input prices with sectoral price formation which ultimately determine overall price levels in the economy. This is done through the use of behavioural equations for final demand that depend on prices and output; and functions for income that depend on production, employment and other variables. Given these attributes, the INFORUM system, like other macroeconomic and dynamic multi-sectoral models is well-suited to forecasting business as usual or reference cases.

Econometric models, including the INFORUM model, are built mainly on historic information. As the structure of the economy changes slowly over time this approach is suitable for impact analysis over a medium term horizon. Over the long term this model, like others, is unlikely to capture structural changes that might occur in the economy adequately. For example, structural changes to employment and capital may be expected as a result of a shift from coal-based electricity generation to gas-based electricity generation, thereby reducing the demand

2. User-friendly Macro-Economic Impact Assessment Model based on the SAM developed for the Development Bank of Southern Africa.
3. The Chamber of Mines; Development Bank of Southern Africa (DBSA); agriculture economists; University of Stellenbosch; Quantec; Transnet; National Energy Regulator of South Africa; Department of Minerals and Energy; Department of Agriculture; South African Chamber of Commerce and Industry (SACCI); South African Federation of Civil Engineering Contractors (SAFCEC) and Steel and Engineering Industries Federation of South Africa (SEIFSA).

for coal (and hence for low-skilled mining labour). To take this into account, the intermediate production structure of the INFORUM model was adjusted in an attempt to take into account changes that will be brought about by the mitigation options, more specifically those affecting the energy sector. The adjustments are discussed fully in Technical Appendix B: Macroeconomics, which address the impacts on national GDP and employment of implementing the mitigation measures identified in this study.

Another important feature of this macroeconomic, multi-sectoral model is its bottom-up approach. In this approach, the model mimics the actual workings of the economy in that the macroeconomic aggregates are built up from detailed levels at the industry or product level, rather than first being estimated at the macroeconomic level and then simply distributed amongst sectors.

When conducting macroeconomic impact analyses, a variety of approaches exist to account for interactions within the economy. INFORUM models differ from computable general equilibrium (CGE) models in that they do not *automatically* take certain constraints into account. However, this has been accounted for by adjusting for monetary and fiscal policy interventions through changing the interest rate, government spending and tax rates, to restore certain requirements, such as a specific percentage GDP deficit on the current account of the balance of payments.

Figure 1 below depicts the dynamic and interrelated workings of the multi-sectoral modelling system. A description of each variable that has to be estimated is shown.

1. The model loop begins on the production block side, where the expenditure components on GDP (supply side) are estimated in constant prices.

    1.1. Next, the personal savings propensity is applied to calculate what portion of total household real disposable income will be spent on consumption. From this total figure, the distribution of per capita consumption expenditures per income group is calculated.

    1.2. Government consumption and investment expenditures are normally determined outside the model. At this point, after all the final demand categories (except for imports and inventory change) have been estimated

    1.3. The investment equations model the substitution (or complementarity) of capital equipment with labour and energy. The scarcity of capital is taken into account as explained above.

    1.5. Exports are usually calculated outside the model (i.e. exogenously) given the dependence of exports on international economic conditions.

    1.4. And 1.6 – 1.11: Additional variables used for the final demand calculation

2. and 3. An input-output mathematical solution is applied to jointly and simultaneously determine output, imports and inventory change.

4. 5. and 6. The model next turns to the important job of forecasting prices at various levels. To start off, all components of value added are calculated, of which the most important one is the hourly labour compensation rate by industry, called the "wage rate". However, as indicated above, the wage rate is dependent on the availability of appropriately-skilled labour. By multiplying the wage rate with the total hours worked, total labour remuneration per industry is obtained. Labour remuneration is the largest component of national income, usually about 60%, and certainly has a major effect on prices. However, it is also important that the various components of capital remuneration are taken into account. Private enterprise gross profits are needed to be able to calculate a number of aggregates namely company taxes, retained earnings and depreciation of capital assets which make up business savings. Together with personal savings these impact heavily on the savings-investment equation in the economy. Furthermore, dividends, proprietors' income, interest income and rental income generated in the private sector all ultimately contribute to personal income.

7. and 8. To calculate prices, value added by industry is summed to total value added, and then passed through a product-industry bridge, to obtain value added per product. Once value added at the product level has been obtained, commodity prices are calculated. The import content of intermediate consumption is taken into account here. The deficit on the current account of the balance of payments before and after the implementation of the mitigation option was taken as a benchmark to ensure that the economic models adequately capture the need to borrow for and pay back the capital investments. For instance, if the deficit on the current account of the balance of payments amounts to 6% of the GDP in the base case scenario, i.e. There are no changes to the existing energy policies, then for controlling purposes the deficit in the current account of the balance of payments should not deviate from 6% for each one of the GHG pathways. This was achieved by increasing or decreasing the prime interest rate.

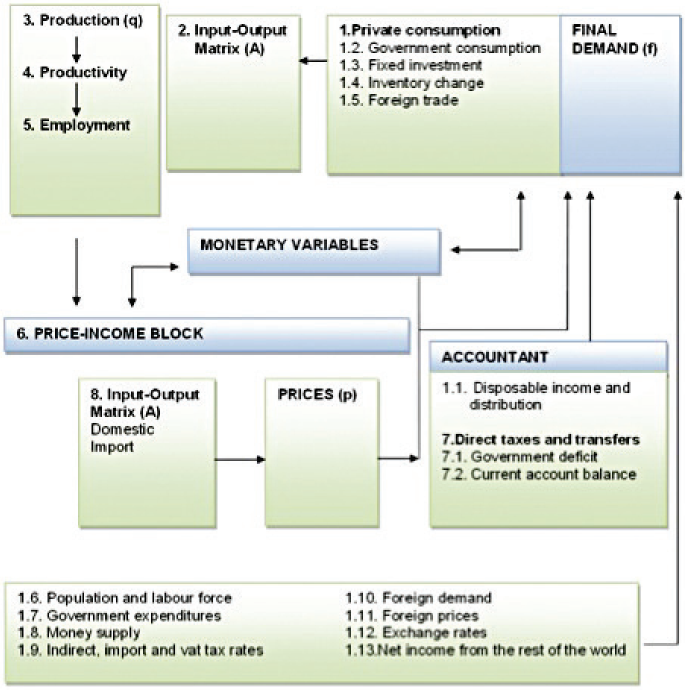


Figure 1: Dynamic and inter-related workings of the South African INFORUM model

3.3. Underlying Assumptions for Purposes of Forecasting

It is important to note that the projection of growth in the economy is done over a very long period which stretches the limits of a standard econometric forecasting model. The assumptions that are usually applied to modelling, such as monetary variables (i.e. interest rates and money supply) as well as short term price fluctuations, which are normally imperative for short- and medium-term forecasting, are not that significant in this case. The long-term forecast is far more susceptible to structural developments in the South African economy, specifically regarding the potential of certain sectors to export over the long-term, such as the long-term positive export potential of iron ore, magnetite, chrome, coal, etc. It is also assumed that South Africa will play a much larger role in the African economy, and will be much less dependent on its traditional trading partners, such as Europe and the United States of America. This will also change the structure of our international trade, where South Africa will become more dependent on exports of manufacturing goods and services; and less dependent on exports of primary commodities.

Specific information regarding Transnet's capital investment programme over the medium term was used to get an indication of the export potential of certain sectors. This information covers increases in both harbour and rail capacity.

On the other hand, the diminishing role gold and diamonds will play in future development of the economy was also taken into account. Furthermore, fundamental economic rules were built into the forecasting scenario, which included the following aspects:

- there should be a measure of balance on the current account of the balance of payments
- the ability to obtain foreign capital
- the growth of the world economy
- South Africa's population growth taking into account the negative effects of HIV and Aids.

GHG emissions projections developed under this study are based on a targeted level of future economic growth based on the moderate growth rate defined by National Treasury. The projection of moderate growth assumes that the economy will grow steadily, with continued skills constraints and infrastructure bottlenecks in the short- to medium-term. The moderate growth scenario forecasts real GDP growth of 4.2% per annum over the medium-term (defined in the Draft Integrated Energy Plan as 2015–2020) and 4.3% per annum over the long-term (2021–2050), according to the 2012 Medium Term Budget Policy Statement (NT, 2012).

This growth rate could currently be viewed as somewhat on the high side, if structural challenges in South Africa, such as the improvement of education, poverty alleviation, and enhancement of income distribution are taken into account. It is also important to note that since the advent of democracy the growth of the South African economy has only been of the order of 3–3.5%, well below the medium growth target of 4%. A summary of the assumptions for the medium growth scenario are depicted in Table 4. A summary of final demand and production projections is presented in Section 3 of Appendix B.

Table 4: Assumptions for the Medium Growth Scenario

	Input Variable	Parameter Value	Source and Explanation
1	**South African population**		Source: *National Development Plan 2030* (NPC, 2012)
	Currently	1.0%	Source: Conningarth Economists: The historic population growth of 1% was increased to about 2% p.a. over the period. This somewhat higher forecasted growth rate is based on a more optimistic view of the prevalence of AIDS in the future. This is also confirmed by recent statistics that the AIDS infection rate has decreased. Furthermore, South Africa still remains a popular destination for immigrants, especially from Africa.
	long-term, declining to 0.5% by 2030	0.5%	
2	**South African inflation targets (SARB objectives between 3.0% and 6.0%)**	6.0%	Source: Conningarth Economists: Although the target for the inflation rate has been set by the SARB at between 3% and 6%, it was very difficult in recent years to achieve a lower inflation rate than 6% per annum. Currently it seems that 6% is an optimistic figure, which could be even higher (see e.g. http://www.resbank.co.za/MonetaryPolicy/DecisionMaking/Pages/TargetsResult.aspx)
3	**World prices/inflation**	3.0%	Source: World Trade Organization (WTO) (short to medium term forecast).
4	**Final consumption expenditure by government**	3.9%	Source: Conningarth Economists: This rate is underpinned by the National Development Plan, 2030 (NPC, 2012). The role of government in the South African economy should be in line with economic growth.
5	**Business cycle**		Source: Econdow Economic Consultants: The information regarding the business cycle was obtained from Econdow Economists who specialize in the short to medium term forecasting of the economy. Use was made of series analyses, as well as business confidence opinion surveys, to calculate shorter and longer term business growth cycles.
	2013 to 2014	average	
	2015 to 2018	above average	
	2021 to 2025	below average	
	all other years	average	
6	**Exchange rate per annum (depreciation of the real effective Rand exchange rate)**	-1.7% p.a.	Source: *A Manual for Cost Benefit Analysis in South Africa with Specific Reference to Water Resource Development (TT305/07)* (Mullins et al., 2007): This real 1.7% is over and above the purchasing power parity theory which means that the Rand will depreciate against its trading partners with this real percentage plus the difference between the South African inflation rate and the inflation rate of its main trading partners.
7	**World economic growth**		Source: *OECD Economic Outlook Volume 2012/1* (OECD, 2012).
	2013	3.3%	
	2014	4.0%	
	2015 to 2023	4.5%	
	2024 to 2052	4.0%	

	Input Variable	Parameter Value	Source and Explanation
8	Current account of balance of payments as percentage of GDP	3.6%	Source: Conningarth Economists: A rule of thumb is that the deficit on the current account of the balance of payments as percentage of the GDP should not be higher than the net investment as percentage of the GDP in order to maintain financial discipline and enable the economy to sustain a high growth rate. The argument behind this is that a country should borrow money only for purposes of investment, but not for current expenditure. The net investment as percentage of the GDP provides a guideline to what extent a country should borrow from international sources. For the last 10 years, South Africa's average deficit on the current account of the balance of payments as percentage of GDP is 3.6%. Per definition, therefore, it can be said that South Africa can have a deficit on the current account of the balance of payments as percentage of GDP of about 6% (the per annum average for the last 10 years). However, to be conservative it was assumed that a future deficit not higher than the historic 3.6% should be taken and, therefore, the target has been set at 3.6%.

3.4. Assumptions Regarding the High and Low Growth Scenarios

The client also requested that high and low growth scenarios be determined. This has been done using a 95% confidence interval/band for each of the final demand components (excluding exports) obtained by conducting a regression analysis of the final demand components over the historical sample period.

The high forecast is the upper limit of the 95% confidence interval, and the lower forecast is the lower limit of the 95% confidence interval. In terms of exports, the major export commodities were reviewed on an individual commodity basis to determine what a high and a low view of growth in that commodity could be.

It is important to note that these high and low growth scenarios have not been developed in the traditional scenario-building manner, where certain of the exogenous variables are entered into a model using a lower or higher assumption for each exogenous variable. For instance, such a scenario approach might use a low assumption of 0.5% for population growth, and a high growth assumption of 2.5%. Similar high and low assumptions might also be made for other exogenous variables such as international trade.

With regard to the high growth scenarios it is important to note that factors such as increased rail capacity and other infrastructure projects, which are currently very much debated, are difficult to consider in the relevant projections without definite plans being on the table. Transnet's current R308 billion capital investment programme was used to obtain a view on these aspects. This is true not only for South Africa but also for neighbouring countries such as Mozambique, Namibia and Botswana. Drastic increases in economic growth in these countries should have a significant positive effect on South Africa's exports due to its proximity to them and its relatively high technology base, specifically in areas such as mining and manufacturing of products for the mining industry.

A summary of final demand and production projections for the low, medium and high growth scenarios is presented in Section 3 of Appendix B.

3.5. Socio-Economic Impact Analysis of Identified Mitigation Interventions

For the economic analysis and appraisal of the initially identified GHG emission mitigation interventions the Macroeconomic Impact Assessment Model based on the South African Social Accounting Matrix (SAM) has been used.

A SAM is a comprehensive, economy-wide data framework that contains systemised information about the flow of financial and economic aggregates between the different economic interest groups and institutions in an economy (i.e. business enterprises, households, government, etc.) on a logical basis during a given period of time – usually one calendar year. The SAM was converted into user-friendly macroeconomic impact models which can be used to calculate the economic impact of interventions by way of programmes and projects on the economy.

A detailed description of the Macroeconomic Impact Assessment Model is provided below.

3.6. Macro-Economic Impact Assessment Model

The Macroeconomic Impact Assessment Model is a partial CGE model based on the Social Accounting Matrix of South Africa. The model combines macro- and socioeconomic impacts emanating from both the construction and the operational phases of projects. It also calculates the direct, indirect and induced effects on the economy emanating from the various development stages.

The direct impact occurs through the various development components, for instance, through production/turnover, payment of remuneration to employees and profit generation. The indirect impacts refer to impacts on industries that provide input to the development of the various phases and components of the superstructures and other backward linkages. The induced or income effect refers to a further round of economic activity that takes place in the economy because of additional consumer spending as a result of the additional salaries and wages generated throughout the economy. The impact analyses are based on the following standard economic parameters that are also used to calculate performance criteria (Table 5).

Table 5: Standard macroeconomic performance criteria

Standard macroeconomic performance criteria	Impact on gross domestic product (GDP)	
	Impact on capital utilisation	
	Impact on employment creation	
	Impact on households	Low income households
		Medium income households
		High income households
	Fiscal impact	National government
		Provincial government
		Local government
	Social impact	
	Efficiency criteria	Utilisation of scarce capital
		Utilisation of labour resources

As indicated previously, the main objective of the study is to estimate the macroeconomic impacts of infrastructural energy projects. For purposes of the analysis, Conningarth Economists used an updated SAM for South Africa which formed the basis of the impact model – namely a partial general equilibrium model.

The compilation of the updated South African SAM was part of a major initiative by the Development Bank of Southern Africa (DBSA), the South African Reserve Bank (SARB), Statistics South Africa (StatsSA) and National Treasury. This SAM was initially compiled and updated in 2006 prices and converted into a user-friendly macroeconomic impact model which takes inflation into account and updates the values to 2010 prices.

This model was used to calculate the economic impact of each mitigation measure on the economy. Structural shifts were accounted for by assessing all measures together in the following manner:

- The INFORUM model was used to calculate the overall impact of all the mitigation options. The INFORUM model is more dynamic and inter alia takes the full effect of price changes in the economy into account.
- The INFORUM model makes provision for adjusting the production structure (intermediate demand input structure) over time, which overcomes the issues associated with the use of a static input-output table. This, for example, provides for a change in the production structure when comparing the impacts of a nuclear power station, to that of a coal-fired power station.
- The model is activated from outside the modelling system (exogenously). Therefore, the unique input structure of an intervention can be used to activate the economic model. The structure of the intervention is not limited to the economic structure of the sector which represents the intervention.

The Impact Assessment Model is based on Excel spread sheets driven by a set of macros. For a specific project or intervention, the model can determine the macroeconomic impacts, for key macroeconomic performance indicators at national, provincial and local government levels.

The model results based on the key macroeconomic performance indicators can be provided for both the construction and the operational phases of a specific mitigation measure which is, from the point of view of modelling, a project or a series of projects. The uniqueness of the model lies in its robustness given that where sector specific information is not readily available, average figures for a similar sector can be generated and provided by the model.

Chapter IV. Identification of Mitigation Opportunities

4. Identification of Mitigation Opportunities

4.1. Methodology

The project team identified and quantified mitigation opportunities for a representative set of emission reduction activities. These mitigation opportunities were defined as physical actions that could be taken to reduce or prevent GHG emissions from a given source. For example, they could constitute the implementation of technology improvements within an industrial process or individual industrial facility (e.g. replacement of an inefficient kiln). The opportunities are not policy measures.

Using the industry sector as an example, the following process was followed to identify and quantify mitigation opportunities:

1. **Development of a long list**: Based on desktop research of international GHG mitigation best practice and best available technology (BAT) for production, a long list of GHG emissions abatement measures was prepared for each industrial subsector.
2. **Refinement of a short list**: The long list was disseminated to the TWG-M and feedback was gathered on the applicability and potential of each measure. Based on this feedback a short list of mitigation opportunities for each subsector was selected.
3. **Further quantitative data gathering**: The data parameters required to construct the marginal abatement cost curves (MACCs), including the abatement potential and costs, were then gathered using international benchmarks and BAT literature. Questionnaires for each industry subsector were disseminated to the TWG-M members, including all of the quantified measures, to verify the parameters based upon sector expertise from South Africa.
4. **Final list of measures**: The final list of data were then prepared based upon the TWG-M final feedback.

The final list of mitigation measures has been described in full together with the MACCs for 2020, 2030 and 2050 and these have been included in the Technical Appendices for the energy (Appendix C), industry (Appendix D), transport (Appendix E), waste (Appendix F) and AFOLU (Appendix G) sectors.

4.2. Data Parameters

For each measure, the team attempted to gather sufficient data within the required parameters to calculate the GHG abatement potential (in tonnes of CO_2e) and the marginal abatement cost (MAC) (in cost per tonne of CO_2 abated) over the 2010–2050 period. The full list of data parameters for the data gathered is described in Table 6. Marginal abatement cost curves (MACCs) for the key focus years (2020, 2030 and 2050) were then constructed using these principal indicators of mitigation performance.

Table 6: List of mitigation measure data parameters

Parameter		Unit	Description
A	**GHG emissions reduction potential (process, fugitive, fuel or indirect emissions)**		
A.1	Reference emissions	$ktCO_2e$	Reference emissions in $ktCO_2e$ (in 2010)
A.2	Emissions abatement potential	$ktCO_2e$	Reduction in emissions compared to the reference emissions in $ktCO_2e$
A.3	Emissions abatement potential	%	Potential percentage (%) reduction in emissions compared to reference emissions.
A.4	Applicability	%	Percentage of total emissions that abatement measures can be applied to (e.g. if 100% of emissions come from process electricity consumption, then a process control improvement measure would be 100% applicable).
B	**Energy saving**		
B.1.1	Reference thermal energy consumption	GJ/t product	Reference thermal energy consumption in GJ/t product (e.g. crude steel).
B.1.2	Thermal energy saving potential	GJ/t product	Reduction in thermal energy consumption compared to the reference energy consumption.

Parameter		Unit	Description
B.1.3	Thermal energy saving potential	%	Percentage thermal energy saving potential compared to reference thermal energy consumption (e.g. if 65% of thermal energy is consumed by the steam reforming step, then a steam reforming process improvement would be 65% applicable).
B.1.4	Applicability	%	Percentage of total thermal energy consumption that abatement measure can be applied to.
B.2.1.	Reference electricity consumption	GJ/t product	The reference electricity consumption in GJ/t product.
B.2.2	Electricity saving potential	GJ/t product	Reduction in electricity consumption compared to the reference consumption.
B.2.3	Electricity saving potential	%	Percentage electricity saving potential compared to reference electricity consumption (e.g. if 22% of energy consumption is from preparation equipment, then a preparation process control improvement would be 22% applicable).
B.2.4	Applicability	%	Percentage of total electricity consumption that abatement measure can be applied to.
C	Costs		
C.1.1	Capital cost	R/site or R/sector	Typical capital investment for measure in 2010.
C.1.2	Additional annual costs	R/year	Additional annual costs e.g. operational and maintenance costs in R/year (not including additional energy cost).
C.1.3	Site production capacity	Tonnes product/year	Typical the site production capacity (tonnes product/year) for reference
C.2.1	Capital cost	R/t	Typical capital investment for measure now. Please specify specific cost in R/t product
C.2.2	Additional annual costs	R/t	Additional annual costs e.g. operational and maintenance costs. Please specify specific cost in R/t product (not including additional energy cost).
C.3	Abatement cost	R/tCO_2e	Abatement cost for measure in R/tCO_2e (in certain cases only the abatement cost was available)
D	**Availability**	%	When the technology is likely to become technically available (2010, 2020, 2030, 2040 and 2050).
E	**Reference sector uptake %**	%	The likely % uptake of the technology across the sector that will happen anyway under current policy, existing measures, technology development status and economics.

4.3. Data Sources and References

The technical, effectiveness and cost data gathered for each mitigation option have been based on a variety of sources. In order of priority, they are.

1. Personal communication with sector experts from South Africa during the TWG-M and via direct email and telephone communication.
2. International benchmarks – examples of best practice and BAT.
3. Best estimates based upon the experience of the project team.

In all case the sources of information have been clearly referenced in the Technical Appendices. Also, the team has attempted to verify the validity of assumptions and data with the TWG-M experts to ensure applicability and accuracy of GHG emissions migration potential.

Final MACCs for all sectors and subsectors have been reviewed and accepted by the relevant sector task teams.

Chapter V. Marginal Abatement Cost Curve Modelling

5. Marginal Abatement Cost Curve Modelling

This report has sought to identify and quantify mitigation opportunities for a representative set of emission reduction activities. By definition, these activities are located within individual facilities, owned by separate companies and state-owned entities. The identification of such activities for quantifying both abatement potential and costs has formed the basis for constructing marginal abatement cost curves (MACCs) and is a widely accepted methodological approach (see e.g. United Kingdom Committee on Climate Change, 2008 and Enkvist et al., 2009).

5.1. Overview of the MACC Approach

A marginal abatement cost curve (MACC) shows the costs and potential for emissions reduction from different measures or technologies, ranking these from the cheapest to the most expensive to represent the marginal costs of achieving incremental levels of emissions reduction. An illustrative MACC is shown in Figure 2 below. MACCs represent a static snapshot of the abatement potential of a selected set of mitigation measures in a specific target year. Relative to the reference case scenario, a MACC shows the additional GHG mitigation abatement potential for each abatement technology along the horizontal x-axis (in tonnes of CO_2e abated). The marginal abatement cost (MAC) (or the cost of implementing each additional measure) is shown along the vertical y-axis (in cost per tonne of CO_2e abated). Phrased differently, a MACC indicates the marginal cost of emission abatement for varying amounts of emissions reduction associated with implementing a range of different mitigation measures.

Each bar on the MACC in Figure 2 (e.g. F, G, A, etc.) describes the cost and potential for emissions reduction from a specific measure. The total cost of delivering an emissions reduction target is represented by the area under the MACC up to the point where the emissions reduction target is reached. This assumes that all measures are taken up in sequence with the cheapest option first, up until the point where the target level of emissions reduction is achieved.

5.2. Strengths and Weaknesses

A MACC is a tool for understanding the level of emissions abatement that can be delivered by specific technical and behavioural measures, at a given point in time. It also provides an understanding of the relative costs of the measures. It is therefore useful for ranking investment decisions, or providing guidance on which measures should be considered for specific policy interventions. A MACC curve can also be used to help assess the cost of delivering a specific emissions abatement target, along with the basket of measures that need to be implemented to meet the target.

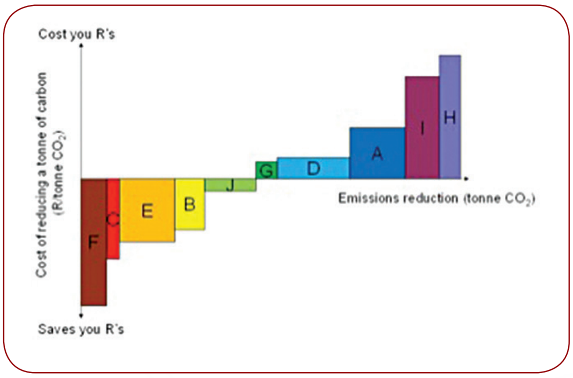


Figure 2: Conceptual diagram illustrating the construction of a marginal abatement cost curve.

However, the information in a MACC represents a static snapshot at a given point in time. The estimates of abatement potential are underpinned by a scenario about how emissions will develop in the respective sector over time, as well as the availability and cost of measures available to reduce emissions at that point in time. This means that the results from a MACC analysis are tied to certain underpinning assumptions. In this way MACC models are not as dynamic as other modelling tools. This can present challenges when attempting to consider sectoral inter-dependencies. For example, mitigation actions taken in one sector (e.g. power generation) will have a knock-on effect in other sectors (e.g. energy prices, and emissions factors for power generation).

5.3. Key Elements of a MACC

Some of the key elements of a MACC are described further below.

5.3.1. Measures data

Underpinning a MACC are detailed data on the cost and abatement potential of the individual measures, assumptions with respect to the uptake of those measures over time (in response to existing policies and other drivers) and adjustments for interaction among measures. For policy-making purposes, the values used to generate the MACC are typically based on estimates of the average cost and the abatement potential of the specific measures for the sector as a whole.

For certain measures the difference in the cost and/or the abatement potential may vary significantly from one setting to the next depending upon, for example, the age of existing equipment, usage levels and fuel mix. Where more accurate data is required the cost estimates should be repeated for the particular site or location in question. The output from this exercise is a site-specific MACC.

This study has focused on the development of MACCs at a broad sectoral level, and has not developed any site specific MACCs. A list of the abatement measures that have been assessed has been presented in each of the Appendices for the energy, industry, transport, waste and AFOLU sectors. It has not been possible to derive quantitative estimates for all potential measures, so in some cases a more qualitative assessment of the cost or abatement potential has been made.

5.3.2. GHG emissions abatement

In the MACC, the GHG emissions abatement potential of each MAC (i.e. The abatement effectiveness) is shown by the width of each measure along the horizontal x-axis (in ktCO_2e abated). For a given MACC and a given time period, the cumulative total of technically-available mitigation in a sector is given by the sum of all abatement across the x-axis.

5.3.3. Marginal abatement costs

In a MACC, the unit cost of a single abatement measure is described as a marginal abatement cost; since it is marginal to measures already in place (i.e. It represents the incremental additional cost). Marginal costs result from the last action taken (e.g. abatement of one extra unit of emission), divided by the total emissions. The marginal abatement cost (MAC) is a measure of overall cost of implementing each additional mitigation measure. The MAC is represented along the vertical y-axis (in R/t CO_2e abated).

5.3.4. Target year

As described above, a MACC represents a static snapshot at a given point in time. In calculating the MACC, an estimate is made of the total technical abatement potential remaining in the target year, taking into account the business-as-usual (BAU) uptake of measures. It therefore allows for a proportion of the total abatement potential to be taken up in the BAU scenario as a result of existing policies and other drivers. In this way the remaining potential represents a more realistic assessment of what might be achieved from additional action.

Assessing the BAU uptake requires a judgement on the uptake of individual measures. However, for certain sectors emissions data is not available at a sufficient level of resolution to account for measures at such a detailed level. In such cases it has been necessary to make certain simplifying assumptions, for example, by considering average efficiency improvements across the sector as a whole. In these instances, abatement measures have been bundled together, and assessed in more aggregated terms.

In calculating the available potential in the target year, certain temporal issues have been taken into account. For example, the penetration rates for technologies (see below) will influence how many new technologies can realistically be taken up. Likewise the availability of certain technologies in the future (see below) also needs to be accounted for. However, the MACC does not explicitly describe the profile of how the abatement measures will be implemented over time. It only describes the total abatement potential that is technically feasible given the temporal constraints. Likewise, all MACCs are based on the same underlying assumptions, therefore the dynamic impact of a decision made in one time period on the abatement potential in a later time period cannot easily be assessed without defining an alternative scenario.

5.3.5. Analytical basis

The analytical basis that underpins the assessment of measures in a MACC can have an important influence on the overall results. Some key considerations that need to be taken into account in these calculations are described below together with the approach to addressing them adopted in the current study.

5.3.5.1. Issue: Choice of discount rate

Discounting is the technique of applying a discount rate to convert future monetary amounts to their equivalent value in today's terms. The concept of discounting is based on the premise that people prefer to receive benefits in the present rather than in the future. By applying a discount rate to costs and benefits arising in the future the MACC reports costs in present-value terms. Only economic values (costs and cost savings) are discounted, emissions are not.

Cost curves can be presented to reflect the discount rate typically used within public policy making, based upon a social discount rate or based upon the discount rates typically used within commercial decision making (private discount rate). Private discount rates are usually higher since they need to account for commercial rates of return. High discount rates will make options with high upfront costs and future streams of benefits (e.g. many energy efficiency investments) appear less attractive. This will shift the MACC upwards and reorder the curve.

Project approach: Since this study is intended to inform public policy making, the project team adopted a social discount rate of 11.3% when generating the MACCs, in accordance with guidelines provided by National Treasury

5.3.5.2. Issue: Choice of global warming potential

The potency of different gases in contributing to global warming is represented by their global warming potentials (GWPs). In generating a MACC for climate change mitigation, it is important that GHG emissions are included, and that all emissions are reported on a consistent basis.

Project approach: All emission reductions have been reported in carbon dioxide equivalents on the basis of the 100 year GWPs used in the IPPC's Third Assessment Report. This is consistent with the 2006 IPCC guidelines (IPCC, 2006).

5.3.5.3. Issue: Choice of emission factor

In calculating the effectiveness of abatement measures, it may be necessary to define the emission factors that will be applied. This is necessary where the savings are provided in energy terms, for example, which need to be converted into emissions savings (in CO_2e). For certain measures it may be useful to define the specific fuel savings in any case, as the fuels that are abated will have different impacts in terms of their GHG emissions.

A related issue concerns the scope of emissions represented by the emission factor. MACCs can be based purely on direct emissions, e.g. emissions from the direct combustion of fuels. However, in some cases indirect emissions may also be included, for example, emissions associated with reductions in electricity consumption, or emissions associated with the production of fuels.

When generating MACCs for specific sectors, it is useful to account for indirect emissions where they are considered significant. However, when generating MACCs across all sectors of the economy this is more complex, as it may lead to double-counting of emissions in upstream/downstream sectors. It is often simplest to focus on just the direct emissions arising from a given sector. However, for some sectors, and for emissions associated with electricity consumption in particular, it is common for these indirect emissions to be included when assessing the effectiveness of measures. This requires an explicit linkage with the analysis of emissions in the power sector.

Project approach: Direct emissions have been estimated in accordance with emission factors used in the draft South African GHGI (DEA, 2013).

In relation to indirect emissions, emissions associated with electricity consumption have also been accounted for. These indirect emissions reflect changes in the carbon intensity of production over time (see above). In the transport sector, the project team has also taken indirect emissions into account; this is important when comparing measures such as biofuels.

The emissions factors that have been used for assessing direct combustion of fuel, as well as the indirect emissions from electricity and fuels have been documented in the sector-specific technical appendices.

5.3.5.4. Issue: Mitigation measures availability

A MACC may include a wider range of abatement measures, including established existing technologies, and less well established emerging technologies. Certain emerging technologies might not be available for application until some point in the future. This is reflected in the assumptions that are made about the availability of technology at a given point in time.

Project approach: Drawing upon published research, the availability of each of the technologies has been defined over the assessment period and its availability has been allocated to the beginning of one of the following 10 year periods: 2010, 2020, 2030, 2040 and 2050.

5.3.5.5. Issue: Determining the mitigation technology uptake and market penetration

The extent to which a specific abatement measure can be implemented at a given point in time in the future is influenced by the availability of the measure (described above), and its market penetration rate. The penetration rate essentially describes the rate at which the measure could realistically penetrate the market. It therefore provides a limit on the abatement potential that can be delivered by a specific measure. For new technologies, this rate is typically assumed to follow existing investment cycles.

In the road transport sector the penetration rate of new technologies will largely reflect the frequency at which new vehicles enter the market. In the building sector the rate of new build or renovation frequency for existing building determines the penetration rate. In the power sector, construction timescales influence penetration rates, and in the industry sector the frequency of plant or process upgrades are key drivers.

Project approach: Drawing on published research, appropriate penetration rates for each of the technologies have been defined in accordance with the characteristics of the sector concerned. The penetration rates have been defined over the full assessment period, namely to 2050.

In the energy sectors (excluding electricity generation) and the industrial sectors, for example, the selected level of implementation of a mitigation measure in a given year have been defined by three parameters outlined below.

- Starting point: when additional mitigation action is implemented.
- Penetration rate: at what rate a measure is implemented over the 2010–2050 time period (i.e. the penetration rate).
- Uptake: the extent to which a measure is implemented and deployed across the sector at a point in time (e.g. 25%, 50% or 100% by 2050),

To determine the starting point, penetration rate and uptake of each measure, a pragmatic approach has been applied, guided by the principle of what is technically possible (and not limited by economic and other non-technical considerations). However, economic considerations, such as an understanding of the relative marginal cost, are used in order to estimate the potential penetration rates of the different measures.

These parameters have been decided based on two factors.

- Mitigation measure availability: as defined above, the availability of each measure has been allocated to the beginning of one of the following 10 year periods: 2010, 2020, 2030, 2040 or 2050.
- Marginal abatement cost: the cost of achieving incremental levels of emissions reduction (i.e. The overall cost per tCO_2e abated).

Additionally, the following straightforward assumptions have been made.

- Measures are implemented between 2010 and 2050, from 0% to 100% additional uptake.
- Measures are implemented starting from when they are deemed to be technically available.
- Measures are typically implemented sector-wide at a rate from 0 to 100% over a period of 10 years, if a measure is a smaller retrofit project (i.e. A lifetime of between 10 and 15 years). If measures are deemed to be locked-in technology (i.e. A lifetime of between 25 and 40 years), then they are assumed to be implemented over 20 years.
- Where a set of measures is mutually exclusive, it is assumed that they will be implemented equally and the total summed uptake of these measures cannot exceed 100%.
- Where a measure is deemed to be too costly in comparison to other options or not feasible due to the prior implementation of another measure, then the uptake has been set to zero and the measure has been removed from the MACC.

The above approach and selected abatement, marginal abatement cost and technically possible levels of uptake have resulted in the creation of the 'with additional measures' (WAM) scenario (see Section 7).

In the case of mitigation of emissions from the residential and commercial building sectors, the starting point, penetration rate and uptake of each measure has been based on the technology share proposed by the South African TIMES model (SATIM) model 'upper bound' scenario (ERC, 2013).

5.3.5.6. Issue: Determining the appropriate lifetime of measures

The assumed lifetime of the measures can have an important influence on their calculated cost-effectiveness. For all measures there is a degree of uncertainty about their lifetime. In particular, this may be greater for emerging technologies.

Lifetime is defined in terms of the technical lifetime of a measure (and its emissions reductions) as opposed to its economic lifetime, which may be defined in a different way.

Project approach: The assumed lifetime for each of the measures has been based on published research and agreed in consultation with sector task teams. In constructing the MACCs it has been assumed that this lifetime holds constant over the whole assessment period, so a new measure installed in 2040, for example, has been assumed to have the same lifetime as if the same measure was implemented in 2015.

5.3.5.7. Issue: Dealing with interaction among measures within a sector

The cost-effectiveness of the abatement measures in a MACC and their abatement potential are expressed relative to the BAU situation. However, for certain measures, there is a degree of interaction, so the uptake of one measure may influence the cost-effectiveness or potential emissions reductions from subsequent measures. For example, reducing the carbon intensity of transport fuels (e.g. biofuels) will reduce the potential savings that could be delivered by more fuel efficient vehicles, and vice-versa.

Project approach: For each emission source, the following has been specified:

- Which measures are additive (could be applied simultaneously without altering emission abatement or costs) and implications for total emissions abatement/costs for all measures;
- Which measures are mutually exclusive (could only be applied independently of each other);
- Which measures could be applied but effectiveness/costs would be affected by other abatement measures for that source.

Measures that apply to different uses are likely to be additive, as are those that apply to releases to different environmental media; those applied for certain lifecycle stages could affect downstream uses.

For those that are mutually exclusive, it has been assumed that the measure with the lowest marginal abatement cost would be applied first. If an alternative measure could also be applied, the cost curve should only reflect the incremental emission reduction and cost that would occur.

For those measures that would be affected by other abatement measures, if the measure with the lowest marginal abatement cost is applied first, the measure with the next lowest marginal abatement cost may no longer achieve the same degree of emissions abatement, so it has been scaled back accordingly.

Measures have been assessed on an individual basis. The interaction among measures has also been taken into account in the development of the mitigation scenarios, which are based on the results of the sectoral MACCs.

5.3.5.8. Issue: Dealing with interaction among sectors

Actions taken in one sector of the economy can have implications for the cost and effectiveness of measures in other sectors of the economy. This is more important when considering interactions among the energy sector and the energy end-use sectors. For example, action taken to decarbonise the electricity sector will have an indirect impact on the apparent effectiveness of measures to reduce electricity consumption in buildings (since less carbon will be saved per unit of electricity saved than previously). Likewise actions to reduce the electricity consumption in the end-use sector will reduce the needs for additional power generation capacity and reduce the overall emissions in the power sector. Similar interactions exist between the liquid fuels sector and the transport sector.

Project approach: Each of the sectors has been assessed on an individual bottom-up basis. This provides a high level of detail on the emissions and associated technologies for a given sector. However, interactions among sectors are not adjusted automatically using this approach and to do so would require the development of an energy system model, which was beyond the scope of the study. Nevertheless, these interactions are still important, and to address this some additional analysis was performed to explore the interaction between the sectors. For example, action taken in the transport sector will have indirect impacts on emissions from other sectors. Specifically, measures that reduce the demand for fuels will reduce the level of fuel production capacity required in future scenarios, and the emissions associated with liquid fuel production. It has not been possible to explore this interaction fully. However, as an illustration, if the abatement measures relating to more efficient and alternative fuelled vehicles were implemented, this may be sufficient to delay a requirement for new investment in refinery capacity, which would be expected in a reference case emissions scenario. This in turn would reduce the overall emissions associated with liquid fuel production.

5.3.5.9. Issue: Choice of marginal abatement cost metric

The measures within a MACC may have different lifetimes. When ranking measures it is necessary to use a metric which takes this into account so that measures are compared on a consistent basis. There are two metrics that are typically used in calculating the marginal abatement cost of measures. The first, net present value (NPV), represents the cost as the net present value of all costs and benefits accruing over the lifetime of the measures, and the effectiveness as the lifetime emissions savings. These are defined as follows:

NPV: ([NPV of future annual costs/savings] – [upfront investment])/total emission saving over lifetime

The second, net annualised cost (NAC) is defined as:

NAC: ([annualised investment] – [average annual cost/saving])/annual emission saving

Project approach: In order to ensure a robust analysis where different options with different lifetimes are present, the MACC has been based on annualised capital costs according to the discount rates to ensure that all measures can be compared against each other. Likewise, any operating and emissions savings have also been annualised.

5.3.5.10. Issue: Accounting for transaction costs

MACCs differ in their approaches to transactions costs. Studies generally do not include transaction costs, communication/information costs, subsidies, taxes or the costs of overcoming barriers to implementation. These missing costs and barriers are often likely to cause the abatement cost estimates to be lower than what can realistically be expected and they explain in large part the continuing existence of negative cost options in the MACC.

Project approach: Transaction costs have not been explicitly considered in the MACCs. However, where transaction costs are important these have been captured in the multi-criteria decision analysis.

5.3.6. Dynamic variables

In calculating the cost and effectiveness of the measures it is also necessary to take into account the fact that certain variables will be dynamic and vary over time. This means that the marginal abatement costs of a given measure may differ, in real terms, from one year to another. In practice, this variance may not be large over a short period of time. However, over long time periods, and taking into account the cumulative impacts of different variables, these differences can be more significant.

5.3.6.1. Issue: Changes in commodity prices

For certain abatement measures, any assumed changes in commodity prices can have an important influence on the overall costs (or benefits). This, in turn, may influence the relative ranking of a given measure in the MAC curve. This is most applicable to changes in energy prices, and the relative cost-effectiveness of energy supply measures, or measures targeting energy consumption.

Project approach: Projected changes in energy prices over time have been taken into account when calculating the cost-effectiveness of the measures in a given year. Therefore, for any given measure, the cost calculation has taken into account projected changes in energy prices over the lifetime of the measure, from its year of implementation. This has required long-run energy price projections from 2010 to 2050. Prices from 2050 are assumed to remain unchanged. Energy price assumptions have been documented in the relevant technical appendices.

5.3.6.2. Issue: Changes in technology costs

For certain technologies, and in particular emerging technologies that have not benefited from economies of scale in production, future costs might be expected to be lower than current costs, due to the effects of innovation.

These cost improvements, which arise from cost efficiencies such as the scaling up of production, are reflected in the technology learning curves. As a result of these effects, the future costs of certain technologies are expected to decline in real terms in the future. This will reflect the relative cost-effectiveness of these technologies in the future.

Project approach: Changes in the costs of key technologies due to learning effects have been taken into account. Learning rates have been taken from published literature, and where unavailable estimates have been made based on data for analogous technologies. Where evidence of the potential for innovation effects is more limited, or uncertain, a conservative approach has been taken and costs have been held at current levels.

5.3.6.3. Issue: Changes in fuel mix

For energy efficiency measures, the relative abatement potential of the measures will be related to the mix of fuels that is assumed to be abated, and their relative emissions factors. This includes savings associated with electricity consumption where the emissions intensity of the generation mix can change over time. To account for these changes it is necessary to estimate the relative change in the fuel mix over time and/or the carbon intensity of the fuel mix.

Project approach: An estimate of the likely fuel supply mix in key sectors has been derived under a BAU scenario. This has been used to calculate energy savings, by fuel type, for key measures. Therefore, for any given measure, the effectiveness calculation has taken into account projected changes in the fuel mix over the lifetime of the measure, from its year of implementation.

This has required long-run projections of the fuel mix from 2010 to 2050. For certain sectors, particularly where the fuel source is tied to a specific process, or energy source, it has been necessary to take into account fuel use at a more disaggregated level.

Chapter VI. Multi Criteria Analysis

6. Multi Criteria Analysis

6.1. Introduction

A multi criteria analysis (MCA) approach has been developed in order to conduct an impact assessment on all identified abatement opportunities, taking a range of criteria into consideration.

This is relevant to this study because a stated objective of the National Climate Change Response Policy (DEA, 2011) is to manage climate change impacts through "interventions that build and sustain South Africa's social, economic and environmental resilience and emergency response capacity."

It is clear, then, that any decision to implement mitigation measures will be based on more considerations than merely abatement potential and cost. This intention is born out clearly in the objectives for this study, which *inter alia* seek to assess the socioeconomic and environmental impacts of the identified mitigation options.

In addition to the impacts assessment for all mitigation options, results from the MCA model have also been used to derive a range of technically-possible future abatement pathways (see Section 7).

6.1.1. Motivation for using MCA

MCA is a technique that explicitly considers multiple, often competing, criteria in a decision-making environment. The key benefits of MCA are that it provides a proper structure for a decision-making process, and that it makes the manner in which multiple criteria are evaluated explicit. MCA does not remove the influence of judgement or personal preference in decision-making; instead it makes those judgements and preferences explicit and thus open to analysis, comment and change if required.

Finally, it should be noted that this approach has considerable advantages compared with the traditional marginal abatement cost (MAC) analysis which considers only the criterion of cost for a given amount of GHG mitigation. Introducing other criteria which also focus on impacts (also referred to as benefits) gives a far more meaningful outcome.

6.1.2. Steps in the MCA process

An MCA typically incorporates a number of steps. These have been followed in the development of the MCA model used in this study. They are summarised in Figure 3 below and discussed in more detail in the following sections.

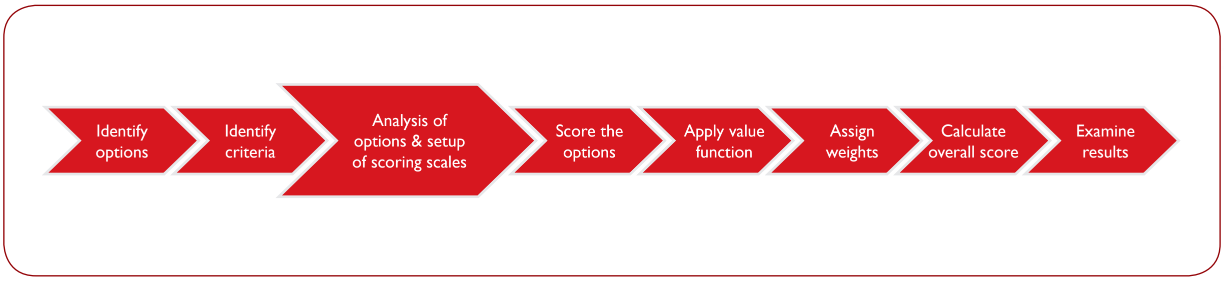


Figure 3: Steps in the MCA process

Step 1: Establish the decision context

The first step involved clarifying the objectives for the MCA and deciding when and how key players would contribute to it. In the case of this project, decision-making responsibility was vested in the Task Teams set up for each sector and ultimately in the Technical Working Group. The role of the consulting team was to support these structures through providing the necessary information and facilitating the decision-making process.

Step 2: Identify options

In the second step, a list of measures to be evaluated is required. It is desirable to limit the number of options to be assessed to a manageable number. If there are too many options, then preliminary screening can be used to reduce the number of options. Screening is conducted based on some agreed criteria (for example, maximum price or minimum acceptable performance). Typically an MCA process should be open to modifying or adding to the list of options as the process progresses, should new options emerge.

For this project, recommendations were made by the consulting team on the mitigation measures. These were presented to the Task Teams at workshops held for each sector in early 2013. Following discussions at these workshops a final list was prepared for further analysis and discussion. Following the analysis, the list of measures was modified. The motivation for these changes has been noted in the Technical Appendices dealing with each sector.

Step 3: Identify criteria

Criteria are specific, measurable objectives that can be used to assess the consequences of selecting a particular option.

For this project, a two-tier structure of criteria was set up, as described later in this appendix. This resulted in what is referred to as a 'value tree' which relates to the objectives of the project.

Step 4: Set up scoring scales and undertake analysis

The next step is to establish scales against which each criterion can be scored. Scales can be quantitative or qualitative.

A quantitative assessment can be done for criteria that can readily be estimated or measured and thus quantified in recognisable units (e.g. cost or economic impact measures such as gross value added (GVA)). For quantitative assessment, the scale emerges directly from the relative numbers. This requires an analysis to be undertaken which is described later in this Appendix.

Where quantitative measurement or estimation cannot be done easily, or the nature of what is being evaluated does not lend itself to quantitative measurement, then a qualitative assessment becomes necessary. In this case, an appropriate scale must be created. This could simply be a ranking (e.g. low, medium, high) or a so-called constructed scale, where each level of performance is described and assigned a relative score.

For this project, scales were set up for each criterion and these have been described later in this Appendix. Where the data and method of analysis is available, a quantitative analysis is applied to calculate the impact of each mitigation measure in relation to the criterion. Where such a quantitative analysis was not possible, a qualitative approach was applied. The scoring for qualitative criteria was based on judgement by stakeholders, informed by expert opinion. The sector Task Teams were responsible for taking the decisions and for agreeing on the scoring scales.

For criteria where quantitative analysis is possible, the following methodology was applied:

1. In the case of the cost criterion, the capital and net operating cost information applied to the MACCs was used to calculate a NPV for the mitigation measure over the period 2010 to 2050.
2. For the economic impact criterion, the Impact Assessment Model described above was run for each measure to get the change in average annual GVA over the full period of analysis.
3. For the job creation sub-criterion, under the social criterion, the Impact Assessment Model was applied as it also provides an output on changes in the average number of jobs created per year, applying existing relationships between GVA and jobs. In some cases where the mitigation measures have very different employment structures – the waste and AFOLU sectors specifically – the results were modified based on employment figures from the literature for the specific measures.

For the criterion dealing with the proportion of unskilled jobs to total jobs the Impact Assessment Model was used once again.

Step 5: Score the options

Each option must be scored against the established scale. For the quantitative criteria where data is readily available, scoring is based on the results of an analysis of numbers which, as noted above, results in a score based on the range of the numbers.

For qualitative criteria, the sector Task Teams were engaged in one-day workshops for each sector where they scored each mitigation measure in relation to the scoring scales. The results were recorded with the motivation for scoring. This approach highlighted one of the advantages of MCA in that judgements could be recorded and made explicit.

Step 6: Use a value function to convert scores to points on a scale of 0 to 100

A value function translates scores on differing scales into points on a scale of 0 to 100, and thus allows comparability between criteria.

A value function may be linear, with scores related to points along a straight line, or non-linear (exponential or fixed points for each score on a non-linear trend). Decisions on value functions are made for each criterion and are then fixed for all sectors and measures. In the case of this project a linear value function was used for all criteria.

Where there is a relatively even distribution of scores across the full spectrum of measures a linear value function is appropriate. However, it is important that outliers are dealt with carefully as they can distort the results by forcing the majority of measures into a narrow band within the 0 to 100 scale. In order to provide for this, the scores for outlying measures, in relation to the criterion concerned, need to be adjusted and a note made of what has been done.

Step 7: Assign weights

Assigning weights is commonly understood as prioritising the criteria, in other words assessing how important the various criteria are relative to one another. This is true to some extent, but weights are in fact scaling constants, allowing a unit of preference on one criterion to be compared to a unit of preference on another. The weight on a criterion should reflect the range of difference between the options as well as how much that difference matters.

The ratios between a sound set of weights should consistently represent the importance of the differences between the top and bottom scores on each criterion.

The process of deriving weights is fundamental to the effectiveness of a MCA process. For this project it was done through a facilitated workshop with the Technical Working Group, in May 2012. A base weighting was derived together with two other sets of weights, as described later in this Appendix.

Step 8: Calculate overall weighted scores at each level in the decision tree hierarchy

This is a mathematical process. In an additive aggregation function process (such as that outlined here); an option's score on a criterion is multiplied by the weight of the criterion. This is done for all criteria, and the products are summed to give an overall preference score. The process is repeated for all criteria.

Mathematically: $S_i = \sum_{j=1}^{n} w_j s_{ij}$

where S_i is the overall preference score for option i, n is the total number of criteria, s_{ij} is the preference score for option i on criterion j, and the weight for criterion j is w_j.

For this project, the scoring and weighting is undertaken in an MCA Excel workbook for each sector, linked to a 'mother' workbook which integrates all the measures considered into a single analysis.

Step 9: Examine the results and make recommendations

The final step in the MCA is to establish a ranking of the options and make recommendations.

For this project this was done in the 'mother' workbook with the weightings also transferred back to the sector MCA workbooks. This allows relative prioritisation of the large number of measures to be undertaken for the 'base case' weighting and for a range of other weightings which need to be assessed.

In addition, a sensitivity analysis was undertaken to assess the implications of changing key parameters or assumptions.

6.2. Identification of Mitigation Measures

The identification of mitigation measures to be evaluated for the purposes of this project is covered in the main body of the report and in other appendices.

The original list of mitigation opportunities numbers 172, distributed across sectors as shown in Table 7.

Table 7:Number of mitigation opportunities per sector

Sector	Number of opportunities
Energy	45
Industry	95
Transport	18
Waste	8
AFOLU	6
Total	172

After accounting for outliers, nine measures were excluded from this list (six in the energy sector in oil and gas; three in the transport sector, one in rail and two in aviation).

These measures are regarded as outliers because they all represent relatively small amounts of abatement potential but are associated with large (positive or negative) marginal abatement costs. In assigning value functions during the development of the MCA model (Step 6 above), inclusion of these measures would skew the results for all remaining measures. Hence they have been excluded as outliers.

6.3. Identification of Criteria

6.3.1. Criteria selection

A process was followed through which criteria were proposed to the TWG, discussed and amended accordingly. The final position is shown in Figure 4 below with further discussion of criteria in Table 8.

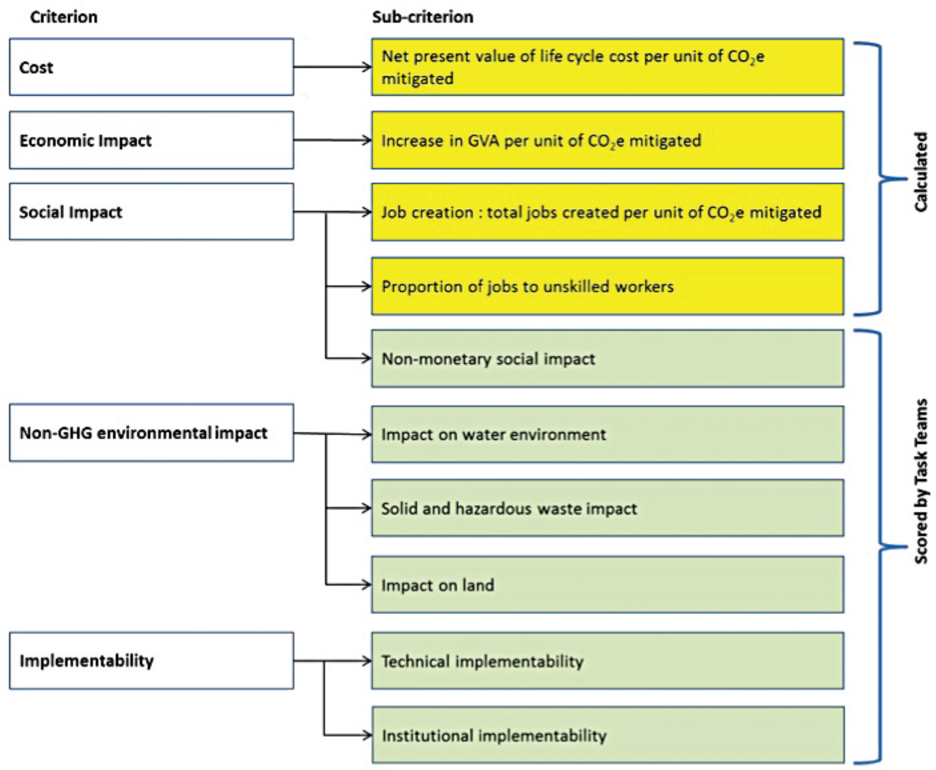


Figure 4: Criteria and criteria hierarchy as applied to the MCA

Table 8: Description and motivation for inclusion of MCA criteria, including record of final decision from the TWG-M

Criterion name	Indicator	Method of scoring	Motivation to TWG-M to Include	TWG-M response regarding inclusion
GVA impact	Change in GVA from counterfactual (Rm).	Analysis: macroeconomic impact (MIA) model.	Yes.	Yes (see explanation of GVA below).
Balance of payments	Difference in balance of payments over period up to 2050 (Rm).	Analysis: MIA model.	No (difficult to measure and relatively unimportant).	No (agree with arguments made by consulting team).
Competitiveness	Extent to which an industry increases its market share internationally.	Expert opinion.	No (too difficult to measure. Double counting with cost criterion).	No but mining sector given an opportunity to motivate for inclusions, which was not taken up.
Job creation	Number of jobs created.	MIA model.	Yes.	Yes, but with requirement that all jobs be included with separate sub-criteria for unskilled and semi-skilled jobs.
Job creation – less skilled jobs	Proportion of jobs which are unskilled or semi-skilled.	MIA model		Additional criterion added.
Household expenditure	Change in household expenditure on energy, transport and food.	Constructed scale (Range from negative, with lowered expenditure to positive).	No (this is a form of double counting with cost).	No (TWG agreed with the double counting argument).
Social impacts other than job creation and lowering costs	This criterion was changed in the process of discussions with the TWG. It shifted from 'impacts on household income' to broader measures of well-being.	Constructed scale.	No (difficult to measure & double counting).	Yes. Request remained for a criterion which deals with non-monetary aspects (See discussion in following sections).
Water consumption	Change in amount of water used for the activity (subsequently amended to include quality considerations).	Some quantitative data but not enough: use constructed scale.	Yes (relatively important).	Yes.

Criterion name	Indicator	Method of scoring	Motivation to TWG-M to Include	TWG-M response regarding inclusion
Land transformation	The extent to which the option reduced biodiversity or reduces options for other land use	Simple scale: positive, negative of zero impact	Yes (relatively important)	Yes
Waste management	Difficulty in disposing of waste	Constructed scale	Yes (relatively important)	Yes
Air quality	Level of emission of gases and particulates listed in Air Quality Act	Constructed scale	No (mainly due to double counting with GHG emissions)	No (consultants asked to prepare written motivation to exclude which was accepted)
Financial implementability	Extent to which private sector funding is available	Constructed sale	No (difficult to measure and double counting with cost criterion)	No
Technical implementability	Extent to which the technology is available internationally and has been applied previously in SA	Constructed scale	Yes	Yes
Skills availability	Extent to which skills are available to implement projects and manage resulting activity	Constructed scale	Yes	No (too much overlap with technical and assumption that skills will always be found)
Institutional implementability	Extent of institutional and regulatory complexity	Constructed scale		New criterion added at request of TWG

6.3.2. Assessment against a counterfactual

For all criteria, the impact has been assessed against a counterfactual, the existing situation against which a measure is compared. For example, in considering the water impact of a wind farm, what is of interest is the volume of water used by wind farms compared to the volume used by current power generation mix (primarily coal fired power) for the same level of power generated. This is in keeping with the manner in which mitigation potential will be assessed under the mitigation opportunities activity of this project, and counterfactuals have been defined under that activity.

Note that assessing options against a counterfactual has made the analysis more complex as data was required on the performance of the counterfactual, as well as the performance of the abatement opportunity relative to that counterfactual. A summary of the approach to counterfactuals for each sector is given in Table 9 below:

Table 9: Description of counterfactuals used in MCA model by sector and subsector

Sector	Subsector	Counterfactual
Energy	Electricity and heat	Electricity generated using existing technology for coal fired power stations.
	Petroleum industry	Petroleum industry measures can be grouped into three from the point of view of counterfactuals: • Change feedstock from coal or crude oil to gas or agricultural products in which case the counterfactual is obvious. • Change production measures which reduce GHG emissions but do not change output where there is no counterfactual. • Energy efficiency measures which reduce amount of electricity required from the grid where the counterfactual is existing grid electricity generation technology.
Industry	Measures other than energy saving	None (mitigation measures do not displace anything, they relate to changes in processes for the same level of production).
	Energy saving measures	Energy saving measures are related to a counterfactual in the sense that they replace existing energy generation measures (coal fired power generation).
	Buildings	Electricity generated using existing technology for coal fired power stations.
Transport	Rail and air based	None (mitigation measures do not displace anything)
	Road-based – modal shifts	Increase in rail based transport contrasted with current extent of rail based transport
	Road-based – vehicles	Additional measures (vehicles requiring less fossil fuel per km travelled) contrasted with counterfactual of existing vehicles (mix of conventional petrol and diesel engine vehicles).
Waste		Waste disposal by landfill with no use of gas.
AFOLU	All except commercial forestry	None (mitigation measures do not displace anything)
	Commercial forestry	Irrigated maize which uses the same amount of water as the amount of forestry proposed. The argument here is that water is the key constraint on expanding forestry and hence forestry will displace agricultural activity.

6.3.3. Normalising' the criteria against mitigation potential

The approach taken when defining the criteria has been to normalise the quantitatively calculated results against tonnes of CO_2e avoided. In this case, the cost criterion was R million per tonne of CO_2e avoided, rather than the total magnitude of the cost in R million. As a consequence, mitigation potential has been omitted as a criterion as this was the basis for comparing relative impact for all other criteria. This modification made the comparison of numbers relatively easy and consistent with the approach used in marginal abatement cost curves (MACCs).

The following criteria were normalised in this way:

- Economic impact measured as R million GVA per unit of CO_2e mitigated.
- Jobs impact measured as number of jobs created per unit of CO_2e mitigated.

Qualitative criteria were not normalised. The implication of this has been that the scoring is for an equivalent amount of mitigation.

6.3.4. Discounting future costs and benefits

Discounting future costs and benefits that can be expressed in monetary terms is common practice and, while there remains significant debate about what discount rate is to be used, there is also considerable precedent with sound underlying rationale on which to rely when choosing a discount rate. Therefore this approach is taken for the cost criterion, with a discount rate of 11.3% applied as agreed with the TWG.

In the case of the economic modelling, the capital and operating costs for the impact model (which deals with the direct and backward linkages associated with the measure concerned) were discounted. In the case of surpluses generated through the implementation of the measure, these were applied as a change in NPV and also discounted.

6.4. Individual Criteria: Data and Scoring

6.4.1. Cost

Cost was included as a criterion based on the argument that lower costs are advantageous and would be a major factor in causing the mitigation option to be implemented.

Like mitigation potential, cost was assessed as part of the mitigation opportunities task on this project.

Note that cost was assessed on a life cycle basis. For the purposes of this analysis, this meant that both capital costs associated with construction and decommissioning (where relevant within the time period) and ongoing operating costs were included.

Note also that financial costs were evaluated on a NPV basis; in other words with future costs discounted. The discount rate used was 11.3%, as agreed with the TWG.

The indicator was defined as NPV of additional expenditure incurred up until 2050, per unit of CO_2e mitigated, in millions of rand, in relation to a counterfactual.

The cost scores for the MCA were calculated on a continuous basis with a linear value function with the highest score being the lowest cost per unit of CO_2e mitigated, and the lowest score being the highest cost.

Several measures have been excluded as outliers i.e. They are at the outer limits of the scoring range and would distort the results unless excluded. As discussed above, nine measures were excluded from the MCA model because their cost assumptions (relative to the abatement potential) identified them as outliers.

6.4.2. Economic impact: Gross value added (GVA)

GVA is a commonly applied measure for the scale of economic activity, measuring the value which the activity adds to the economy in millions of rand (simply put, the sum of all the outputs of organisations undertaking the activity less the inputs they purchase from others). The impact of a mitigation intervention on the economy is clearly important. Impact on GVA is a key component of an assessment of economic impact.

The indicator was defined as additional gross value added (GVA) created (or lost) up until 2050 in millions of rand, per unit of CO_2e mitigated, in relation to the counterfactual. GVA was calculated using the economic models, as described below.

The scores for the MCA were calculated on a continuous basis with a linear value function with the highest score being the highest value of GVA per unit of CO_2e mitigated. As with the cost criterion, results were analysed to ensure that measures which are at the outer limits of the scoring range did not distort the results.

6.4.3. Social impact: Job creation – total jobs

In the context of a country with an unemployment profile such as that seen in SA, the creation of unskilled or semi-skilled jobs is critical for social development.

The indicator was defined as the number of additional jobs (unskilled, semi-skilled and skilled) created or lost over the period up to 2050, in relation to the counterfactual.

Job numbers were calculated using the economic models (described in greater detail in Section 3).

The scores for the MCA were calculated on a continuous basis with a non-linear value function with the highest score being the highest number of jobs created per unit of CO_2e mitigated. Outliers have been taken into consideration.

6.4.4. Social impact: Nature of jobs created

This criterion is introduced to provide for the fact that unskilled and semi-skilled jobs are more important from the point of view of social development than skilled jobs. The indicator is the ratio of unskilled jobs and semi-skilled jobs to skilled jobs. The numbers of jobs in each of these three categories was an output from the economic models as described below. Therefore the required ratio can be calculated from these outputs.

The scores for the MCA were calculated on a continuous basis with a linear value function with the highest score being the highest ratio: most unskilled and semi-skilled jobs created in relation to skilled jobs.

6.4.5. Social impact: Non-monetary social impact

This criterion is introduced to measure non-monetary social impacts: those which do not relate to income (jobs) or expenditure (prices). The indicator is described as: "The extent to which the measure improves 'liveability' or 'happiness' for people, with the primary emphasis on poor people."

The mitigation measures were scored against this criterion based on the informed opinion of Task Team members, applying the following scale (Table 10):

Table 10: Scores and interpretation for non-monetary social impact criterion

Score	Interpretation
-1	Has a negative impact (e.g. unsightly or noisy facilities likely to be built close to settlements).
0	No impact.
1	Small positive impact (e.g. improved experience of nature outside settlements).
2	Moderate positive impact.
3	High positive impact (e.g. tree planting in urban areas; new public transport facilities reducing travel time; improved homes).

These scores were converted to points on a 0 to 100 scale using a linear value function with a score of -1 being zero and +3 being 100.

6.4.6. Environmental impact: Water

Under circumstances of water scarcity, such as those in South Africa, any intervention which requires additional water represents a negative impact on the environment. This takes place both through quantity impacts – using more water – and through quality impacts – lowering the quality of wastewater returned to the environment or increasing the level of pollutants in runoff. It is accepted that the impact on the water environment has a significant locational element: a specific activity that uses water in a water-vulnerable area has a far more significant impact than one that uses water in an area that is not water-vulnerable. However, when conducting a national-scale analysis, such as this one, the locational component cannot be assessed and a judgement is required on the aggregate impact across the country.

The indicator was stated simply as: "The impact of the measure on the water environment in terms of quantity and quality." This needed to be related to the counterfactual, as described earlier in this appendix.

The mitigation measures were scored against this criterion based on the informed opinion of Task Team members, applying the following scale (Table 11):

Table 11: Scores and interpretation for environmental impact (water) criterion

Score	Interpretation
-3	Very negative impact in terms of increase in quantity of water abstracted and/or reduced quality of water in receiving water bodies (e.g. forestry with no trading of water with other users).
-2	Moderate negative impact.
-1	Small negative impact.
0	No significant impact.
1	Has a positive impact in terms of improving water quality or reducing the amount of water abstracted thereby increasing the amount of water available for other uses (e.g. grassland and thicket rehabilitation).

The importance of the counterfactual with regard to electricity generation measures was notable. Each measure was compared against the impact of coal fired power stations with the associated mining of coal included.

The scores for each measure were converted to points on a 0 to 100 scale using a linear value function with a score of -3 being zero and 1 being 100.

6.4.7. Environmental impact: Land

Land impact is taken to have two components:

- Impact on reducing biodiversity.
- Reducing future land use options.

While it is, in theory, possible to calculate the impact quantitatively, this is not practical and therefore a qualitative assessment is required taking both these components into consideration.

With regard to change in biodiversity, three factors are relevant: the area of land transformed, the current state of the land, and the future state of the land after the measure has been implemented. In the case of limiting future land use options this is likely to relate primarily to the extent to which human settlement options are reduced in the future due to the mitigation measure.

Again, there is a strong locational element here (so the impact of a wind farm to be located on a site that is currently virgin forest is very different to one that is to be located on an area that is currently grassland). As with water, this impact cannot be assessed nationally taking location into consideration because the siting of projects is not known. As a result, land transformation is assessed at a relatively high level taking the aggregate position of mitigation measures into consideration.

The indicator was stated as: "The extent to which the measure impacts on land either in terms of reducing biodiversity or limiting the uses of land for a variety of other purposes in the future." This needed to be related to the counterfactual, as described earlier in this appendix. The mitigation measures were scored against this criterion based on the informed opinion of Task Team members, applying the following scale (Table 12):

Table 12: Scores and interpretation for environmental impact (land) criterion

Score	Interpretation
-2	Substantially negative impact (e.g. new commercial forestry).
-1	Moderate negative impact.
0	No significant impact.
1	Moderate positive impact.
2	Substantially positive impact (e.g. restoration of grasslands or other improving other natural biomes).

These scores were converted to points on a 0 to 100 scale using a linear value function with a score of -2 being zero and 2 being 100.

6.4.8. Environmental impact: Waste

Waste management is a significant concern for some mitigation measures. This criterion is intended to assess the extent of difficulty in disposing of waste (both solid and other hazardous wastes) relative to the counterfactual. Increased difficulty in disposing of waste will relate both to a change in the magnitude of the waste stream produced and to a change in its nature (general, or hazardous).

The indicator was stated as: "The extent to which solid waste and other hazardous wastes impact on the environment." The mitigation measures were scored against this criterion based on the informed opinion of Task Team members, applying the following scale (Table 13).

Table 13: Scores and interpretation for environmental impact (waste) criterion.

Score	Interpretation
-3	Extremely high negative impact typically associated with hazardous waste or large quantities of industrial waste.
-2	Moderate to high negative impact.
-1	Small negative impact.
0	No significant impact.
1	Moderately positive impact, relating to a reduction in the quantity of waste produced or quantity of waste disposed of to landfill (e.g. waste recycling measures).
2	Highly positive impact in relation to existing situation. For example avoiding a large proportion of coal based energy generation and associated coal mining

It was notable again that the counterfactual in the case of electricity generation measures (existing coal based power generation) was particularly important due to the high impact which these existing generation measures (including coal mining) have relating to waste. This meant that other electricity generation options which have a high waste impact may have resulted in 'no significant impact' as they were more or less equal in impact to the counterfactual.

The scores for all measures were converted to points on a 0 to 100 scale using a linear value function with a score of -3 being zero and 1 being 100.

6.4.9. Implementability: Technical factors

Ready access to technology and the ability to implement this technology easily in South Africa are key factors which need to be taken into consideration when comparing mitigation measures. This criterion is intended to deal with both factors: the extent to which the technology is available internationally and the extent to which it has been implemented in South Africa.

The indicator was described as: "The extent of difficulty in implementing the measure, taking the availability of technology and the extent of development of the field in SA into consideration."

The mitigation measures were scored against this criterion based on the informed opinion of Task Team members, applying the following scale (Table 14).

Table 14: Scores and interpretation for implementability (technical factors) criterion

Score	Interpretation
1	No implementation difficulties from a technical point of view: widely applied in SA; well-developed industry.
2	Technology previously applied in SA but industry in early stages of development.
3	Technology applied relatively widely internationally but not in SA; industry not developed in SA.
4	Technology applied to a limited degree internationally; no experience in SA over past two decades.
5	High degree of difficulty expected both because of nascent stage of development of technology and lack of industry experience with this measure.

The scores for all measures were converted to points on a 0 to 100 scale using a linear value function with a score of 5 being zero and 1 being 100.

6.4.10. Implementability: Institutional factors

The extent to which a measure can be easily implemented also relates to the difficulty in the process of getting approvals for a project. This covers both the need to meet regulatory requirements imposed by government and the need to gain support by other key stakeholders.

The indicator was described as: "The extent to which implementing the measure requires engagement and approval of multiple public bodies and involves multiple regulations."

The mitigation measures were scored against this criterion based on the informed opinion of Task Team members, applying the following scale (Table 15).

Table 15: Scores and interpretation for implementability (institutional factors) criterion

Score	Interpretation
-1	Public bodies activate measures and actively support measures, effectively building the industry, with no regulatory requirements (e.g. urban tree planting).
0	No significant difficulties with institutional aspects, no regulatory requirements.
1	Small degree of difficulty: some straight-forward approvals needed (e.g. grassland rehabilitation).
2	Moderate degree of difficulty: engagement with several public bodies and other stakeholders required to get approvals but approvals relatively standard (e.g. establishment of a new waste composting facility).
3	High degree of difficulty expected because of the complexity of both approvals and stakeholder engagement process. e.g. Nuclear power station.

The scores for all measures were converted to points on a 0 to 100 scale using a linear value function with a score of 3 being zero and -1 being 100.

6.5. Application of Economic Modelling

In assessing both the economic impact (measured in terms of GVA) and the social impact sub-criteria related to job creation, it was necessary to apply economic models. These models allow the changes in economic activity associated with the implementation of a mitigation measure to be assessed in relation to how they impact on the economy as a whole. Typically this was done through assessing the following.

- **Backward linkages**: how the intervention in the sector associated with the mitigation measure would impact on other sectors of the economy which provide inputs to the intervention sector.
- **Forward linkages**: how the change in activity associated with the intervention in a particular sector would impact on other sectors due to changes in outputs and prices.

Three macroeconomic models detailed below were applied.

6.5.1. Impact model

A Macroeconomic Impact Model (MIA) was used to assess the impacts of the full set of abatement measures. While this model was not applied to the overall economic projections, it was specifically designed for assessing the impact of an individual intervention in the economy. The MIA is a partial equilibrium model, and relies on a Social Accounting Matrix (SAM).

It provides results at a discrete level (for example, impacts on GVA, unskilled, semi-skilled and skilled jobs in the economy).

The impact model works only on direct activity in the sector concerned and on backward linkages: the impacts that changes in the industry being considered have on other sectors which may be either positive or negative. Positive impacts are related to increased expenditure (capital and operating expenditure) which increases economic activity in the sectors which serve the industry within which the mitigation measure is being considered. Negative impacts (reduced economic activity) relate to reductions in expenditure by the sectors concerned if, for example, less energy is required.

6.5.2. The surplus model

The macroeconomic models applied include a 'surplus model' which looks at forward linkages: what will the change in surplus resulting from an intervention in a particular industry achieve in the economy? Surplus is measured as the change in NPV for the measure in relation to the counterfactual. So, for example, if a mitigation measure results in a net increase in costs, this means a negative surplus and a negative impact on the economy as the stakeholders affected by the intervention have less money to put into the economy. This applies, for example, to industries which need to spend more money on a new plant for the same amount of production resulting in a decline in their surplus. On the other hand, if the surplus is positive (savings in cost) the impact on the economy will be positive: more money will be available to those affected which will put additional money into the economy.

6.5.3. Data required by the models and sources of data

Key inputs into the MIA included:

- project investment value
- % of investment in new assets
- operational years
- production/turnover per annum
- number of skilled, semi-skilled and unskilled workers
- apportionment of production between domestic sales and exports
- split of production between intermediate inputs, labour remuneration and gross operating surplus
- split of intermediate demand between commodities
- mix of assets that make up investment value

In some cases, this data needed to be accessed specifically for a mitigation measure by the consulting team (with advice from industry specialists). However, given the complexity associated with the large number of measures considered, primary reliance had to be made on standard figures available from economic models, which were adjusted by the project team conducting the modelling.

6.6. Weighting of Criteria

Once scores were allocated, a large amount of information about the relative performance of the abatement opportunities became available.

The various sub-criteria were weighted in order to come up with a score for each criterion. In addition, the various criteria were then weighted in order to come up with an overall weighted score for each opportunity. This was then used to generate a ranked list of opportunities based on their overall impact. While the ranked list was a significant output from the MCA, the primary objective was to provide information on where opportunities perform strongly and where they perform poorly. Applying weights and doing a sensitivity analysis for different sets of weights provided insight with regard to which opportunities performed consistently well and which performed particularly well in certain areas.

In addition, the application of weights was seen as a key step in developing overall mitigation pathways for the project. Weighting the criteria allowed weighted scores for each measure under the different scenarios to be generated. This allowed users (the TWG-M, for example) to define different pathways and then allocate weights that corresponded with those definitions.

The weightings in the scenarios used in this report were assigned during a TWG-M workshop facilitated by the project team, at which the results of the MCA were also examined and tested. The outcome was that there were three different weightings identified for further analysis and application in the analysis pathway:

- A balanced weighting representing the best compromise between the interests of various stakeholders.
- A weighting favouring cost efficiency and ease of implementation.
- A weighting favouring higher social impact and lower environmental impact.

The application of these weightings represents the key characteristics of the pathways.

7. Developing Abatement Pathways

The approach and methodology for identifying and analysing mitigation measures has been developed along with the extent of mitigation which can be achieved with each measure and the associated costs of implementing each measure. If only cost was important this would result in a prioritisation of mitigation measures based on one criterion (cost); a single path.

However, the GHG Mitigation Potential Analysis has broader objectives, specifically to take other criteria (or impacts) into consideration and to rank the mitigation measures which will need to be implemented to achieve a given level of mitigation, based on multiple criteria. This leads to the concept of 'abatement pathways' with various pathways defined by different sets of criteria for selecting mitigation measures (which way to go in terms of prioritising measures) and the extent of mitigation required (how far to go).

7.1. Defining Abatement Pathways

This study has involved the development of reference case emission projections, the identification and analysis of mitigation in key sectors, and assessments of the broader socio-economic and environmental impacts of those measures. In this section, how those elements have been combined to develop national abatement pathways will be explained. The distinction between projections, scenarios and abatement pathways is explained in Box 2.

The phrase 'abatement pathway' has been adopted in this study to characterise a set of emission reduction trajectories (pathways) over time, which are technical achievable. The assumptions regarding abatement potential and marginal abatement costs have been determined in the process of developing MACCs. Similarly, the MCA framework which has been developed has allowed the socioeconomic and environmental impacts of specific measures to be determined. Once a set of pathways has been determined (discussed further below), this means that the wider macroeconomic impacts of implementing the set of measures which make up that pathway have also been determined.

However, the report makes a distinction between abatement pathways and emission reduction scenarios. The pathways presented in this study identify a set of technically possible outcomes. While quantified with rigour, they do not meet the full and strict definition of "a coherent, internally consistent and plausible description of a possible future state of the world" which characterises an emission reduction scenario. In particular, no detailed assessment of baseline conditions under which a set of scenarios for South Africa's transition toward a lower-carbon economy would take place has been made. It is also recognised that any such transition implies a very broad set of economic, social, environmental and political choices to be made. This fell outside the scope of the current study, which is specifically aimed at providing a technical assessment of mitigation potential.

Box 2: Distinguishing between Projections, Scenarios and Abatement Pathways

Projection

In general usage, a projection can be regarded as any description of the future and the pathway leading to it.

Scenario

A scenario is a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold. A projection may serve as the raw material for a scenario, but scenarios often require additional information (e.g., about baseline conditions).[4]

Abatement Pathway

An abatement pathway defines a set emission reduction trajectories (pathways) over time, which are technically achievable. The pathway merely identifies what is technically possible without providing a detailed scenario-based description of how that outcome would be achieved.

4. http://www.ipcc-data.org/ddc_definitions.html

In developing the abatement pathways, the project team has provided a powerful set of tools and a framework for evaluating mitigation choices. The decision-making process associated with the definition and determination of desired emission reduction outcomes (DEROs) for individual sectors of the South African economy is the subject of the next phase in the implementation of the National Climate Change Response Policy (NCCRP). The technical assessment of mitigation potential completed in this study makes a valuable contribution to that process but should not be confused with it.

7.2. Approach to Developing Abatement Pathways

Overview of approach

The approach applied is illustrated in the diagram below:

Each step includes the following.

- Sector analysis and options: mitigation and associated costing for each measure, with measures aggregated into sectors.
- Undertake multi-criteria analysis (MCA) considering each measure against the agreed criteria.
- Develop ranked list of measures for each weighting of criteria considered, taking all measures into consideration.
- Develop pathways which take into consideration the different ways criteria have been weighted and the extent of mitigation to be achieved.
- Make projections of mitigation measures (WAM curves) for each pathway based on the progressive application of measures ranked by priority.

The analysis was undertaken using a set of tools: These are available as Excel™ workbooks with associated graphics, as illustrated in Figure 5 below.

The main features of the methodology applied for each stage of analysis are highlighted:

- All information is available in a consistent format.
- While the workbooks are not all linked (in the sense that cells are read electronically from one to the other) the results from each stage can be cut and pasted easily into the workbooks for later stages.
- All tables and graphical results included in this report are copied from the workbooks.

7.2.1. Sector analysis

This has been described above in Section 5.

7.2.2. Multi-criteria analysis (MCA)

The MCA process is described in Section 6. Three pathways, based on different criteria weightings were determined.

- A balanced weighting pathway (B), representing a broad consensus among all interest groups represented on the Technical Working Group on Mitigation.
- A pathway (CI) which emphasises costs and implementability of mitigation measures.
- A pathway (SE) which emphasises social and non-GHG environmental impacts of mitigation measures.

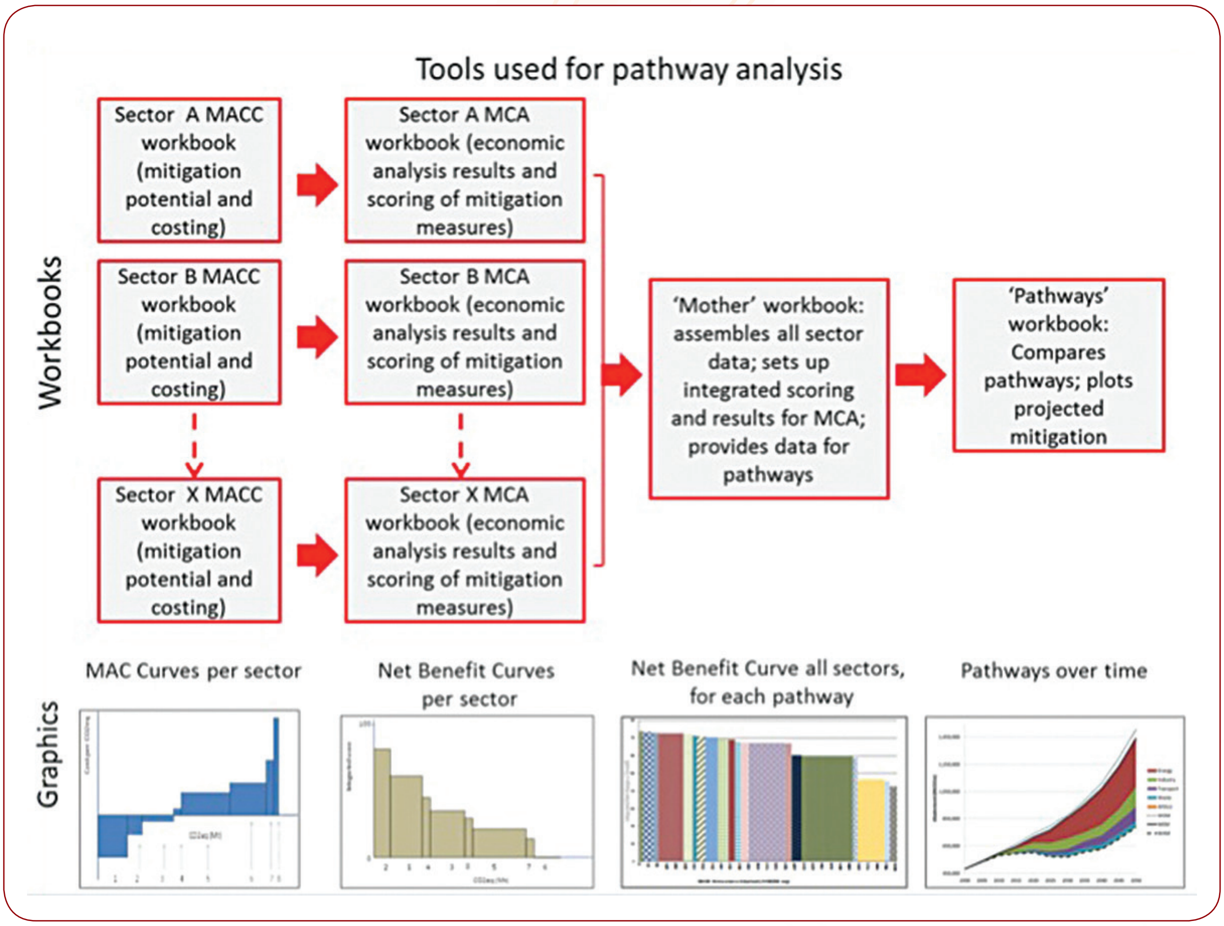


Figure 5: Tools used to undertake analysis of mitigation options and associated pathways

7.2.3. Selecting which pathway to take

It is likely that different stakeholders will favour different pathways. For example, those who have an implementer's approach will prefer the CI pathway (lowest costs and easiest to implement). Those with sustainability in mind may choose the SE pathway. In the end, a combined group of stakeholders needs to reach a compromise and this is what the TWG considered in coming up with the balanced weighting (B) pathway.

7.2.4. Choosing how far to go

Although the order of implementation of each measure will change for each pathway under the 'with additional measures' (WAM) projections, the total mitigation achievable will be the same. However, the MCA results demonstrate that the lower priority measures become less favourable and the situation where lower priority measures will not be implemented needs to be considered. Therefore this analysis has looked at the impact of applying measures to achieve three intermediate levels of mitigation: 25%, 50% and 75% of the maximum possible.

7.2.5. Choosing which measures to implement

In choosing which measures to implement, both the amount of mitigation which can be achieved and the relative priority as scored in the MCA analysis (taking all criteria into consideration) need to be considered. For this reason, the concept of marginal abatement net benefit (MANB) has been developed for this project. The concept of marginal net benefit and the use of marginal abatement net benefit curves (MANBCs) allow a ranked list of mitigation options to be established which, as they are applied incrementally, create increasing levels of mitigation with decreasing net benefit, taking all criteria into consideration.

For any one pathway the MANBC provides a measure of net benefit achieved through implementing the next mitigation measure – effectively describing in a single metric the ease of implementation for each measure. This concept is combined with the concept of abatement ambition to construct a framework for decision making to select a target level of abatement and implement mitigation measures to achieve it. Intuitively, it will be reasonably straightforward to achieve a certain level of mitigation, based on the mitigation potential identified in this study. But as the level of abatement ambition increases, so the costs, technological complexity and potential for significantly negative economic, social and environmental impacts associated with implementing additional measures grows. A framework for considering these issues when developing national abatement pathways has been presented in this study. The final decision-making process in this regard falls outside the scope of the current study. The concept can be applied as a graph, or a curve, as illustrated in Box 3.

7.2.5. Balancing ambition against the choice of measures

With the pathway plotted as a MANBC, it is possible to read from the horizontal axis how much mitigation is to be achieved, with 25%, 50%, 75% and 100% of maximum ambition used for illustration purposes.

7.3. Final results

The final results for pathways have a structure as follows.

	Level of ambition			
	25%	50%	75%	100%
Balanced pathway		→	→	→
CI pathway		↓		
SE pathway		↓		

The impacts for each pathway and level of ambition can be analysed. But there are limits to the use of this analysis which is voluminous and time consuming.

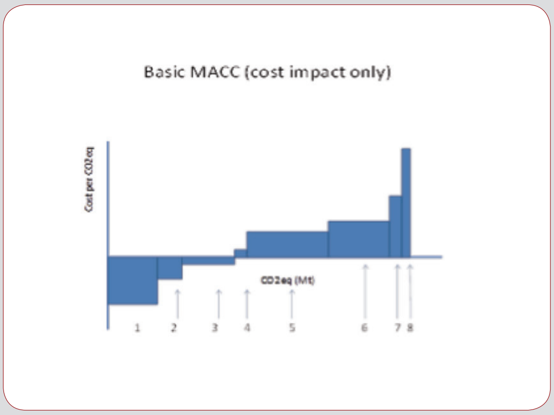
Therefore the full economic analysis, reported in Appendix B, focuses only on the shaded cells in the table above with the aim of showing how impact changes across pathways at the 50% ambition level and how it changes longitudinally as the level of ambition increases from 50% to 75% to 100%.[5]

5. The reason for excluding 25% is that this level of ambition is unrealistically low.

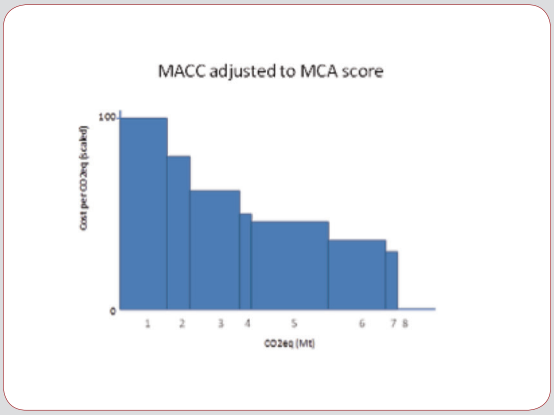
Box 3: *Marginal Abatement Net Benefit Curves*

The concept of MANBCs is developed progressively from a MACC curve (A), through first of all converting costs per unit of mitigation into a score on a 1 to 100 scale (B) and then applying other criteria also scored on a 1 to 100 scale (C&D). Putting the results together with the criteria weighted for each pathway gives the final curve which takes all criteria into consideration and shows what additional mitigation is achieved in moving from left to right from higher priority to lower priority measures (E).

A



B



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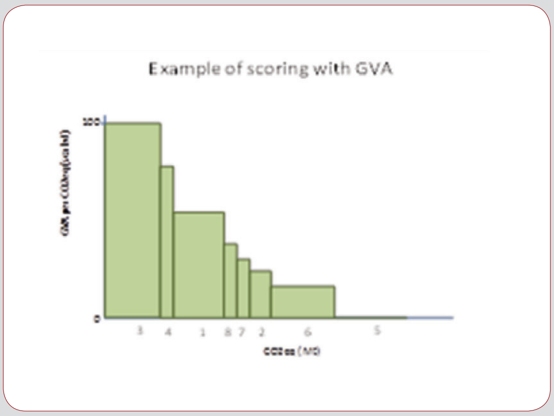

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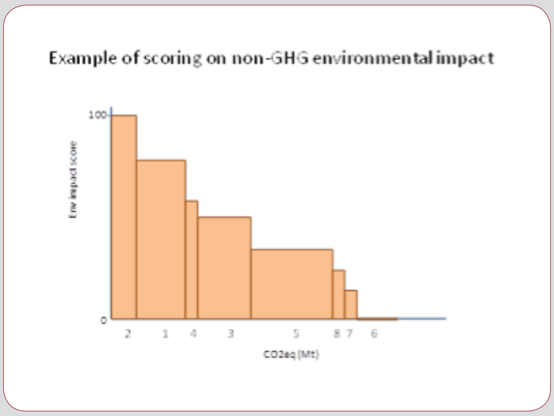
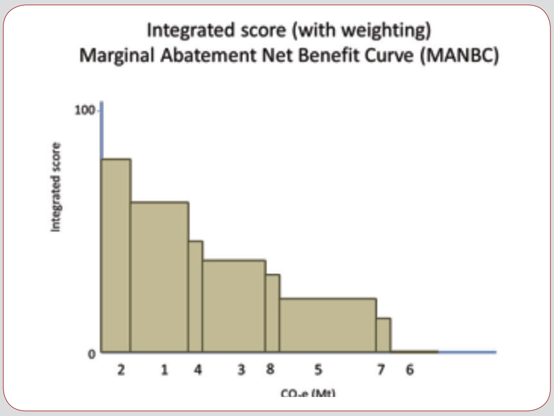


E



Note:

- *The total potential abatement (horizontal axis) remains the same for all the graphs.*
- *Where a single criterion is scored (e.g. cost) the first measure will score 100 and the last 0.*
- *If there are multiple criteria there is unlikely to be a measure scoring zero or 100.*

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