mitigation REPORT

SOUTH AFRICA'S GREENHOUSE GAS MITIGATION POTENTIAL ANALYSIS

environmental affairs
Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
of the Federal Republic of Germany





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The following citation should be used for this report:

Department of Environmental Affairs, 2014: ***South Africa's Greenhouse Gas (GHG) Mitigation Potential Analysis***. Pretoria, Department of Environmental Affairs.

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List of Abbreviations

Acronym	Definition
AD	anaerobic digestion
AFOLU	agriculture, forestry and other land use
BAT	best available technologies
BAU	business as usual
BF	blast furnace
BFAP	Bureau for Food and Agricultural Policy
BOD	biological oxygen demand
BOF	basic oxygen furnace
Capex	capital expenditure
CCC	(UK) Committee on Climate Change
CCGT	combined cycle gas turbine
CCS	carbon capture and storage
CDM	Clean Development Mechanism
CER	certified emissions reduction
CGE	computable general equilibrium
CH_4	methane
CHP	combined heat and power
CNG	compressed natural gas
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CoGTA	Department of Cooperative Governance and Traditional Affairs
CSP	concentrated solar power
CTL	coal to liquid
DAFF	Department of Agriculture, Forestry and Fisheries
DBSA	Development Bank of Southern Africa
DEA	Department of Environmental Affairs
DERO	desired emission reduction outcome
DME	Department of Minerals and Energy
DoE	Department of Energy
DRI	direct reduced iron
Dti	Department of Trade and Industry
EAC	equivalent annual cost

Acronym	Definition
EAF	electric arc furnace
EDD	Economic Development Department
EFOM	energy flow optimisation
EfW	energy from waste
EMU	electric multiple unit (train set)
EPA	United States Environmental Protection Agency
ERC	Energy Research Centre, University of Cape Town
EV	electric vehicle
FCEV	fuel cell electric vehicle
FL	fluorescent lamp
GDP	gross domestic product
Gg/yr	gigagrams per year
GHG	greenhouse gas
GHGI	National Greenhouse Gas Inventory
GJ	gigajoule
GVA	gross value added
GW	gigawatt
GWC	growth without constraint
GWh	gigawatt hour
GWP	global warming potential
HCV	heavy commercial vehicle
HFC	hydrofluorocarbon
HVAC	heating, ventilation and air conditioning
HYL	gas-based direct reduced iron (DRI) steelmaking process
ICAO	International Civil Aviation Organisation
IEA	International Energy Agency
IEP	Integrated Energy Plan
INFORUM	Inter-industry Forecasting Model
I-O	input-output
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
JRC	Joint Research Centre
$ktCO_2e$	kilotonnes of carbon dioxide equivalent
kW	kilowatt
kWh	kilowatt hour

Acronym	Definition
LCV	light commercial vehicle
LFG	landfill gas
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LRMC	long run marginal costs
LTMS	long-term mitigation scenarios
MAC	marginal abatement cost
MACC	marginal abatement cost curve
MANBC	marginal abatement net benefit curve
MARKAL	market allocation
MBT	minibus taxi
MCA	multi-criteria decision analysis
MCV	manufacturing commercial vehicle
MIA	macroeconomic impact
MJ	megajoule
MSFM	municipal services financial modelling
MSW	municipal solid waste
Mt	million tonnes (megatonnes)
$MtCO_2e$	million tonnes (megatonnes) of carbon dioxide equivalent
MW	megawatt
MWh	megawatt hour
N_2O	nitrous oxide
NAC	net annualised cost
NCCRP	National Climate Change Response Policy
NDP	National Development Plan
NERSA	National Energy Regulator of South Africa
NGP	New Growth Path
NPC	National Planning Commission
NPV	net present value
NT	National Treasury
OCGT	open cycle gas turbine
OECD	Organisation for Economic Co-operation and Development
Opex	operating expense / operational expenditure
PFRK	parallel flow regenerative kiln
PHEV	plug-in hybrid electric vehicle

Acronym	Definition
PPD	Peak, Plateau and Decline (trajectory)
PRASA	Passenger Rail Association of South Africa
PV	photovoltaic
RBS	required by science (scenario)
RFG	refinery fuel gas
RHE	rural high income electrified
RLE	rural low income electrified
RLN	rural low income non-electrified
SAM	social accounting matrix
SARB	South African Reserve Bank
SATIM	South African TIMES model
SF_6	sulphur hexafluoride
SRMC	short run marginal costs
Stats SA	Statistics South Africa
SULTAN	sustainable transport illustrative scenario accounting tool
SUV	sports utility vehicle
SWH	solar water heating
TIMES	The Integrated MARKAL-EFOM System
TMP	total mitigation potential
TWG-M	Technical Working Group on Mitigation
UHE	urban high income electrified
ULCORED	gas-based direct reduced iron (DRI) steelmaking process (not yet in operation)
ULE	urban low income electrified
ULN	urban low income non-electrified
UNFCCC	United Nations Framework Convention on Climate Change
Vkm	vehicle kilometres
VSD	variable speed drive
WAM	'with additional measures' scenario
WEM	'with existing measures' scenario
WOM	'without measures' scenario
WTO	World Trade Organization
WTT	well to tank (indirect emissions)
WTW	well to wheel (life cycle emissions)
ZAR (R)	South African rand

Glossary

Term	Definition
Abatement	Actions taken to reduce GHG emissions (see ***Mitigation***)
Abatement pathway	An abatement pathway defines a set of emission reduction trajectories (pathways) which are technologically achievable over time. The pathway merely identifies what is technically possible without providing a detailed scenario-based description of how that outcome would be achieved.
Carbon dioxide equivalent (CO_2e)	The universal unit of measurement used to indicate the global warming potential (GWP) of each of the six Kyoto greenhouse gases. It is used to evaluate the impacts of releasing (or avoiding the release of) different greenhouse gases.
Carbon intensity	The amount of emissions of CO_2 per unit of GDP. Carbon intensity can also be expressed on a per capita basis.
Climate change	A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods (Source: United Nations Framework Convention on Climate Change - UNFCCC).
DERO	Desired emission reduction outcomes (DEA, 2011a).
Direct emissions	Emissions that are produced by organisation-owned equipment or emissions from organisation-owned premises, such as carbon dioxide from electricity generators, gas boilers and vehicles, or methane from landfill sites.
Emission reduction scenario	Scenario describing plausible future emission trajectories to reflect the likely quantity and trend of greenhouse gas emissions released for a given period, including variances related to levels of economic growth, the structural makeup of an economy, demographic development and the effect of emission reduction policies.
Emissions sink	Any process, activity or mechanism that removes a greenhouse gas from the atmosphere.
Emissions source	Any process, activity or mechanism that releases a greenhouse gas, an aerosol or a precursor of a greenhouse or aerosol into the atmosphere. Only greenhouse gases are considered for the purposes of this study.
Emissions trajectory	Future greenhouse gas emissions are the product of complex dynamic systems, determined by driving forces such as demographic development, socio-economic development and technological change. Emission trajectories are alternative computations of the likely quantity and trend of greenhouse gas emissions released for a given period, including variances related to levels of economic growth, the structural makeup of an economy, demographic development and the effect of emission reduction policies.
Greenhouse gas	Greenhouse gases (GHGs) are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Besides carbon dioxide, nitrous oxide and methane, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) (IPCC, 2007).
Greenhouse gas sink	A sink is defined as any process, activity or mechanism that removes a GHG from the atmosphere (IPCC, 2007).
Greenhouse gas source	A source is defined as any process, activity or mechanism that releases a GHG, an aerosol or a precursor of a GHG or aerosol into the atmosphere. In this study, only South African sources of GHG emissions have been considered (IPCC, 2007).

Term	Definition
Indirect emissions	Emissions that are a consequence of the activities of the reporting company but occur from sources owned or controlled by another organisation or individual. They include all outsourced power generation (for example, electricity, hot water), outsourced services (for example, waste disposal, business travel, transport of company-owned goods) and outsourced manufacturing processes. Indirect emissions also cover the activities of franchised companies and the emissions associated with downstream and/or upstream manufacture, transport and disposal of products used by the organisation, referred to as product life cycle emissions.
Integrated Energy Plan (IEP)	An energy planning document managed by the Department of Energy that provides overall national energy sector guidance and macro-planning. An IEP considers the appropriate balance between demand and supply options for providing the requisite energy services in South Africa, based on the inclusion and consideration of all fuel types and energy carriers. Normally it covers a twenty year planning period and has the overall objective of balancing energy supply and demand with resources, in concert with safety, health and environmental issues.
Integrated Resource Plan (IRP)	South Africa's Integrated Resource Plan for Electricity (DoE, 2011), published as a notice under the Electricity Regulation Act (No. 4 of 2006), is a planning framework for managing electricity demand in South Africa for the period 2010 to 2030. The Integrated Resource Plan (IRP) 2010 assesses a range of potential scenarios to deliver the country's future electricity demand, based on an assumed average economic growth of 4.6% for the period. The IRP estimates that electricity demand by 2030 will require an increase in new generation capacity of 52 248MW. This substantial increase in capacity is required to address projected demand, the decommissioning of a number of existing power stations (commencing from 2022 onwards), and the need to provide for an adequate electricity reserve margin.
Marginal abatement cost curve (MACC)	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 costs of achieving incremental levels of emissions reduction.
Mitigation measures	Typically, mitigation measures are technologies (that is, a piece of equipment or a technique for performing a particular activity), processes, and practices which, if employed, would reduce GHG emissions below anticipated future levels, when compared to the status quo or existing counterfactual techniques normally employed.
Mitigation opportunity	An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.
Mitigation potential	The mitigation potential of a measure is the quantified amount of GHGs that can be reduced, measured against a baseline (or reference). The baseline (or reference) is any datum against which change is measured. Mitigation potential is represented in tonnes of carbon dioxide equivalent (tCO_2e).
New Growth Path (NGP)	The New Growth Path (NGP), released in November 2010, represents government's new 'framework for economic policy and the driver of the country's jobs strategy'. The NGP prioritises job creation in all economic policies and outlines strategies to enable South Africa to develop in an equitable and inclusive manner. A particular focus is placed on investment in infrastructure and skills development. The NGP's priority sectors are manufacturing; mining and beneficiation; agriculture, rural development and agro-processing; infrastructure development; tourism; the creative industries; and certain high-level business services. The NGP targets 5 million new jobs by 2020.
Peak, Plateau and Decline (PPD) trajectory	South Africa's benchmark national GHG emissions trajectory range. According to the Peak, Plateau and Decline (PPD) emissions trajectory, South Africa's long-term mitigation strategy calls for the carbon emissions trajectory to peak between 2020 and 2025, plateau for approximately a decade and decline in absolute terms thereafter (DEA, 2011a).

Term	Definition
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 may unfold. A projection may serve as the raw material for a scenario, but scenarios often require additional information (for example, about baseline conditions).
Technical mitigation potential	Technical mitigation potential is the amount by which it is possible to reduce GHG emissions or improve energy efficiency by implementing a technology or practice that has already been demonstrated. In some cases implicit economic considerations are taken into account (IPCC, 2007).
Technical Working Group on Mitigation (TWG-M)	In order to develop the mitigation approaches set out in the National Climate Change Response Policy, the Department of Environmental Affairs established a Technical Working Group on Mitigation. The purpose of the TWG-M was to provide technical inputs and support identification of mitigation options, as well as to assist the DEA to coordinate and align mitigation work at sectoral and national levels.

Acknowledgements

The South African Greenhouse Gas Mitigation Potential Analysis was supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), on behalf of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) of the Federal Republic of Germany.

The analysis was conducted by Camco Clean Energy, in partnership with Ricardo-AEA, PDG and Conningarth Economists.

The project team acknowledges the support of Dr Bruno Merven and Dr Andrew Marquard, both of the Energy Research Centre of the University of Cape Town, for providing updated energy price projections based on the South African TIMES model (SATIM).

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Executive Summary

A greenhouse gas mitigation potential analysis has been conducted for South Africa. The analysis has identified and analysed mitigation options in key economic sectors. In the process, an updated projection of national greenhouse gas (GHG) emissions into the future has been developed, along with marginal abatement cost curves (MACCs) for key sectors and subsectors. A socio-economic and environmental assessment of the identified mitigation options has also been conducted, leading to the development of national abatement pathways and an assessment of the wider macroeconomic impacts of implementing a broad set of mitigation options.

Projections of economic growth are aligned to targeted levels of future economic growth. The targeted level of future economic growth is based on the moderate growth rate defined by National Treasury. The moderate growth scenario forecasts real growth in gross domestic product (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). A detailed inter-industry economic modelling framework, the Inter-industry Forecasting Model (INFORUM), was used as the basis for projecting economic growth in all sectors of the South African economy.

Reference case GHG emissions projections are based on the projections of economic growth. Two projections have been provided. The first is a reference case 'without measures' (WOM) projection of emissions from 2000 to 2050, which assumes that no climate change mitigation actions have taken place since 2000. Under the WOM projection, emissions are projected to reach 1,692 $MtCO_2e$ by 2050. The second 'with existing measures' (WEM) projection incorporates the impacts of climate change mitigation actions including climate change policies and measures implemented to date. For the period 2000 to 2010 the projections follow the actual path of observed emissions according to the draft 2010 National Greenhouse Gas Inventory (GHGI), apart from the power sector where additional information from Eskom[1] was used to revise the emissions estimate in the draft GHGI. Under the WEM projection, emissions are projected to reach 1,593 $MtCO_2e$ by 2050.

GHG emissions projections are sensitive to economic growth. A sensitivity analysis was carried out based on a projection of higher and lower economic growth. Growth projections for low and high growth of 3.8% and 5.4%, respectively per annum by 2050 were based on inputs provided by National Treasury. Under the low growth scenario, GHG emissions are projected to be 15% lower (1,361 $MtCO_2e$) by 2050 than the reference case WEM projection. Under the high growth scenario, GHG emissions are projected to be 18% higher (1,882 $MtCO_2e$) by 2050 than the reference case WEM projection.

Mitigation potential has been identified and analysed for key sectors. These sectors include energy, industry, transport, waste, and agriculture, forestry and other land use (AFOLU). Marginal abatement cost curves have been developed for subsectors, sectors and key sectors, providing an estimate of mitigation potential and marginal abatement cost for a broad range of mitigation measures.

Estimates of mitigation potential for key sectors have been calculated independently of changes in other sectors and hence may overestimate the potential of electricity saving measures. The estimate of national mitigation potential (see below) includes an estimate of the impact of these interactions.

For the energy sector, technical mitigation potential in 2020, 2030 and 2050 is 33, 173 and 467 $MtCO_2e$ (accounting for 33%, 51% and 55% of available potential at a national level in those three snapshots). The power sector's contribution to technical mitigation potential at a national level in the three snapshots is 29, 137 and 417 $MtCO_2e$ (or 29%, 40% and 49%). In calculating total technical mitigation potential for the energy sector, abatement estimates for the other energy industries and petroleum refining sectors show only the impact of measures which can be implemented in the sector. They do not show savings which might occur due to a reduced need for new capacity in the sector if demand for liquid fuel is reduced as a result of successful implementation of mitigation options in the transport sector.

The industry sector accounts for 45, 104 and 258 $MtCO_2e$ in 2020, 2030 and 2050. For the transport sector, the equivalent mitigation estimates (based on direct emission savings only) are 7, 23 and 62 $MtCO_2e$. Mitigation estimates in the waste and AFOLU sectors are smaller: 10, 22 and 40 $MtCO_2e$ in the waste sector and 5, 10 and 5 $MtCO_2e$ in the AFOLU sector.

National mitigation potential has been estimated. National mitigation potential (assuming 100% implementation of all identified mitigation options) is estimated at 100 $MtCO_2e$

1. On the energy content of coal burnt for generation

in 2020, 340 $MtCO_2e$ in 2030 and 852 $MtCO_2e$ in 2050. This represents a reduction of reference case WEM emissions of 15%, 40% and 54% in 2020, 2030 and 2050, respectively. When considering the total mitigation which might be achieved across all sectors it is important to account for the interaction between sectors. For example, implementation of mitigation measures in the power sector will reduce the carbon intensity of electricity supplied, hence reducing the savings achieved by demand side electricity saving measures. Similarly, mitigation measures in the transport sector will reduce demand for liquid fuels, reducing the amount of new capacity and hence emissions in the refining and other energy industries subsectors. The national estimates of mitigation potential account for these interactions.

The national MACC indicates the proportion of mitigation potential which can be implemented at a negative marginal abatement cost. Marginal abatement costs estimated in this study vary widely. Nonetheless, significant potential exists to implement mitigation options which have a negative marginal abatement cost. In 2020, 38% of the total estimate of mitigation potential (40 $MtCO_2e$) can be achieved through implementing mitigation measures with a negative marginal abatement cost. In 2030, this figure is 25% (88 MtCO2e). In 2050 the figure is similar at 26% (227 MtCO2e) as abatement potential, costs and energy prices rise.

Absolute levels of emissions in South Africa do not reduce over the long term. Assuming all identified mitigation potential is implemented, emissions decrease in absolute terms in both 2020 and 2030. But in 2050, and for all other levels of implementation of abatement potential, no absolute emission reductions relative to 2010 are achieved. The assumptions driving the decarbonisation of South Africa's electricity supply (which are aligned to the Integrated Resource Plan, 2010), effectively place a cap on the mix of coal and other energy sources (such as renewables, biofuels and nuclear power) between 2010 and 2030. Beyond this horizon, the share of coal and non-coal-based power in South Africa is effectively held constant – with growth in supply driven by demand from end-use sectors.

Three illustrative national abatement pathways have been developed. Three mitigation pathways have been determined, based on different weightings of the main criteria in the multi-criteria analysis framework developed for the purpose of assessing the socio-economic and environmental impacts of mitigation options. The multi-criteria decision analysis (MCA) model allows a range of evaluation criteria to be combined in a decision-making framework. The resulting ranking of measures is thus based on more than merely the consideration of abatement potential and marginal abatement cost. The selected pathways are a) a balanced weighting pathway, which allows for relatively equal consideration of all key factors in the MCA model, b) a pathway which emphasises the cost and implementability of mitigation measures, effectively assigning a larger weight to those measures which have lower marginal abatement costs and are easier to implement and c) a pathway which emphasises social and environmental factors, effectively prioritising measures with lower impacts in these areas.

Implementation of mitigation potential becomes more difficult as targeted levels of national emissions reduction increase. 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. As these are applied incrementally, they create increasing levels of mitigation with decreasing net benefit, taking all evaluation criteria into consideration. The curves illustrate that, with increasing targets for national emissions reduction, implementation of mitigation potential will become harder as measures become increasingly costly, with more substantially negative social and environmental impacts and also as the limits of technological possibilities are reached.

The wider macroeconomic impacts of implementing a broad range of mitigation options have been assessed. The INFORUM model has been used to assess the wider macroeconomic impacts of implementing the mitigation options identified in this study. At average levels of impact on GDP of the order of 1.5% and employment of 1.2%, with all mitigation measures included, the GHG mitigation measures will not have a major impact on the economy. What gains there are from direct employment and backward linkages are counteracted by losses due to forward linked effects: prices typically increase with increasing costs associated with implementing most measures without a related gain in revenue. The complexity of the economy combined with the complex set of mitigation measures applied to many sectors of the economy mean that the results are useful mainly to show the broad scale and trends with respect to economic impacts. Further work will be required to identify the economic costs of climate change and compare them to various mitigation options. As part of this further work, there is a need to better understand the drivers and barriers of investment in greener technology.

Chapter 1: Introduction

1. Background

The South African economy has developed on the basis of energy-intensive industry and low-cost, coal-fired electricity. As a consequence, the country's absolute and per capita greenhouse gas (GHG) emissions are high in comparison to many developing countries. About 83% of South Africa's GHG emissions are derived from energy supply and consumption in comparison to an average of 49% among other developing countries.

Like many developing countries, South Africa also faces a number of social, economic and environmental challenges. Consequently, South Africa's approach to mitigating climate change seeks to strike a balance that will enable the reduction of GHG emissions (voluntarily as a good global citizen), whilst maintaining economic competitiveness, realising the developmental goals and harnessing the economic opportunities that accompany the transition to a lower carbon economy.

As a responsible global citizen and with both moral and legal obligations under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, South Africa is committed to contributing its fair share to global GHG mitigation efforts in order to keep global temperature increases below 2°C. In this regard, President Jacob Zuma announced on 6 December 2009 that South Africa will implement mitigation actions that will collectively result in a 34% and a 42% deviation below its business as usual emissions growth trajectory by 2020 and 2025, respectively. In accordance with Article 4.7 of the UNFCCC, the extent to which this outcome can be achieved depends on the extent to which developed countries meet their commitment to provide financial, capacity-building, technology development and technology transfer support to developing countries.

According to the Peak, Plateau and Decline (PPD) emissions trajectory, South Africa's long-term mitigation strategy calls for the carbon emissions trajectory to peak in the period 2020 to 2025 in a range with a lower limit of 398 Mt carbon dioxide equivalent (CO_2e) per annum and upper limits of 583 and 614 MtCO_2e for 2020 and 2025, respectively. Emissions will then plateau for up to 10 years within a range extending from 398 MtCO_2e to 614 Mt CO_2e, after which emissions will decline in absolute terms within a range with a lower limit of 212 MtCO_2e and an upper limit of 428 MtCO_2e by 2050.

The last comprehensive modelling system to explore mitigation potential and develop mitigation scenarios in the South African economy was the Long Term Mitigation Scenarios (LTMS) study. The last published National Greenhouse Gas Inventory report was completed for the year 2000. However, the LTMS and the GHG Inventory are now considerably out of date and there was a need to conduct a new assessment of mitigation potential. In accordance with the National Climate Change Response Policy (NCCRP), the overall objective of this study has been to conduct an updated, bottom-up assessment of mitigation potential in key economic sectors in order to identify a set of viable options for reducing GHGs.

2. The National Climate Change Response Policy

The National Climate Change Response Policy (NCCRP) is government's comprehensive policy framework for responding to climate change, providing a strategic approach to both mitigation and adaptation. It presents the vision for an effective climate change response and the long-term transition to a climate-resilient, equitable and internationally competitive lower-carbon economy and society. This vision is premised on government's commitment to sustainable development and a better life for all. The Response Policy outlines a strategic response to climate change within the context of South Africa's broader national development goals, which include economic growth, international economic competitiveness, sustainable development, job creation, improving public and environmental health, and poverty alleviation.

The Response Policy highlights the challenges facing development in South Africa brought on by the physical effects of climate change, while recognising the role to be played by the country in reducing emissions. The two main objectives of the policy are to:

- Effectively manage inevitable climate change impacts through interventions that build and sustain South Africa's social, economic and environmental resilience and emergency response capacity.
- Make a fair contribution to the global effort to stabilise greenhouse gas concentrations in the atmosphere at a level that avoids dangerous anthropogenic interference with the climate system, within a timeframe that enables economic, social and environmental development to proceed in a sustainable manner (DEA, 2011a p5).

2.1 Approach to Mitigation

South Africa's approach to mitigation, which is addressed by Section 6 of the NCCRP, balances the country's contribution, as a responsible global citizen, to the international effort to curb global emissions with the economic and social opportunities presented by the transition to a lower-carbon economy, and with the requirement that the country successfully tackles the development challenges facing it. The NCCRP is intended to promote adaptation and mitigation measures that will make development more sustainable, both in socio-economic and environmental terms. South Africa recognises that stabilisation of GHG concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system will require effective international cooperation. The country therefore regards mitigation as a national priority and is committed to actively engaging in international negotiations under the UNFCCC and its Kyoto Protocol, which South Africa has ratified.

Section 6 of the NCCRP outlines the key elements of the overall approach to mitigation. One of those elements requires the identification of desired emission reduction outcomes for each significant sector and subsector of the economy based on an in-depth assessment of the mitigation potential, best available mitigation options, science, evidence and a full assessment of the costs and benefits. The mitigation potential analysis supports this element.

2.2 The Technical Working Group on Mitigation

In order to develop the mitigation approaches set out in the NCCRP, the Department of Environmental Affairs (DEA) established a Technical Working Group on Mitigation (TWG-M). The TWG-M is comprised of a range of stakeholders that includes government departments, business representatives, civil society and academics.

The purpose of the TWG-M is to provide technical inputs and support identification of mitigation options, as well as to assist the DEA to coordinate and align mitigation work at sectoral and national levels. Among other things the TWG-M has therefore assisted the DEA in the following work:

- developing a list of sectors as the basis for mitigation analysis
- reviewing the assessment of mitigation potential and best available mitigation options in all sectors of the economy
- reviewing the assessment of economic, environmental and social impacts of proposed mitigation approaches.

2.3 Sector Task Teams

Five sector task teams were established to support the identification of mitigation options in relevant sectors. The task teams were established to lead and coordinate sectoral work in the identification of viable mitigation options in the agriculture, forestry and other land use (AFOLU) energy, industry, transport and waste sectors. The functions of the task teams covered the following:

- discussing and recommending a list of mitigation options in relevant sectors
- discussing and agreeing on levels of realistic mitigation potential
- reviewing marginal abatement cost curves (MACC) and scoring mitigation options using agreed multi-criteria analysis (MCA) model criteria
- helping to resolve specific sector-related issues
- assisting the appointed service provider to obtain relevant data and or documents where possible
- ensuring a strong link to the relevant sector policies, plans and programmes.

3. The Long Term Mitigation Scenarios Study

The LTMS study was commissioned by the Department of Environmental Affairs in an effort to build mitigation scenarios based on the best available research and information at the time. The process was initiated in 2005 and a series of reports were published in 2007 (ERC, 2007a). One of the key motivations behind the LTMS study was to assist the South African Government "to define not only its position on future commitments under international treaties, but also shape its climate policy for the longer-term future" (ERC, 2007b). In fact, the scenarios developed under the LTMS study did inform South Africa's commitments under the Copenhagen Accord of the UNFCCC, and the core elements of that work also inform the NCCRP and are still in use today.

The key objectives of the LTMS process were to ensure that South African stakeholders understand and are focused on a range of ambitious but realistic scenarios of future climate action, both for themselves and for the country, based on best available information. Notably these include long-term emissions scenarios and their cost implications; that the SA delegation is well-prepared with clear positions for post-2012 dialogue; and that Cabinet can approve (a) a long-term climate policy and (b) positions for the dialogue under the UNFCCC (ERC, 2007b).

3.1 The LTMS Scenario Framework

A scenario development approach, driven by stakeholder inputs, was central to the LTMS study. The boundaries of the LTMS scenario framework are defined by a 'growth without constraints' (GWC) emission scenario (based on an assumption of growth without any carbon constraint) and a 'required by science' (RBS) emission scenario. RBS is a purely notional scenario which assumes that South Africa implements mitigation to the extent required by science to meets its fair contribution towards global emission reductions. The same scenarios inform the PPD emissions trajectory referred to above (see Figure 1 and Table 1 for detail).

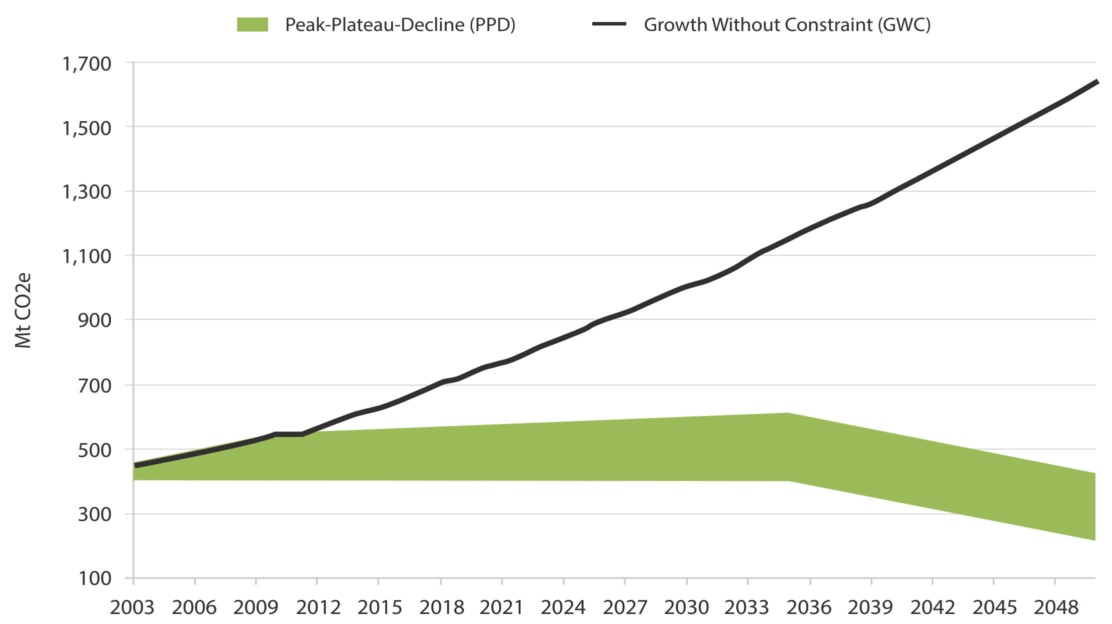


Figure 1: LTMS emission trajectories for 'growth without constraint' and 'peak, plateau and decline' scenarios (after DEA, 2011a)

Table 1: GHG emission projections based on LTMS GWC and PPD scenarios, in ktCO_2e equivalent (after DEA, 2011a)

	2010	2020	2030	2040	2050
Growth Without Constraint (GWC)	546,974	749,325	1,004,933	1,297,991	1,638,695
Peak, Plateau and Decline (PPD)					
Upper Boundary	547,000	583,000	603,667	552,000	428,000
Lower Boundary	398,000	398,000	398,000	336,000	212,000
Range	149,000	185,000	205,667	216,000	216,000

The scenarios developed within the LTMS framework are illustrated in Figure 2. A third scenario, current development plans (CDP), shows what implementing existing policy would achieve, if extended into the future. A similar distinction between an emission scenario which assumes no mitigation and a projection of emissions based on existing policy and mitigation actions will be made in the current study (see Chapter II). The LTMS study referred to these three scenarios as envelope scenarios. They define the space within which mitigation action occurred under the LTMS study.

The LTMS study also defined two further action-oriented scenarios that indicate alternative paths between current emission trajectories and what is required by science. Unlike the other scenarios, these scenarios were built from the bottom up. Stakeholders reviewed mitigation actions proposed by the LTMS consulting team, which were then modelled by the research teams. Based on these results, actions were combined into action packages. Actions could be grouped on the basis of costs or interest (e.g. green, nuclear or coal agendas). The scenarios were described in the study in terms of what South Africa can do or could do (ERC, 2007b).

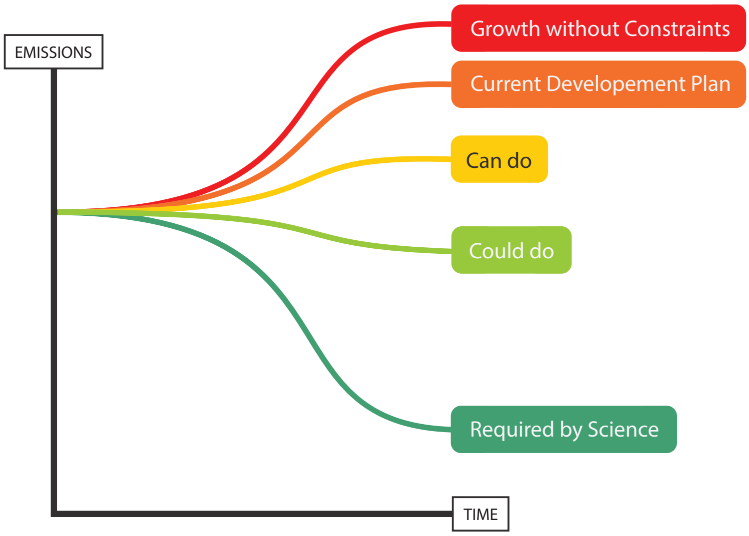


Figure 2: Schematic diagram illustrating the main emission scenarios developed within the LTMS scenario framework (ERC, 2007b)

The LTMS study adopted the term "wedges" to describe sets of mitigation actions to reduce emissions from the GWC to the RBS pathway. These are shown graphically in Figure 3. These wedges refer to estimated emission reductions over time. As emission reductions increase over time, the resulting graphs take on the shape of a wedge. These wedges described an initial set of mitigation actions that could be immediately initiated (start now), and a set of actions that would see the ambition and level of mitigation grow over time (scale up). Further emission reductions were estimates based on the adoption of a range of economic instruments in a set of actions referred to as 'use the market'.

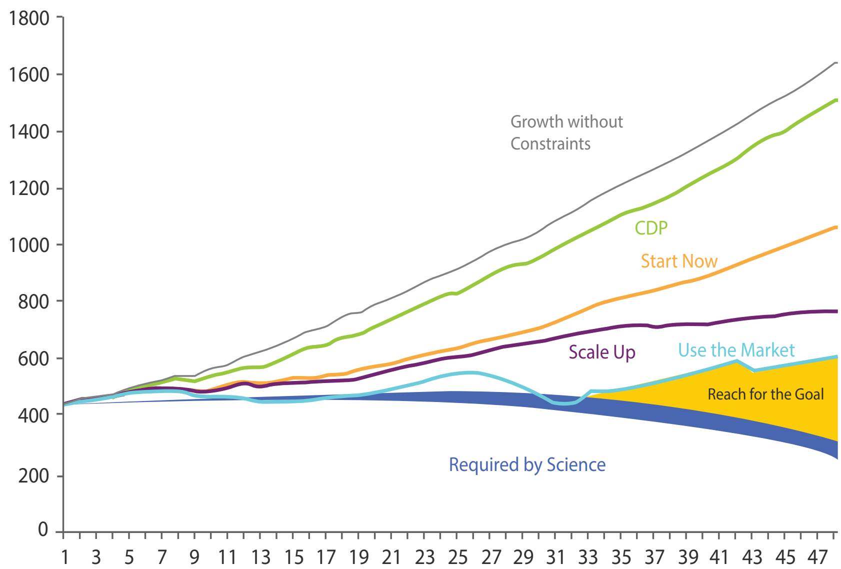


Figure 3: Graphical representation of the main mitigation actions under the LTMS study (ERC, 2007b)

The scenarios and mitigation actions developed in the LTMS study showed that the gap between GWC and RBS could not be fully closed if the identified mitigation actions were all implemented. In discussing this result, the authors of the LTMS study noted that a rigorous quantitative analysis relies on current (known) technologies and cannot model future (as yet undeveloped) technologies that may reduce this gap. The study also did not model behavioural changes which may be important to emission reductions in future.

3.2 Differences Between the LTMS Study and the Current Greenhouse Gas Mitigation Potential Analysis Study

The current study differs from the LTMS study in a number of ways:

1. Different economic growth assumptions

Although assumptions of future economic growth are a key driver of both analyses, the economic growth rates assumed in the LTMS were generally more optimistic than those in the current study.

2. Detailed assessment of mitigation potential

The mitigation potential analysis has been more detailed, both in terms of its sectoral and subsectoral coverage as well as in its engagement with stakeholders to identify and quantify mitigation potential than the LTMS study. It is also worth noting that stakeholders have been able to provide more detailed and better-informed estimates of firm- and sector-level mitigation potential than was possible during the LTMS study.

3. Focus on implementation options not policy formulation

The current analysis is geared towards implementation (in the context of the NCCRP) rather than policy formulation itself, which was the case for the LTMS study (ERC, 2007a).

4. Update of the LTMS study

The mitigation potential analysis has provided an updated assessment of mitigation options to the LTMS study. Projections of national GHG emissions have been aligned to the draft National Greenhouse Gas Inventory, including historically-observed emissions for 1990, 1994, and annually between 2000 and 2010 (DEA, 2013). This is both a more complete and higher-quality historical dataset and a more up-to-date assessment. The LTMS study (completed in 2007) was based on the 1990 and 1994 inventories (by then already out of date). In addition, all estimates of mitigation potential have been updated in the current study. There are now revised inputs from sectoral experts (consulted during 2012 and 2013), which have been augmented by international benchmark studies (based on best available technology) where applicable.

5. Assessing wider impacts of mitigation options

Unlike the previous study, the current analysis has also explicitly assessed the wider socioeconomic and environmental impacts of a range of mitigation options. The need to conduct this form of analysis was recognised, although not performed explicitly in the LTMS study. As stated in the NCCRP, the intention is to promote mitigation measures that will make development more sustainable, both in socio-economic and environmental terms.

6. Assessment of technical mitigation potential

The LTMS was framed as an exercise in assessing options for reducing emissions from a GWC to a RBS trajectory. The mitigation potential analysis does not seek to combine measures into this context. As stated in the NCCRP, the in-depth assessment of the mitigation potential, best available mitigation options, science, evidence and a full assessment of the costs and benefits for each significant sector and subsector of the economy will be used as an input to the process of identifying desired sectoral mitigation contribution through defining desired emission reduction outcomes. The focus of this study lies in the identification and analysis of technical mitigation potential in key sectors of the South African economy.

4. Study Objectives

In order to meet Government's mitigation objectives, and in accordance with the DEA's mandate to oversee the implementation of the NCCRP, the overall objective of this report is to present a set of viable options for reducing GHG emissions in key economic sectors. To achieve this, the specific activities undertaken within the study are as follows:

1. Development of reference case projection of national GHG emissions into the future

Reference case projections of GHG emissions have been developed based on clearly-stated assumptions about the expected changes in the key sectors. Gross domestic product (GDP) growth estimates are based on the application of a macroeconomic growth model, using estimates of national economic growth that are consistent with the National Development Plan (NPC, 2012). The first reference case projection assumes an emissions trajectory without any mitigation, starting in 2000 and extending to 2050. A second reference case projection, starting in 2010 and also extending to 2050, accounts for the effects of existing policy and mitigation measures, as of the start date.

2. Identification and analysis of mitigation opportunities in key sectors of the economy

Mitigation options have been identified in each of the five key sectors selected by the TWG-M and for agreed subsectors. Mitigation options identified in each sector are based on stakeholder inputs and feedback via the sector task teams. Where insufficient data has been provided, options have been identified and abatement potential has been quantified based on the application of international benchmarks. Results, including the construction of MACCs, are presented for the short, medium and long-term (2020, 2030 and 2050).

3. Socio-economic and environmental assessment of the identified mitigation options

In the study, an impact assessment for individual measures and an assessment of the wider macroeconomic impacts that would result from the implementation of a range of mitigation measures have been conducted.

4. Development of different scenarios which project the various options for reducing emissions in the short, medium and long term using the mitigation options identified above

These scenarios should be realistic, aligned with national development objectives and based on best available information. In accordance with the NCCRP, there is also a requirement to consider more than merely abatement potential and cost when prioritising mitigation interventions. Any mitigation measures which are selected should make development more sustainable, both in socio-economic and environmental terms. A multi-criteria decision analysis framework has been developed to allow a range of other criteria, including the broader socioeconomic and environmental impacts of individual mitigation options to form part of the process of selecting measures for implementation. A set of abatement pathways has been developed which illustrate how mitigation measures can be combined to construct emission reduction trajectories which take into account a broad range of factors including mitigation potential, cost and also the potential social and environmental impacts of the mitigation measures identified in the study.

5. Sectors Covered in this Report

This report covers five key sectors of the South African economy. Within each of these key sectors, mitigation potential has been analysed for a number of sectors and subsectors identified in Table 2 below.

Table 2: List of key sectors and sub-sectors covered in the mitigation potential analysis

Key sector	Sector	Subsector
Energy	Power	Electricity and heating
	Non-Power	Petroleum refining
		Other energy industries
		Coal mining
		Oil and gas
Industry	Metals	Aluminium production
		Ferroalloys production
		Iron and steel production
	Minerals	Cement production
		Lime production
	Chemicals	Chemicals production
	Mining	Surface and underground mining
	Buildings	Residential
		Commercial / institutional
	Other	Pulp and paper production
Transport	Road	Road
	Rail	Rail
	Aviation	Aviation
Waste	Waste	Municipal waste
Agriculture, forestry and other land-use (AFOLU)	AFOLU	AFOLU

6. Report Structure

Figure 4 graphically illustrates the structure of the report. The current chapter (Chapter I) has provided an introduction to the current study in the context of previous assessments of national mitigation potential and the South African Government's strategic mitigation objectives under the NCCRP.

The report continues with two chapters which focus on methodological issues. Chapter II provides a summary of the approach to building reference case emissions projections into the future. A summary of the approach to identifying and analysing mitigation potential in key economic sectors, including the construction of marginal abatement cost curves, is presented in Chapter III. In both cases, the assumptions adopted in building reference case projections and estimating mitigation potential, are also presented.

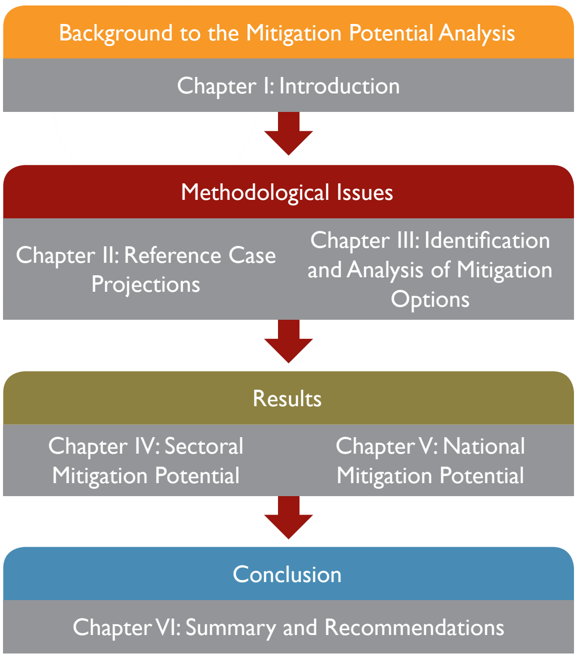


Figure 4: Structure of the Mitigation Potential Analysis report

Results from this study are presented on both a sectoral basis (Chapter IV) and on a national basis (Chapter V). The results include a summary of projections, abatement potential (including MACCs), an assessment of the wider socioeconomic and environmental impact of those options and a national abatement curve derived from the sectoral MACCs which are intended to reflect national mitigation potential. The report concludes with a summary and recommendations in Chapter VI.

In addition to the main report, additional detail on the methodology adopted in this study as well as the sectoral analyses conducted is available in a series of technical appendices. These appendices are:

- 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.

Chapter II: Reference Case Projections

7. Projecting Economic Growth

Future GHG emissions were projected on the basis of projected future economic growth. A detailed inter-industry economic modelling framework was used as the basis for projecting economic growth in all sectors of the South African economy.

7.1 The Inter-industry Forecasting Model

The Inter-industry Forecasting Model (INFORUM) was used to conduct the long-term forecasting of economic growth. The INFORUM modelling system is macroeconomic, dynamic and multi-sectoral. It depicts the behaviour of the economy in its entirety, that is, the interrelated, dynamic workings of all the major markets are accommodated. It therefore lends itself to projecting aggregate GDP and all its components, as well as the demand categories that determine GDP, instantaneously and dynamically.

The system is multi-sectoral and 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 determines 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 income functions that depend on production, employment and other variables.

The dynamic, macroeconomic and multi-sectoral nature of the INFORUM modelling system makes it well-suited for forecasting business-as-usual or reference cases. However, it shares certain limitations with other econometric models, since they are built mainly on historic information and the structure of the economy changes slowly over time. As a consequence, they are only ideally suitable for impact analysis over a medium term horizon. Over the long term this model, like others, is unlikely to adequately capture structural changes that might occur in the economy; for example, as a result of a shift from coal-based electricity generation to gas-based electricity generation. To take this into account, the intermediate production structure of the INFORUM model was adjusted in an attempt to take into account changes that the mitigation options will bring, more specifically those affecting the energy sector.

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 among 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 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.

Details of the INFORUM modelling system, and the approach to modelling future growth in the South African economy, are described in Technical Appendix A: Approach and Methodology. Results for the growth projections are shown in Technical Appendix B: Macroeconomic Modelling.

7.2 Underlying Assumptions for the Purposes of Forecasting

It is important to note that the projection of growth in the economy is done over a very long period which tests the limits of any standard econometric forecasting model. The assumptions that are usually applied to modelling, such as monetary variables (that is interest rates and money supply) as well as short term price fluctuations, which are normally imperative for short- and medium-term forecasting are not as significant in this case. The long-term forecast is much 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 potential of iron ore, magnetite, chrome, coal, and so on. 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, with South Africa becoming 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 involves the increase of both harbour and railway capacity.

The diminishing role that gold and diamonds will play in the 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.

7.2.1 Targeted Level of Future Economic Growth

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 and published in the 2012 Draft Integrated Energy Plan (DoE, 2013a). 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). Detailed modelling of sectoral growth and the resulting GDP growth rates that drive the emission projections are described in Technical Appendix B: Macroeconomic Modelling. Other modelling of the economic impacts of individual measures as well as modelling of the wider macroeconomic impacts of implementing a range of measures are described below as well as in the two technical appendices already mentioned.

The final demand projections for South Africa for the medium growth scenario are set out in Table 3 below. These projections form the basis for the production projections for the 46 subsectors in the INFORUM model. The forecasts by National Treasury for the Integrated Energy Plan (IEP) are also included for comparative reasons. The forecasts by Conningarth Economists are slightly lower than those by the National Treasury. A summary of production projections for the main economic sectors from the INFORUM model is shown in Table 4.

Table 3: Final demand projections for the medium growth scenario (%)

GDP and final demand components (2012 constant prices)	Growth rate per annum over period						
	2013-2052	2013	2014	2015-2022	2023-2032	2033-2042	2043-2052
Final consumption expenditure by households	3.9	2.2	3.8	3.6	3.8	4.2	4.3
Final consumption expenditure by government	3.9	4.4	5.1	3.7	3.8	4.0	4.0
Gross capital formation:	5.0	1.6	3.7	4.8	5.0	5.3	5.3
Exports of goods and services	3.4	2.8	3.0	3.3	3.3	3.5	3.6
Imports of goods and services	4.1	2.4	3.5	4.1	4.1	4.2	4.3
Total GDP (2012 Constant Prices)	4.0	2.4	3.7	3.6	3.9	4.3	4.5
National Treasury Forecast for the IEP Model	4.2	3.0	3.8	4.2	4.3	4.3	4.3

Table 4: Production projections for the main economic sectors for the medium growth scenario (%)

No	Sectors	2013-2052	2013	2014	2015-2022	2023-2032	2033-2042	2043-2052
1	Agriculture, forestry and fishing	2.5	2.2	2.9	2.3	2.2	2.6	2.8
2	Mining and quarrying	3.7	1.9	3.0	3.4	3.3	3.9	4.3
3	Manufacturing	4.1	1.5	3.5	3.8	3.8	4.4	4.6
4	Electricity, gas and water	3.5	2.2	3.4	3.3	3.2	3.7	3.9
5	Construction	4.6	2.3	4.2	4.7	4.4	4.9	4.9
6	Wholesale and retail trade; hotels and restaurants	4.1	2.3	3.7	3.9	3.8	4.3	4.5
7	Transport, storage and communication	4.1	2.8	4.1	4.1	3.8	4.3	4.4
8	Finance, real estate and business services	4.3	2.9	4.0	4.1	4.0	4.5	4.6
9	General government services	4.0	4.0	4.8	4.0	3.8	4.1	4.2
10	Personal services	4.5	3.3	4.2	4.4	4.2	4.7	4.7
	Total Production	**4.1**	**2.5**	**3.9**	**3.9**	**3.8**	**4.4**	**4.5**

8. Building Reference Case Projections

The study has produced projections to 2050 for all GHGs from all sectors included in the Greenhouse Gas Inventory for South Africa (GHGI). 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 (UNFCCC, 2000).
- ***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. For the period 2000 to 2010 the projection follows the actual path of observed emissions.

The projections were produced using a bottom-up methodology. Models were produced for each sector, and are described fully in the appendices for each sector. Overall the projections are consistent with the moderate growth rate for the economy and with growth rates for particular economic sectors as defined in the macroeconomic modelling. The methodology used in the models is consistent with that used in the GHGI, and historic emissions in the period from 2000 to 2010 are taken from the latest (draft) version of the GHGI (DEA, 2013) for the WEM projection, updated in some cases by more recent information from industry.

Common key assumptions for the projections are the following.

- A moderate growth rate for the economy, with growth rates for particular economic sectors as defined in the macroeconomic modelling (see Section 7.2). The governing assumptions for macroeconomic growth are based on the moderate growth target as defined by National Treasury and published in the 2012 Draft Integrated Energy Plan (DoE, 2013a).
- 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 the other energy industries subsectors where increases in production are linked to the demand for liquid fuel, and upstream oil and gas, 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 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 revisions are 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. This results in estimates of historic emissions from the power sector that are about 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 draft GHGI was used as the primary source of energy data, as it is considered by the DEA to more accurately reflect sectoral consumption than data in the Energy Balance (DoE, 2013b). 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.

For further detail regarding the projection of GHG emissions, please refer to Section 1 in Technical Appendix A: Approach and Methodology.

Box 1 below outlines how the impacts of climate change mitigation actions, which have been implemented since 2000, were assessed in each of the key sectors. Further details are given in the relevant sector appendices.

Box 1: Accounting for Early Mitigation Action when Projecting Emissions

Mitigation actions implemented in each sector between 2000 and the present were determined through a review of climate change policies and measures, and through consultation with industry. For some actions, the impact on the emissions or energy savings achieved was assessed based on information provided directly by industry or the relevant implementing bodies. In some cases, for mitigation measures in industry and the energy sector, the emissions reductions were calculated based on the levels of uptake of the measure in 2010 which were agreed with industry. Unless specific data on the timing of implementation was available, a linear implementation between 2000 and 2010 was assumed. For the power sector and transport sector, policies which have been adopted only have an impact post 2010, but are included in the assessment as the policy itself has already been adopted.

The main policies and measures which were identified in each sector are shown in Table 5. The estimated savings achieved from each measure are shown in Table 6.

Table 5: Existing policies and measures assessed

Sector	Subsector	Existing mitigation actions
Energy	Power sector	Committed new build under the Integrated Resource Plan (IRP) e.g. introduction of renewables (see DoE, 2011 Table 5).
	Oil refining	Improved process heater efficiency, use of refinery fuel gas, waste heat boiler, improved process control.
	Coal mining	Improved efficiency of mine haul and transport operations, general energy efficiency measures, and onsite clean power generation
	Other energy industries	Conversion of feedstock from coal to gas, compressor upgrades and use of open cycle gas turbines for generation.
Industry	Aluminium	Improved process control and general energy efficiency measures, including energy efficiency utility systems.
	Chemicals	Several general energy efficiency measures and process related measures for nitric acid, ammonia and carbon black.
	Ferroalloys	Best available production techniques; use of closed type furnaces, general energy efficiency measures.
	Iron and steel	Improved process control and general energy efficiency measures, including energy efficient utility systems and improved heat exchanger efficiencies.
	Lime	Installation of shaft preheaters, use of alternative fuels, improved process control and general energy efficiency measures, including energy efficient utility systems and improved heat exchanger efficiencies.
	Mining	Improved efficiency of mine haul and transport operations, general energy efficiency measures, and onsite clean power generation.
	Paper	Improved process control, use of biomass, energy recovery systems, and general energy efficiency measures, including energy efficient utility systems.
	Buildings	ESKOM demand management programme (includes roll out of energy efficient lighting and national solar water heating programme).
Transport	Aviation	Implementation of an international voluntary sectoral agreement to reduce net CO_2 emissions.
Waste	Landfill sites	Landfill gas recovery and generation at several sites.

Box 1: *Accounting for Early Mitigation Action when Projecting Emissions - continued*

Table 6: Estimates of reductions to be achieved with existing policies and measures, per key sector ($MtCO_2e$)

	2010	2020	2030	2040	2050
Energy	25.1	34.8	43.2	71.8	88.6
Industry	0.0	0.0	0.0	0.0	0.0
Transport	0.0	0.8	2.3	5.6	10.9
AFOLU	0.0	0.0	0.0	0.0	0.0
Waste	0.4	0.4	0.4	0.4	0.4
Total	26.8	36.0	46.0	77.9	99.9

Note: Reductions associated with lower electricity demand in end use sectors are shown under the energy sector in Table 6. More detailed breakdowns of savings by sector are given in the individual sector appendices.

8.1 Emissions with No Mitigation

Projections of all GHGs in the economy are shown for the reference case WOM projection in Table 7 and Figure 5. The projections show that if no climate change mitigation measures had been implemented then emissions in 2010 would have been 28% higher (at 555,151 $ktCO_2e$) than in 2000 (432,467 $ktCO_2e$). Projected emissions continue to rise steadily, due largely to the assumed economic growth[2], reaching 903,700 $ktCO_2e$ by 2030, and 1,692,471 $ktCO_2e$ by 2050, almost four times more than emissions in 2000. The largest contributor to emissions is the power sector, where carbon intensity is high, as it is predominantly based on coal fired generation. In 2010, together with other energy related sectors it accounted for 58% of emissions. If emissions from the power sector are allocated to end users of electricity (Figure 6 and Table 8), then the industry sector, which includes buildings, dominates emissions accounting for 63% of emissions in 2010 (rising to 76% by 2050).

2. 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)

Table 7: National GHG emissions under the reference case WOM projection (2000–2050) ($ktCO_2e$)

	2000	2010	2020	2030	2040	2050
Energy	251,718	323,174	410,788	537,301	741,938	1,042,549
Industry	78,265	113,116	149,182	199,296	281,609	409,578
Transport	35,481	47,715	61,070	80,411	106,678	136,684
AFOLU	56,801	54,311	53,268	52,506	52,216	52,159
Waste	10,202	16,836	24,999	34,186	43,251	51,502
Total	**432,467**	**555,151**	**699,307**	**903,700**	**1,225,692**	**1,692,471**

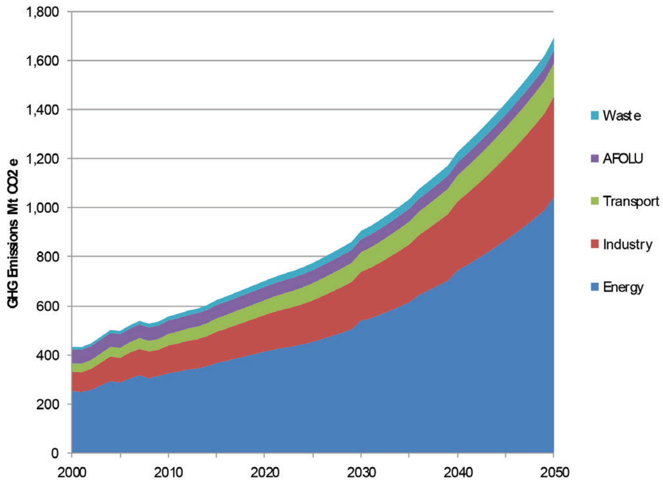


Figure 5: National GHG emissions under the reference case WOM projection, showing a breakdown per sector (2000–2050)

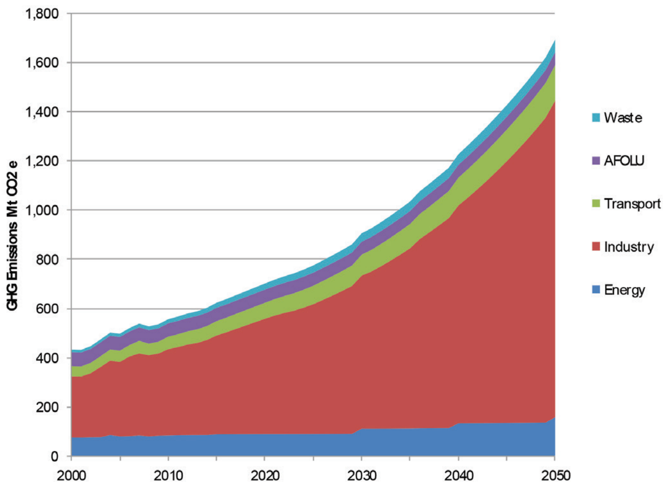


Figure 6: National GHG emissions under the reference case WOM projection, showing a breakdown per sector (2000–2050), with electricity emissions allocated to end use sectors

Table 8: National GHG emissions under the reference case WOM projection (2000–2050) (ktCO_2e), with electricity emissions allocated to end use sectors

	2000	2010	2020	2030	2040	2050
Energy	75,072	81,560	86,138	108,306	130,063	154,436
Industry	249,126	351,501	469,854	623,243	887,008	1,289,562
Transport	41,266	50,943	65,048	85,459	113,153	144,812
AFOLU	56,801	54,311	53,268	52,506	52,216	52,159
Waste	10,202	16,836	24,999	34,186	43,251	51,502
Total	**432,467**	**555,151**	**699,307**	**903,700**	**1,225,692**	**1,692,471**

8.2 Emissions with Existing Measures Only

The WEM projection (Figure 7 and Table 9) shows climate change mitigation measures which have already been implemented, together with the impact of existing climate change policies and measures. Here total GHG emissions are forecast to be 25,479 ktCO_2e lower than in the WOM scenario in 2010 and 99,866 ktCO_2e lower in 2050. The reduction in 2010 is mainly due to measures already implemented by industry. The reduction in 2050 is predominantly due to some decarbonisation of the power sector as a result of commitments by the power sector under the Integrated Resource Plan for Electricity 2010–2030 (IRP) (DoE, 2011). Figure 8 shows the breakdown of emissions when power sector emissions are allocated to end use sectors. As in the WOM projection, emissions are dominated by the industry sector, as it is the principal user of electricity.

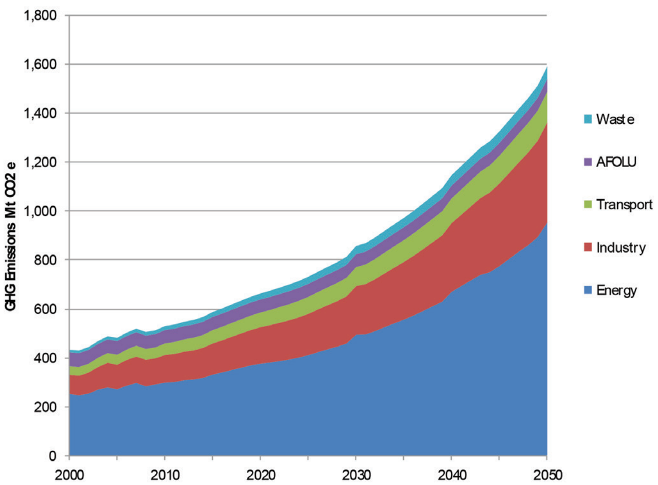


Figure 7: National GHG emissions under the reference case WEM projection, showing a breakdown per sector (2000–2050)

Table 9: National GHG emissions under the reference case WEM projection (2000–2050) (ktCO_2e)

	2000	2010	2020	2030	2040	2050
Energy	251,718	298,109	375,994	494,066	670,107	953,956
Industry	78,265	113,116	149,182	199,296	281,609	409,578
Transport	35,481	47,715	60,242	78,106	101,066	125,825
AFOLU	56,801	54,311	53,268	52,506	52,216	52,159
Waste	10,202	16,421	24,584	33,771	42,836	51,087
Total	**432,467**	**529,672**	**663,270**	**857,745**	**1,147,834**	**1,592,605**

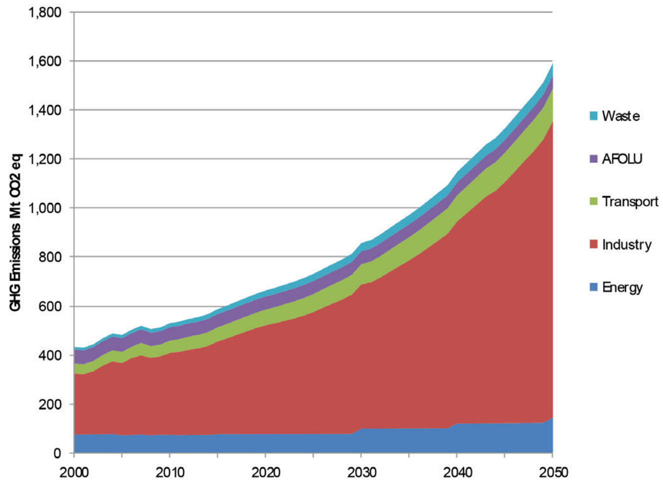


Figure 8: National GHG emissions under the reference case WEM projection, showing a breakdown per sector (2000–2050), with electricity emissions allocated to end use sectors

Table 10: National GHG emissions under the reference case WEM projection (2000–2050) (ktCO_2e), with electricity emissions allocated to end use sectors

	2000	2010	2020	2030	2040	2050
Energy	75,072	73,074	76,935	98,779	119,644	143,783
Industry	249,126	334,923	444,346	589,713	826,055	1,212,168
Transport	41,266	50,943	64,137	82,977	107,084	133,408
AFOLU	56,801	54,311	53,268	52,506	52,216	52,159
Waste	10,202	16,421	24,584	33,771	42,836	51,087
Total	**432,467**	**529,672**	**663,270**	**857,745**	**1,147,834**	**1,592,605**

9. Sensitivity Analysis

A sensitivity analysis was carried out based on a higher and lower rate of economic growth. These growth assumptions were again based on the inputs provided by National Treasury. Following the 2012 Budget forecast (National Treasury, 2012), the low-growth scenario assumed real GDP growth of 3.8% per annum over the medium and long-term. The main drivers of the low growth over the period were the assumptions of continued skills constraints, infrastructure bottlenecks and low global growth. The high growth scenario assumed an improved domestic outlook and recovery from the financial crisis with stronger commodity prices, reduced infrastructure bottlenecks and higher global growth. Real growth was assumed to be 4.8% per annum over the medium-term and 5.4% per annum over the long-term

The changes in growth were used to derive high and low growth emissions projections for the energy, industry and waste sectors, as detailed in Appendix A. As projections for the transport and AFOLU sectors are based on forecasts of transport demand, and agricultural production made by other studies, it was outside the scope of this study to update these projections.[3]

Figure 9 shows projections under high and low economic growth compared to the medium economic growth scenario (for the WEM scenario). Figure 10, Figure 11 and Table 11 give a sectoral breakdown of emissions under the low and high economic growth scenarios. Overall, with lower economic growth, emissions are projected to be 15% (232,079 ktCO_2e) lower than in the medium growth scenario by 2050, reducing the growth in emissions between 2010 and 2050 by 44%. This is driven by lower emissions in the industry and energy sectors. Emissions from industry are 23% (95,548 ktCO_2e) lower under the low growth scenario in 2050 and emissions from the energy sector 14% (135,509 ktCO_2e) lower. Emissions from the waste sector are only 2% lower in the high GDP per capita rates forecast for 2050, as waste generation per capita shows little increase with rises in GDP per capita.

If economic growth were to be higher than the moderate growth rate assumed for the WEM projection, then emissions are projected to be 18% (289,718 ktCO_2e) higher in 2050 than under a medium growth scenario, increasing the growth in emissions between 2010 and 2050 by 55% to 355%. Additional emissions come from the industry sector (133,306 ktCO_2e) which grows at a faster rate, and from the energy sector (155,983 ktCO_2e), where emissions from the power sector increase to meet additional electricity demand from the industry sector.

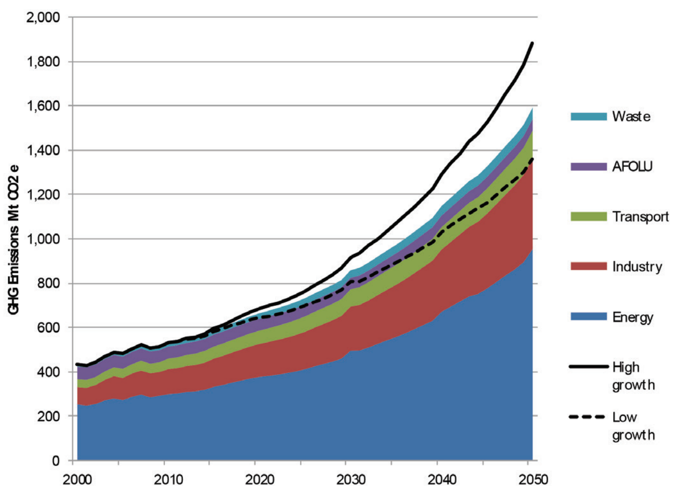


Figure 9: National GHG emissions under the reference case WEM projection, showing high and low growth compared to medium growth (2000–2050)

3. Transport and AFOLU are projected to account for 8% and 3% of total emissions in 2050 under the WEM scenario. Exclusion of these sectors from the sensitivity analysis means that emissions in the high growth scenario are likely to be underestimated by a small amount – probably no more than a few percent. The emissions under the low growth scenario are similarly likely to be overestimated by a small amount.

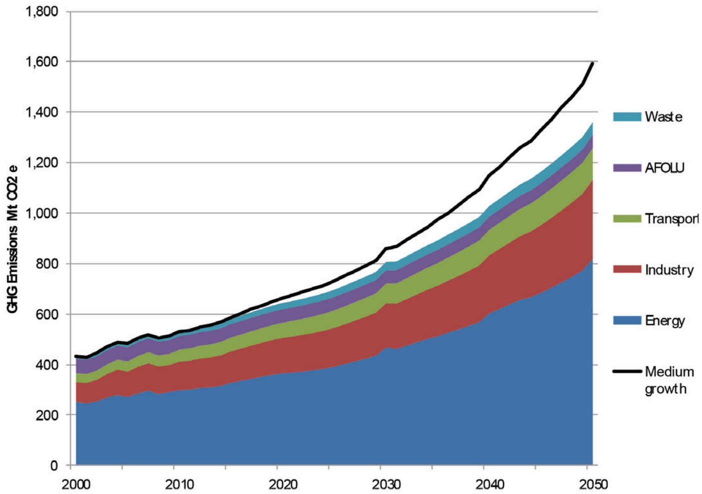


Figure 10: National GHG emissions under the WEM projection, with low economic growth (2000–2050)

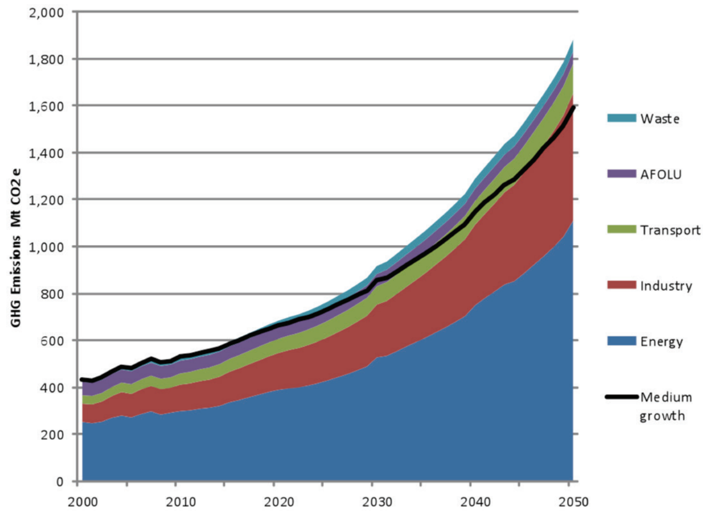


Figure 11: National GHG emissions under the WEM projection, with high economic growth (2000–2050)

Table 11: National GHG emissions under the WEM projection (2000–2050) (ktCO_2e) for low and high economic growth

	2020	2030	2040	2050
Low economic growth				
Energy	365,256	467,470	602,590	818,447
Industry	140,551	175,115	231,045	314,030
Transport	60,242	78,106	101,066	125,825
AFOLU	53,268	52,506	52,216	52,159
Waste	24,404	33,000	41,850	50,064
Total	**643,720**	**806,197**	**1,028,766**	**1,360,526**
High economic growth				
Energy	388,652	527,038	748,533	1,109,939
Industry	157,420	225,076	343,547	542,884
Transport	60,242	78,106	101,066	125,825
AFOLU	53,268	52,506	52,216	52,159
Waste	24,485	33,887	43,166	51,515
Total	**684,066**	**916,613**	**1,288,527**	**1,882,323**

Chapter III: Identification and Analysis of Mitigation Potential

This chapter outlines the approach to identifying and analysing mitigation potential and provides clarity on the main assumptions used in that process. The chapter covers the following sections:

- Section 10: Identifying Mitigation Potential
- Section 11: Quantifying Mitigation Potential
- Section 12: Developing Abatement Pathways

Please refer to Technical Appendix A: Approach and Methodology and to the detailed technical appendices for key sectors for further details on the approach and methodology followed in each sector.

10. Identifying Mitigation Potential

For the purposes of the analysis of mitigation potential presented in the report, a mitigation opportunity is defined as an anthropogenic intervention to reduce the sources or enhance the sinks of GHGs. The Kyoto Protocol deals with the following six GHGs, which are the main focus for this study (United Nations, 1998):

- carbon dioxide (CO_2)
- methane (CH_4)
- nitrous oxide (N_2O)
- hydrofluorocarbons (HFCs)
- perfluorocarbons (PFCs)
- sulphur hexafluoride (SF_6)

A source is defined as any process, activity or mechanism that releases a GHG, an aerosol or a precursor of a GHG or aerosol into the atmosphere (IPCC, 2007). In this study, only South African sources of GHG emissions have been considered. A sink is defined as any process, activity or mechanism that removes a GHG from the atmosphere.

Typically, mitigation measures are technologies (that is, a piece of equipment or a technique for performing a particular activity), processes, and practices, which, if employed, would reduce GHG emissions below anticipated future levels when compared to the status quo or an existing counterfactual technique normally employed.

The mitigation potential of a measure is the quantified amount of GHGs than can be reduced, measured against a baseline (or reference). The use of the term potential is consistent with the IPCC's Fourth Assessment Report, where it was used to report the quantity of GHG mitigation compared with a baseline or reference case that can be achieved by a mitigation option with a given cost (per tonne) of carbon avoided over a given period (IPCC, 2007). Mitigation potential is represented in equivalent tonnes of carbon dioxide (tCO_2e).

Technological potential is the amount by which it is possible to reduce GHG emissions or improve energy efficiency by implementing a technology or practice that has already been demonstrated. Economic potential is the portion of technological potential for GHG emissions reductions or energy efficiency improvements that could be achieved cost-effectively through the creation of markets, reduction of market failures, or increased financial and technological transfers.

The mitigation potential presented in the report is defined as technological potential and not economic potential.

Mitigation potential for South Africa has been identified following a bottom-up sectoral approach for the 2010 to 2050 time period, outlined as follows:

- First, for each sector (and defined subsectors), a set of possible mitigation measures has been identified. This has involved significant research, literature review, data gathering, preparation of a list of mitigation options, consultation with South African sector experts and stakeholders, and shortlisting.
- Second, for each measure, the technological mitigation potential and marginal abatement cost was quantified. This involved analysis, gathering of international benchmark information and further consultation with South African sector experts and stakeholders.
- Third, the measures were then grouped (at national, sector or subsector level) and the mitigation potential of each group of measures was summed to give the overall mitigation potential.
- Finally, the groups of measures (national, sector or subsector) were ranked based on their marginal abatement cost and presented in the form of MACCs.

The mitigation potential of the identified measures was estimated on an annual basis and presented for 2020, 2030 and 2050. The total mitigation potential over the entire duration from 2010 to 2050 was also calculated.

10.1 Identification of Mitigation Measures

GHG emissions mitigation opportunities for each of the five key sectors were identified and quantified following the process described below.

- *Development of a long list*: Based on literature review and desktop research of international GHG mitigation best practice technologies and best available techniques (BAT), a long list of mitigation options was prepared for each key sector (and the stipulated sectors and subsectors).
- *Refinement of a short list*: The long list was disseminated to sector task teams and to the TWG-M and feedback was gathered on the applicability and potential of each measure. A short list of mitigation opportunities was then selected based on this feedback.
- *Further quantitative data gathering*: The data parameters required to construct the MACCs, including the abatement potential and costs, were then gathered using international benchmarks and best practice estimates. Questionnaires for key industry subsectors were disseminated to the TWG-M members, including all of the quantified measures, to verify the parameters based upon sector expertise from South Africa, and to allow the TWG-M members to provide quantitative information on additional mitigation activities.
- *Final list of measures*: The final list of data was then prepared, incorporating final feedback from the TWG-M.

For each measure, the data parameters required to calculate the GHG abatement potential (in tonnes of CO_2e) and the marginal abatement cost (MAC), (in rand (R) per tonne of CO_2 abated) over the 2010–2050 analysis period, have been gathered, quantified based upon benchmark documentation and analysed in consultation with TWG-M sector experts.

The final list of identified mitigation measures, together with abatement potential and marginal abatement cost are listed in Table 32 below. Identification numbers shown in the legends of the marginal abatement cost figures presented below may be used to look up details in Table 32.

10.2 Development of Marginal Abatement Cost Curves

Marginal abatement cost curves were developed at national, key sector and subsector level as snapshots for 2020, 2030 and 2050, presenting the annual technical mitigation potential relative to the reference WEM emissions projection.

These MACCs show the costs and potential for emissions reduction from different measures or technologies, ranking them from the cheapest to the most expensive to represent the marginal costs of achieving incremental levels of emissions reduction. Relative to the reference WEM emissions projection, the MACC shows the GHG mitigation abatement potential for each abatement technology along the horizontal x-axis (in tonnes of CO_2e abated) and the marginal abatement cost of implementing the measures along the vertical y-axis (in R per tonne of CO_2e abated).

A bottom-up sectoral approach has been taken in developing the MACCs and determining the overall sectoral and national level technical mitigation potential. Generally, the sectoral mitigation potential (for 2020, 2030 and 2050) for each measure has been estimated compared to the reference WEM emissions projection for each key sector (and specified subsectors), based upon an assessment of three key percentage factors:

- *Emissions reduction potential*: Percentage reduction of applicable sector reference emissions (fugitive, process, direct emissions from fuel combustion and/or indirect electricity emissions).
- *Applicability*: The percentage of the total reference sector emissions that the mitigation measure's reduction potential can be applied to.
- *Sector uptake/penetration*: The percentage of the sector that implements the mitigation measure.

The sector-wide mitigation potential is then simply estimated by multiplying the reference emissions by the three factors above for each measure and then adding the mitigation potential of all measures identified for the sector.

The approach taken and methodology applied in developing the MACCs for the key sectors is described in detail in Technical Appendix A: Approach and Methodology. The MACCs have been constructed using a computer-based Microsoft Excel™ spreadsheet. A summary of the key methodological assumptions affecting GHG mitigation potential and the marginal abatement cost made is described below.

10.2.1 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.

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 also present challenges when attempting to consider sectoral interdependencies. For example, mitigation actions taken in one sector (such as power generation) will have a knock-on effect in other sectors (such as energy prices, and emissions factors for power generation).

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 measures in a given sector. In these circumstances, the MACC does not necessarily provide a precise estimate of the cost or abatement of a given measure in a specific circumstance or for a specific entity. However, it does provide a reasonable approximation of the marginal abatement cost of 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 the 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.

Further discussion of the MACC methodology developed for this study is provided in Section 5.3 of Technical Appendix A: Approach and Methodology.

10.2.2 Estimating Mitigation Potential

The GHG mitigation abatement potential for each abatement technology is displayed along the horizontal x-axis of the MACC (in tonnes of CO_2e abated).

The annual technical mitigation potential for each measure is calculated on a sectoral basis for each year between 2010 and 2050. The mitigation potential is measured based on the WEM reference emissions projection (for fugitive emissions, process emissions, direct fuel emissions and/or indirect electricity related emissions, as defined by the emissions sources of each key sector).

Generally speaking, the mitigation potential for each identified mitigation measure, in each key sector, has been estimated based upon data parameters gathered and the formulas defined below, according to the emissions sources of each sector. The data parameters stipulate the emissions reduction potential and applicability (that is, fugitive, process, direct fuel and/or indirect related), fuel saving potential and applicability, and/or electricity saving potential and applicability, and the assumed sector uptake.

Sector Mitigation Potential (tCO_2e/year) = *Fugitive/Process Emissions Reduction (tCO_2e/year) +*
Direct Fuel Emissions Reduction (tCO_2e/year) +
Indirect Electricity Emissions Reduction (tCO_2e/year)

The fugitive emissions reduction potential for a given mitigation measure is calculated using the following formula:

Fugitive Emissions Reduction (tCO_2e/year) = *Reference Fugitive Emissions (tCO_2e/year) x*
Fugitive Emissions Reduction Potential (%) x
Applicability (%) x Sector Uptake (%)

The process emissions reduction potential for a given mitigation measure is calculated using the following formula:

Process Emissions Reduction (tCO_2e/year) = *Reference Process Emissions (tCO_2e/year) x*
Process Emissions Reduction Potential (%) x
Applicability (%) x Sector Uptake (%)

The fuel emissions reduction potential for a given mitigation measure is calculated using the following formula:

Direct Fuel Emissions Reduction (tCO_2e/year) = *Reference Direct Fuel Emissions (tCO_2e/year) x Fuel Energy Saving Potential (%) x Applicability (%) x Sector Uptake (%)*

The indirect electricity emissions reduction potential of a given mitigation measure is calculated using the following formula:

Indirect Emissions Reduction (tCO_2e/year) = *Reference Indirect Electricity Emissions (tCO_2e/year) x Electricity Saving Potential (%) x Applicability (%) x Sector Uptake (%)*

The emissions reduction potential and applicability, fuel saving potential and applicability, and electricity saving potential and applicability for each measure have been selected based upon benchmark information and/or in consultation with the TWG-M sector experts. The selected parameters for all mitigation measures identified in each sector together with relevant assumptions are presented in detail in the technical appendices.

The selected level of sector uptake for each measure determines the extent to which a measure is available and implemented across the sector and impacts the overall mitigation potential.

10.2.2.1 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 technology available at a given point in time.

Drawing on published research, the availability of each of the technologies over the assessment period has been defined. For each technology the availability has been allocated to the beginning of one of the following 10-year periods: 2010, 2020, 2030 and 2050.

10.2.2.2 Sector 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 measure's availability 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.

The selected levels of uptake for each measure are presented in the technical appendices. These levels of uptake have been selected in consultation with the TWG-M sector experts.

10.2.3 Estimating the Marginal Abatement Cost

The marginal abatement cost (MAC) is an indicator of the cost required to implement a given technical measure to abate a unit of CO_2e. The MAC describes the net cost of implementing a measure by comparing the capital and operational costs against potential energy cost savings (or additional energy overheads) per tonne of abatement. The MAC is shown along the vertical y-axis of the MACC (in cost per tonne of CO_2e abated).

The marginal abatement cost for a measure in a given year is defined as follows:

MAC (R/tCO_2e) = Net Annual Cost (R/year) / Total Emissions Reduction (tCO_2e/year)

The net annual cost (NAC) for a measure in a given year is the sum of the equivalent annual cost (EAC) and the annual operation and maintenance cost (Opex) minus the energy cost saving. The NAC is defined as follows:

NAC (R/year) = Equivalent Annual Cost (R/year) + Annual Operation & Maintenance Cost (R/year) – Energy Cost Saving (R/year)

The equivalent annual cost (EAC) for a given measure is defined as the capital investment cost (Capex) of the technical measures annualised over the measure's lifetime, applying an assumed discount rate. This can be calculated by taking the negative value returned by the PMT function in MS Excel™.

Capex is annualised because the measures within the MACC may have different lifetimes and, therefore, this allows the marginal abatement costs of different measures to be compared and ranked accordingly. The Capex is based on the estimated overnight capital cost[4] for the measure in the given year. The Capex, Opex and lifetime were largely based on benchmark information, which was cross-checked with the sector task team representatives. In cases where more accurate costing information has been made available by the TWG-M, this was used instead. The selected Capex, Opex and lifetimes for all of the mitigation measures identified in each energy sector are displayed in the relevant technical appendices.

10.2.3.1 Other cost assumptions

The energy cost saving (R/year) for a given measure in a given year is based upon the estimated annual fuel and/or electricity saving (GJ/year) multiplied by the assumed price for that year (in R/GJ). The assumed fuel and electricity costs for the period 2010 to 2050 are presented and explained in Box 2.

Box 2: Energy Price Assumptions

The assumed fuel prices for 2010, 2020, 2030 and 2050 used in the mitigation analysis and the development of the non-power energy, industry and transport sector MACCs are presented in Table 12. The prices are based on the supply costs of various indigenous production of primary fossil and renewable energy and on import prices from the Appendix I. Primary Energy Supply Sector - Reference Case Assumptions of version 3.2 of the SATIM Energy Model Methodology Appendices (ERC, 2013) provided in R/GJ (with the exception of metallurgical coke, petcoke and refinery fuel gas which are not specified in the SATIM model). This source was considered to be the most comprehensive, up-to-date and consistent data source for South African fuel prices on which to base the fuel price assumptions. The assumed prices are net prices and do not include tax or additional local distribution charges.

Exceptionally, the 2010 base year price for metallurgical coke and petcoke is based upon average market price information (Resource-Net, 2011). The refinery fuel gas (RFG) production cost is based on the SATIM energy model crude oil cost, and the assumption that 5% of feed crude stock is converted into RFG, and RFG production costs are 2.5% of total refinery product energy. The 2020, 2030 and 2050 prices are all extrapolated based upon the SATIM growth trend for crude oil.

In reality, the fuel prices paid by different businesses and industry subsectors may vary depending on several factors (for example, amount of fuel purchased, supply contract terms and so on). As no other single and consistent information source was available for fuel prices paid in the non-power energy and industry subsectors, the SATIM energy model and DoE energy prices were applied.

The electricity price for 2010 and projection up to 2050 is based upon the anticipated average electricity price path included in the Integrated Resource Plan (IRP) for Electricity 2010–2030 (DoE, 2011 Figure 4). This was considered to be the most appropriate data source on which to base the electricity price assumption and projection and is consistent with the power sector mitigation analysis assumptions.

4. The lump sum cost disregarding interest for a construction project.

Table 12: Assumed energy prices for 2010 base year and projected prices up to 2050

Item	Units	Source	Note	2010	2020	2030	2040	2050
Coking coal	R/GJ	(ERC, 2013; DoE, 2011)	Imports of coal coking	55	60	66	70	75
Bituminous coal	R/GJ	(ERC, 2013)	Extraction of coal	27	30	33	35	37
Metallurgical coke	R/GJ	(Resource-Net, 2011)	Projection linked to coal trend, SATIM model 2013	112	123	134	143	152
Petcoke	R/GJ	(Resource-Net, 2011)	Projection linked to crude oil trend, SATIM model 2013	111	137	170	192	213
Natural gas	R/GJ	(ERC, 2013)	Imports of gas Southern Mozambique piped	44	55	68	77	85
Crude oil	R/GJ	(ERC, 2013)	Imports of oil crude	97	121	150	168	187
Natural gas liquids (NGL)	R/GJ	(ERC, 2013)	Imports of gas international NGL	72	88	108	121	133
Liquid petroleum gas (LPG)	R/GJ	(ERC, 2013)	Imports of oil LPG	276	300	329	348	367
Motor gasoline	R/GJ	(ERC, 2013)	Imports of oil gasoline	124	153	188	211	234
Gas diesel oil	R/GJ	(ERC, 2013)	Imports of oil diesel	117	145	180	203	226
Heavy fuel oil	R/GJ	(ERC, 2013)	Imports of oil HFO	97	121	150	168	187
Kerosene	R/GJ	(ERC, 2013)	Imports of oil kerosene	127	154	189	211	232
Biomass bagasse	R/GJ	(ERC, 2013)	Renewable resource: biomass bagasse	20	20	20	20	20
Biomass wood	R/GJ	(ERC, 2013)	Renewable resource: biomass wood	20	20	20	20	20
Biodiesel	R/GJ	(ERC, 2013)	Imports of Biodiesel	123	152	189	213	237
Electricity	R/GJ	(DoE, 2011)	IRP projection, Figure 4. Breakdown of anticipated average electricity price path	117	264	264	264	264
Bioethanol	R/GJ	(ERC, 2013)	Imports of bioethanol	131	160	198	222	246
Refinery fuel gas	R/GJ	Specific assumption	Linked to imported crude oil projection	8	10	13	14	16

While a specific set of energy prices was assumed for the study, it is recognised that when developing sector specific feasible mitigation options, prices that are applicable to the specific activity will need to be applied.

10.2.4 Constructing the marginal abatement cost curve

Once the technological mitigation potential and marginal abatement cost have been quantified for each measure, the measures are then grouped (at national, sector or sub-sector level) and the mitigation potential of each group of measures is summed to give the overall mitigation potential. Finally, the groups of measures (national, sector or subsector) are ranked based upon their cost effectiveness and presented as MACCs at national, key sector and subsector level for 2020, 2030 and 2050. The mitigation measures are ranked from left to right along the x-axis from cheapest to most expensive.

The MACC development process has taken a number of iterations to finalise. Draft versions of each MACC in each sector have been presented for discussion to members of the TWG-M. Feedback has been gathered in an effort to model the technical mitigation potential as accurately and realistically as possible. The sector-specific assumptions made for each identified mitigation measure are detailed in the technical appendices.

10.2.5 MACC Development Approach for Power Sector

Assumptions regarding the selection and implementation of measures in the power sector are consistent with the options specified under the IRP Policy-Adjusted Scenario (DoE, 2011). The project team was requested to seek consistency with the IRP scenarios; therefore the choice was influenced by the technologies defined in the report. Most of the options analysed are advanced generation technologies, and energy generation from renewable sources.

The abatement potential and associated cost of the different technologies have been analysed using a scenario tool for the power sector specifically designed to project emissions and consider abatement options for the sector. The tool and the approach to building MACCs for the sector are described in detail in Technical Appendix C: Energy Sector.

10.2.6 MACC Development Approach for Non-power Energy and Industry Sectors

In the industry and non-power energy (excluding electricity generation) sectors, the selected level of implementation of a mitigation measure in a given year is 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.
- *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 is applied guided by the principle of what is technically available (and not limited by economic and other non-technical limitations).

The following straightforward assumptions have been made.

- Generally, 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 (that is with a lifetime of between 10 and 15 years). If measures are deemed to be locked-in technology (with a lifetime of between 25 and 40 years), then they are implemented sector-wide over 20 years.
- Where a set of measures is mutually exclusive, then it is assumed that they will be implemented equally and the total summed uptake of these measures cannot exceed 100% (for example, post combustion and oxyfuel carbon capture and storage (CCS) technologies).
- Where a measure is considered to be far 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.

Indirect emissions reductions caused by interventions which reduce grid electricity consumption (for example, increased onsite electricity generation) are included in the MACC analysis, as well as reductions of fugitive emissions, industrial process emissions and direct emissions from fuel combustion.

10.2.7 MACC Development Approach for Transport Sector

In analysing abatement opportunities for the transport sector, the potential emission reductions have been assessed on a life cycle basis. This means, for example, that abatement measures associated with changes in electricity consumption take into account any impacts on emissions in the electricity production sector (1A1[5]). Likewise, emission factors associated with the use of biofuel take into account upstream emissions from

5. 1A1 is the IPCC source category comprising emissions from fuels combusted by the fuel extraction or energy-producing industries.

biofuel production. This approach is more comprehensive than that adopted within other sectors of the study, where, with the exception of indirect emissions from electricity consumption, the analysis has only considered direct emission reduction. For the transport sector, a more complete assessment of emissions is important as the indirect emissions from transport fuels are significant. In addition, the abatement measures in the transport sector include different powertrains and fuel technologies, with very different life cycle impacts.

For each of the types of measures considered for the transport sector, international benchmarks were reviewed, compiled and analysed in a South African context. For the technology measures (that is, more fuel efficient and alternative fuel vehicles), international benchmarks provide a good basis for the likely costs in South Africa. However, for certain other measures, such as those associated with modal shifts, the characteristics of the measures are much more site or project specific and it is much more difficult to define generic benchmarks for the cost or effectiveness of these measures. The assumptions used for making mitigation projections and costing the intervention in each case are provided in Technical Appendix E: Transport Sector.

The assessment of the marginal cost of the measures was based on evaluating the additional cost of the measures, relative to the measures that would have been implemented otherwise. This cost included the additional capital cost of the abatement measures, but also the ongoing operating and maintenance costs.

For road transport, the marginal cost calculations depend on the following metrics: fuel price projections, capital costs of new cars, their fuel efficiency and maintenance costs. The rail sector mitigation options are based on differing uptake of improved efficiency train fleets, fleet replacement and the use of alternative fuels. The main driver of the MAC analysis here is the cost associated with each measure. For aviation, the key technical data, including cost assumptions, have drawn upon international benchmarks. Since the market for aircraft is global the measures data is assumed to be applicable to a South Africa context. All assumptions and sources are detailed in Technical Appendix E: Transport Sector.

10.2.7.1 Key assumptions

The following key assumptions are made in constructing MACCs for the transport sector:

- *Penetration of measures*: The assumed penetration of the measures is based on expert judgement, taking into account cost and technical factors, and informed by standard (s-curve) assumptions for the penetration of emerging technologies over time. This essentially implies a greater share of new sales for more established technologies initially, with the penetration of emerging technologies increasing over time.
- *Measures interaction*: Interaction between measures is particularly important for biofuels. For rail and aviation, the penetration of biofuels has been limited to a relatively low level, reflecting an assumption that available resources of sustainable biofuels will be constrained, and therefore decisions will be required on where the available resource will be used. The conservative assumptions made regarding biofuels are further justified by the considerable uncertainty surrounding the future availability and costs of biofuel resources.
- *Counterfactual technology*: For the vehicle technologies, the abatement costs have been defined relative to the same counterfactual technology (which in most cases is a less efficient version of the conventional technology), ensuring an equal comparison of the technologies. Changes in costs over time, and differences in energy sources mean that the relative cost effectiveness of different technology measures varies over time. Furthermore, the rate at which costs evolve varies between technologies, and this in turn changes the relative ranking of measures over time. However, for all measures the general trend is a reduction in cost over time. For the modal shift measures, the assessment is based on a single case study and extrapolated to a national summary. The savings represent the relative difference in emissions between different modes, and can be considered relatively robust in isolation. The costs for the modal shift measures are overall much more uncertain because they are very project-specific. Results for these measures should be treated with greater caution as a result.
- *Emission factors*: For all measures the emissions have been assessed on a life cycle basis. For electric vehicles this means that emissions from power generation have been taken into account, and for biofuels emissions have been assessed on a life cycle basis. To ensure comparability, the emission factors for fossil fuels have also been assessed with indirect emissions included. This provides a more complete assessment of the mitigation potential from the sector.

10.2.8 MACC Development Approach for Waste Sector

The assessment of mitigation potential for the waste sector was restricted to municipal waste, because data for industrial waste emissions were not available. As many of the technologies considered for the waste sector have not been implemented yet in South Africa, robust data on specific costs for projects in South Africa was difficult to obtain. Therefore, international data was used, although wherever possible this was cross checked against the high level data or indicative cost estimates available in-country. In some cases, with agreement from experts within South Africa, cost estimates were adjusted to reflect South African conditions.

Due to interactions between measures, the abatement potential and cost-effectiveness of single options in the waste sector depend on assumptions about the implementation of other options. In order to construct the MACC curves, the cost-effectiveness of each of the options was calculated, assuming, for options which involve diverting waste away from landfill, that there was no landfill gas recovery. This shows that recovery of landfill gas with flaring, and with electricity generation are the most cost-effective options. Implementation rates for these options were therefore applied, giving reduced savings for the diversion options. It is then assumed that the waste diversion options are implemented; their abatement potential and cost-effectiveness is recalculated given the assumptions regarding landfill gas recovery. The reduction in waste going to landfill is then used to scale back the actual savings achieved by landfill gas recovery options. Waste diversion options are implemented in order of their cost effectiveness, subject to limitations on their applicability.

For options which involve electricity generation, while the value of the electricity generated was included in the cost effectiveness assessment, additional GHG savings which might be realised by avoiding the need for fossil fuel-based electricity generation were not included to ensure no double counting of emissions savings with the power sector.

A full description of abatement and marginal cost estimates for the waste sector is provided in Technical Appendix F: Waste Sector.

10.2.9 MACC Development Approach for Agriculture, Forestry and Other Land Use Sector

Based on an analysis of land use data, the opinions of specialist consulting team members and the AFOLU task team discussions, it has been assumed that land areas under crop production and commercial forestry are stable. 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 production on the same area of land complemented by growing imports. The key assumptions regarding costing and estimating mitigation potential for each of the measures is summarised in Table 13 below.

Table 13: Assumptions regarding costing mitigation measures for the AFOLU sector

Mitigation option	Basis for estimating quantum of emission mitigation
Treatment of livestock waste	All pigs are in piggeries; Cattle in feedlots during fattening stage increases at current rate to a maximum of 70%. Percentage of piggery and cattle feedlot waste treated with anaerobic digestion increases to 70%.
Expanding plantations	Current plans for 100 000 ha of new forests to be implemented. In addition, a further 100 000 ha to be developed with an associated loss of water to the agriculture sector. The assumption is that irrigated maize production will be reduced to allow for an equivalent amount of water to be used for commercial forestry.
Urban tree planting	Assumption is that there will be one tree per household with the 'backlog' to be made up over 20 years and then for all new urban developments to have this number of trees.
Rural tree planting (thickets)	Assumption is that thicket regeneration is only possible in 800 000 ha of the Eastern Cape. Assuming the current rate of planting (based on the Subtropical Thicket Restoration Programme (STRP)), 20% of this area will be planted over 40 years.
Restoration of mesic grasslands	Restoration assumed to take place only on degraded mesic grasslands.
Biochar addition to cropland	Assumption is made that only alien invasive trees will be used as feedstock. 30% of wood to be used for biochar.

The assumptions for making mitigation projections and costing the interventions in the AFOLU sector are provided in Technical Appendix G: AFOLU Sector.

11. Quantifying Mitigation Potential

11.1 Technical Mitigation Potential

The previous section described the approach to identifying mitigation options and calculating marginal abatement cost curves. Through a process of discussion with the TWG-M and with sector experts represented on each of the five sector task teams, a final list of mitigation measures for each subsector was developed. These are summarised in Table 32 at the end of this report, as well as in each of the technical appendices for key sectors. Table 32 also contains the finalised estimates of abatement (in ktCO_2e) and marginal abatement costs (in R/tCO_2e), which represent the inputs to the MACCs for each of the three periods considered: 2020, 2030 and 2050. These estimates effectively summarise the technical mitigation potential estimate in each subsector in this study.

The technical mitigation potential is the amount by which it is possible to reduce GHG emissions or improve energy efficiency by implementing a technology or practice that has already been demonstrated. In some cases implicit economic considerations are taken into account (IPCC, 2007).

11.2 Projecting Emissions with Additional Measures

Having determined the technical mitigation potential for all measures in a sector (or group of sectors), it is then possible to project future reductions in emissions based on that potential. These projections are all based on mitigation measures identified under this study which are, by definition, in addition to any pre-existing mitigation actions. Accordingly, these are referred to as 'with additional measures' (WAM) projections.

In all cases, mitigation is an estimate relative to a reference case projection. Two projections of future GHG emissions have been provided as reference cases under this study. The first assumes no mitigation actions have occurred at all and is hence referred to as the 'without measures' (WOM) projection. The second projection accounts for existing mitigation measures implemented between 2000 and 2010 in projecting emissions forwards to 2050. As this projection is aligned to the draft national GHGI between 2000 and 2010 and because it most closely represents future emissions, assuming no additional measures will be implemented after 2010, this 'with existing measures' (WEM) projection is used as the reference against which abatement under the WAM projections is calculated.

The starting point of the WAM projections is thus 2010 and they extend to 2050. A WAM projection can effectively be built using any combination of the mitigation measures quantified in this study. Results are displayed in the technical appendices and typically assume that all available measures are fully-implemented (that is, 100% of technically-feasible mitigation potential is implemented). It is worth noting that the rate at which emissions are reduced over time, and the final level of reduction achieved, is a matter of priorities and requires careful choices to be made. The intention under the NCCRP is to prioritise the implementation of mitigation options on the basis of several considerations, not merely abatement potential and costs. Accordingly, the MCA framework has been developed as part of this study to aid in selecting mitigation measures, based on a given set of evaluation criteria and the relative weights assigned to those criteria. How these inputs are combined to develop indicative future abatement pathways is discussed in the next section.

12. Developing Abatement Pathways

The previous two sections of this report described the approach used to identify the mitigation measures together 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 ranking of mitigation measures based on one criterion (cost); hence a single emission reduction trajectory, or pathway.

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 ranking measures for implementation) and the extent of mitigation required (how far to go).

This section describes the approach to developing abatement pathways, namely:

- defining the pathways (using different criteria weightings)
- ranking measures (based on the marginal abatement net benefit curve)
- developing a framework for evaluating targeted levels of emissions reduction against the effort required to implement the required measures
- assessing the wider macroeconomic impacts of implementing the measures required to achieve a targeted level of abatement.

12.1 Defining Abatement Pathways

This study has involved the development of reference case emissions projections, the identification and analysis of mitigation in key sectors, and assessments of the broader socioeconomic and environmental impacts of these measures. An explanation is provided in this section for how these elements have been combined to develop national abatement pathways. The distinction between projections, scenarios and abatement pathways is explained in Box 3.

Box 3: 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 (for example, about baseline conditions).[6]

Abatement Pathway

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

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

The phrase *abatement pathway* has been adopted in this study to characterise a set of emission reduction trajectories (pathways) over time, which are technologically 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 assessed. Once a set of pathways have been determined (discussed further below), the wider macroeconomic impacts of implemented 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. They do not meet the full definition of scenarios, which are a coherent, internally consistent and plausible description of a possible future state of the world. No detailed assessment of baseline conditions under which a set of scenarios for South Africa's transition toward a lower-carbon economy could be developed have been made. It is also recognised that any such transition implies that a very broad set of economic, social, environmental and political choices need to be made. This falls outside of the scope of the current study, which is aimed at providing a technical assessment of mitigation potential only.

The concept of abatement pathways has been developed to illustrate a range of emission reduction trajectories – all of which are technically feasible. As discussed below, the application of the concept of marginal abatement net benefit allows any user to explore the necessary trade-offs between the targeted level of abatement and the effort involved in any decision to implement a range of mitigation measures.

12.2 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. Preparation of MACCs (see Section 10.2 as well as Technical Appendix A: Approach and Methodology and detailed assumptions regarding costing and estimating mitigation potential in the seven individual sector appendices C to G).
- *Multi-criteria analysis*: Undertake MCA considering each measure against the agreed criteria (see Section 12.2.1 and Technical Appendix A: Approach and Methodology).
- *Ranked list*: Develop ranked list of measures for each weighting of criteria considered, taking all measures into consideration (see Section 12.2.5).
- *Develop pathways*: Develop pathways that take into consideration the different ways criteria have been weighted and the extent of mitigation to be achieved.
- *Projections*: Make projections of mitigation measures (WAM projections) for each pathway based on the progressive application of measures according to their ranking.

The analysis was undertaken using a set of tools that are available as Excel™ workbooks with associated graphics, as illustrated in Figure 12 below.

The methodology applied for each stage of analysis is described in detail in Technical Appendix A: Approach and Methodology. The main features are highlighted below:

- 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.

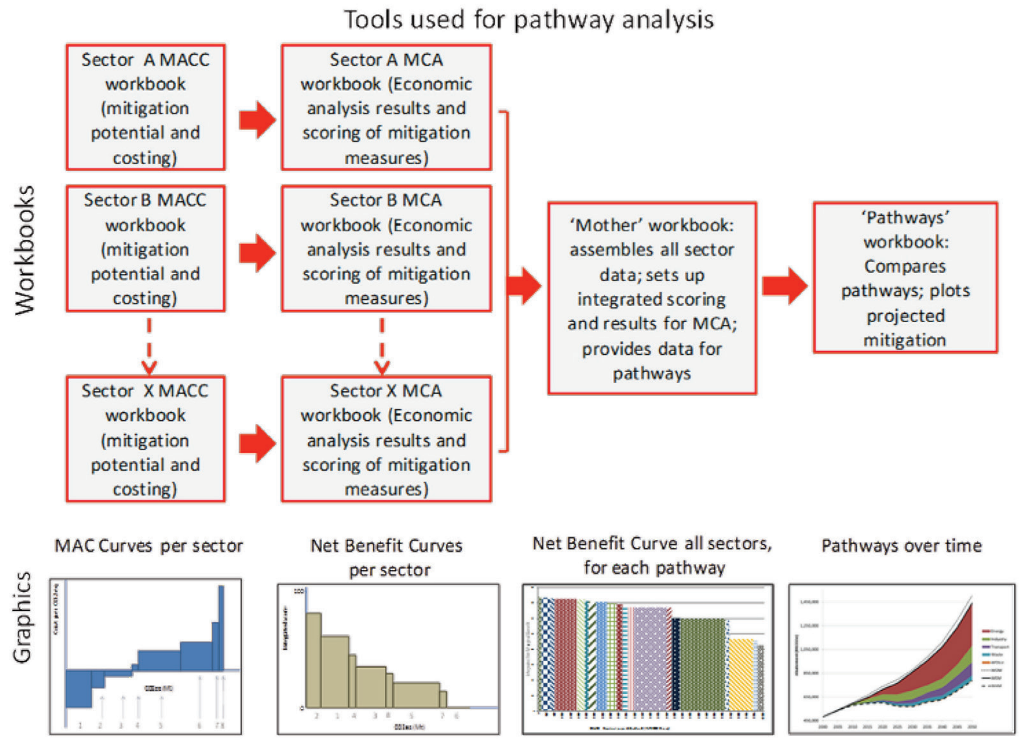


Figure 12: Tools used to undertake analysis of mitigation options and associated pathways

Multi-Criteria Analysis

The requirement to assess mitigation measures based on multiple criteria has been noted above. These criteria are strongly aligned with impacts, for example: how much will it cost, what will the effect be on the economy and how will communities be affected? For each of these impacts a criterion or criteria are identified so that mitigation measures can be assessed in relation to these criteria and then compared to other measures. As soon as multiple criteria are being considered an analysis framework is required to make decisions around how the criteria are applied and what the results mean. For this project the technique of multi-criteria analysis is used. This is described briefly in Box 4 and more fully in Section 6 of Technical Appendix A: Approach and Methodology.

Box 4: Multi-Criteria Analysis

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 the 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.

Steps in the MCA process

Firstly, it is important to establish a decision making structure: who will take what decisions and when? For this project the overall responsibility for deciding on options vested with the Technical Working Group which represents all key stakeholders. Sector Task Teams were responsible for decisions associated with scoring and weighting individual projects.

Box 4: Multi-Criteria Analysis - *continued*

An MCA process then follows the steps illustrated in the figure below and described in the table below that.

Step	Description
Identify options	*A list of measures to be evaluated is required with the process to identify measures described elsewhere.*
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 elsewhere in this report.*
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 (which requires analysis) or qualitative (which is based on the opinions of stakeholders and experts).* *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.*
Score the options	*Each option must be scored against the established scale. For the quantitative criteria, scoring is based on the results of an analysis of numbers. For qualitative scores, opinions of Sector Task Team members were applied.*
Apply a value function	*A value function translates scores on differing scales into points on a scale of 0 to 100, and thus allows comparability between 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 with a note made of what has been done. A linear relationship is applied for all criteria for this project.*
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.*
Calculate overall weighted scores	*This is a mathematical process: 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.*
Examine the results	*The final step in the MCA is to establish a ranking of the options and make recommendations.*

12.2.1 Selecting and Applying Criteria to Get Pathways

The Technical Working Group on Mitigation (TWG-M) agreed to apply the following criteria, structured into two tiers (Figure 13). Each mitigation measure is scored in relation to each of these criteria.

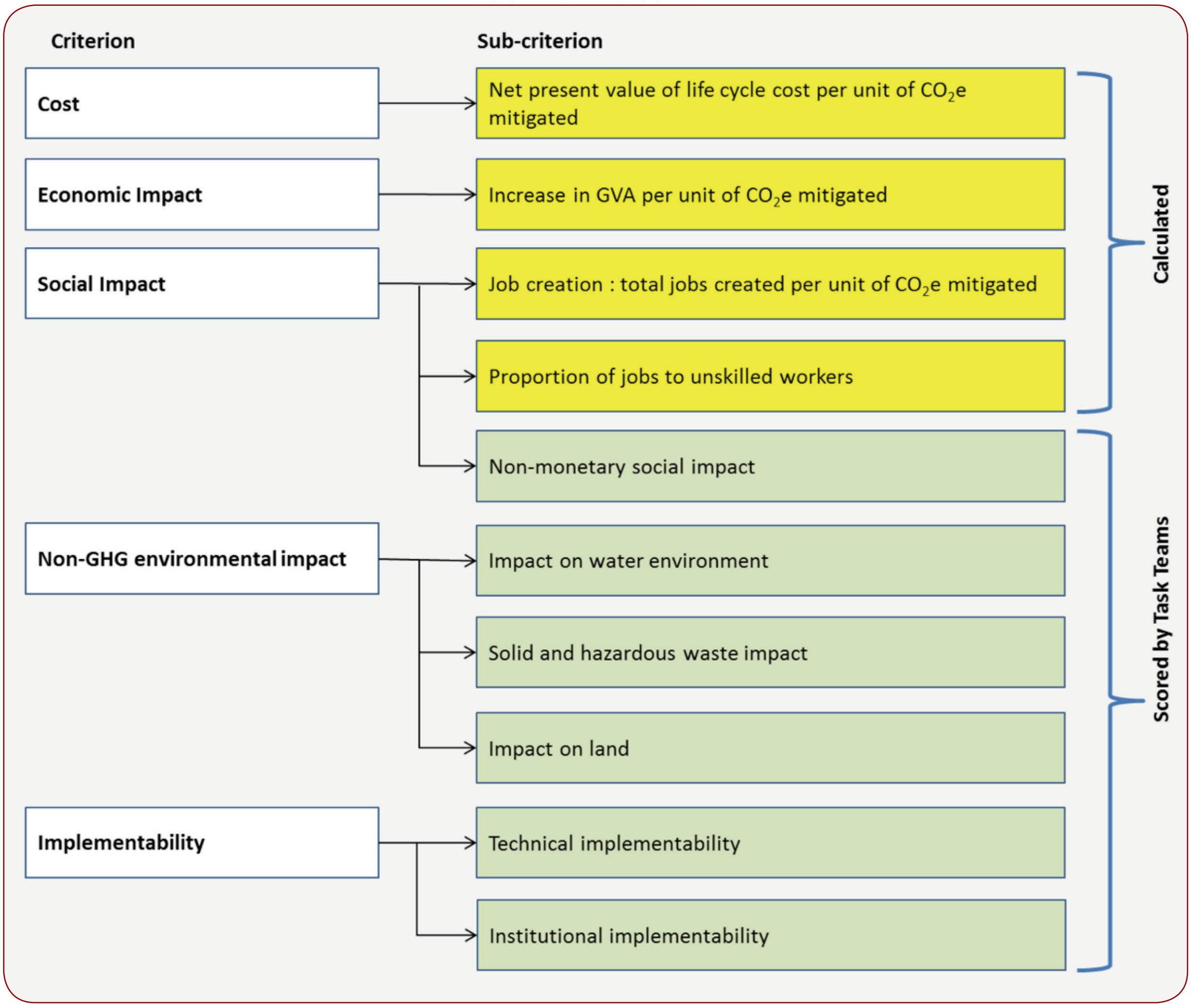


Figure 13: Criteria and sub-criteria for the MCA model (as approved by the TWG-M)

12.2.2 Apply weightings to criteria

The important next step is to apply weightings to the criteria. Based on its weighted average score, a relative position of each measure in the full list of mitigation measures is determined. This overall score is then used to define the pathway – the progressive application of mitigation measures in order of priority to get to a given level of abatement.

The Technical Working Group on Mitigation (TWG-M) agreed to three primary sets of weightings as illustrated in Table 14. The three different primary weighting selections have been defined as pathways. These pathways are:

- a balanced weighting pathway, representing a broad consensus among all interest groups represented on the TWG-M
- a pathway which emphasises costs and implementability of mitigation measures
- a pathway which emphasises social and non-GHG environmental impacts of mitigation measures.

Table 14: Weighting of criteria to define abatement pathways[7]

Primary criterion	Sub-criteria split (common to all pathways)		Balanced weighting pathway	Pathway with emphasis on costs and implementability	Pathway with emphasis on social and non-GHG environmental Impacts
Cost			23	40	10
Economic impact			14	10	10
Social impact	Job creation	50	24	10	35
	Non-monetary	40			
	Nature of jobs	10			
Non-GHG environmental impact	Water	60	20	10	35
	Land	20			
	Waste	20			
Implementability	Technical	70	19	30	10
	Institutional	30			

As is evident from Table 14, the pathways are defined by the weighting of criteria. This gives a different ranking of mitigation measures and selection of the ranked mitigation options which together account for a specific percentage of the total mitigation potential.

Quantitative data informing the MCA scoring of options for all measures as well as the score for the main criteria and the overall weighted score for the balanced weighting pathway are shown in Table 33.

Overall scores and rankings for all measures under the balanced weighting pathway, the pathway which emphasises costs and implementability, and the pathway which emphasises social and environmental factors are shown in Table 34.

12.2.3 Selecting which Pathway to Take

Different stakeholders are likely to favour different pathways. Three mitigation pathways have been determined, based on different weightings of the main criteria in the MCA framework developed for the purpose of assessing the socio-economic and environmental impacts of mitigation options. The MCA model allows a range of evaluation criteria to be combined in a decision-making framework. The resulting ranking of measures is thus based on more than merely the consideration of abatement potential and marginal abatement cost. As described above, the balanced weighting pathway allows for relatively equal consideration of all key factors in the MCA model, the second pathway emphasises the cost and implementability of mitigation measures, assigning a larger weight to measures which have lower marginal abatement costs and are easier to implement, while the third pathway emphasises social and environmental factors, effectively prioritising measures with lower impacts in these areas.

12.2.4 Choosing How Far to Go

Estimates of abatement 'with additional measures' (WAM) have been provided for all sectors covered in the report. The WAM projection assumes that all measures identified in this report have been implemented to their full technical potential (that is, 100% of technical mitigation potential). Although the order of implementation of each measure will change for each pathway, the total mitigation achievable will be the same in all cases regardless of the order in which the measures are implemented.

7. In retrospect it is arguable that a greater shift in weightings should have been applied. However, these three weightings were decided by the TWG-M and the analysis has proceeded with them as they are.

However, it is clear that for each case, the lower-ranked measures become less favourable. This analysis has looked at the impact of applying measures to achieve three intermediate levels of mitigation: 25%, 50% and 75% of the maximum technical potential. Differences in average scores from the MCA model across all three pathways are shown in Table 15.

Table 15: Average scores from the MCA model under each of the three abatement pathways, shown for each 25th percentile

Average score for all criteria for progressive 25 percentiles	Balanced weighting pathway	Pathway with emphasis on costs and implementability	Pathway with emphasis on social and non-GHG environmental impacts
1st 25 percentile	68.8	75.8	65.5
2nd 25 percentile	61.2	64.6	59.4
3rd 25 percentile	54.5	57.2	53.3
4th 25 percentile	41.6	43.9	37.2

12.2.5 Choosing which measures to implement

In ranking the measures for implementation, both the amount of mitigation which can be achieved and the relative ranking provided by the weighted average score from the MCA analysis (taking all criteria into consideration) need to be considered. For this reason, the concept of 'marginal abatement net benefit' has been developed for this project. Here the term net benefit is intended to take cost, impacts and implementability into consideration – all the factors taken into consideration in the MCA. These can be expressed as a value which has any meaning other than as a relative measure applicable to comparing measures and assessing the relative benefit of groups of measures. The concept can be applied as a graph, or a curve, as illustrated in Box 5.

12.3 Evaluating National Abatement Pathways

12.3.1 Moving from the Assessment of Individual Measures to Assessing Pathways

At this stage of the mitigation assessment process a shift takes place from assessing individual measures to assessing pathways which are groupings of mitigation measures.

The above sections of the report define three mitigation pathways and set up a ranked list of mitigation measures which, assuming they are applied incrementally, create increasing levels of mitigation with decreasing net benefit, taking all criteria into consideration, as illustrated in Table 15. Further, the methodology results in 'marginal abatement net benefit curves' (MANBCs). Using these curves, it is possible to read from the horizontal axis how much mitigation is to be achieved, with 25%, 50%, 75% and 100% of the technical mitigation potential nationally used for illustration purposes. The results, with actual MANBCs plotted, are shown in Section 19.

Quantitative and qualitative inputs and scores for all measures in the balanced weighting pathway are shown in Table 33 below.

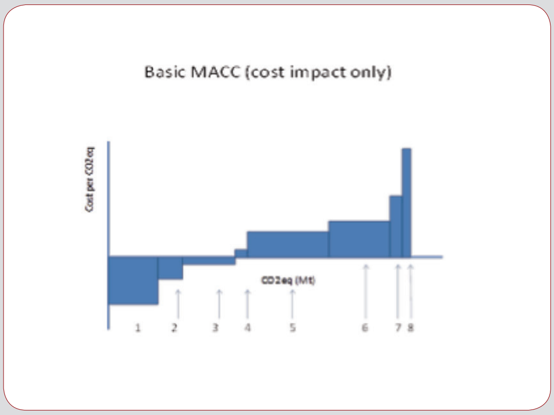
12.3.2 Economic impact associated with pathways and level of implementation of potential mitigation

A further feature of the decision-making arrangements is available through the application of economic modelling for each pathway, taking the grouping of measures in each sector into consideration. For this purpose the INFORUM economic model is applied, with the methodology for doing this described in Technical Appendix B: Macroeconomic Modelling. This allows for the aggregated impact of a set of measures to be assessed. The results of this analysis are reported in detail in Technical Appendix B with the results summarised in Section 20.

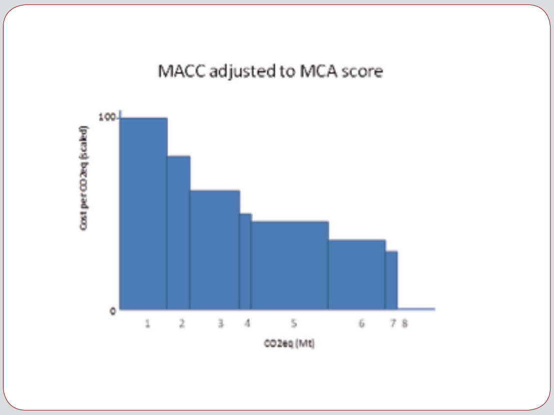
Box 5: Marginal Abatement Net Benefit Curves

The concept of MANBCs is developed progressively from a MACC curve (A), first through 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).

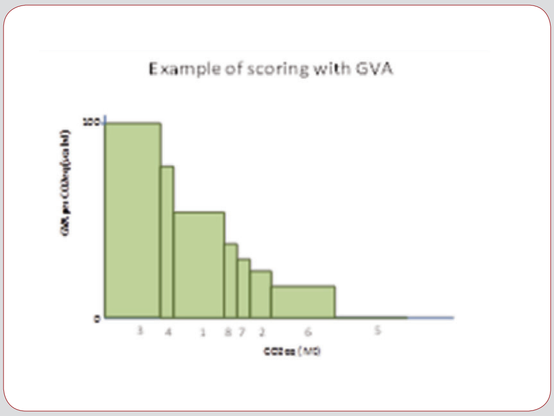
A



B



C



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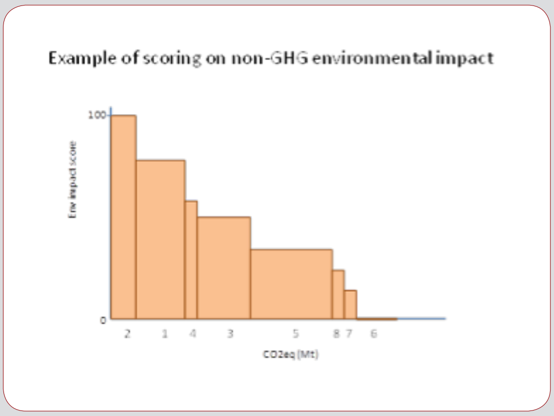
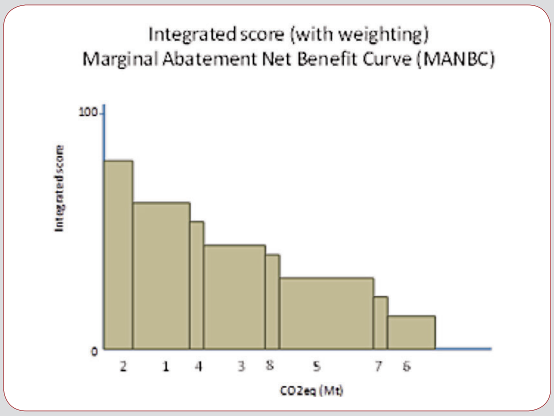


E



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.*

Chapter IV: Mitigation Potential by Sector

This chapter presents a summary of mitigation potential for each of the five key sectors considered in this study. Results are summarised as follows:

- Energy (Section 13)
  - Power sector
  - Non-Power sector
- Industry (Section 14)
  - Metals
  - Minerals
  - Chemicals
  - Surface and underground mining (excluding coal)
  - Buildings (commercial, institutional and residential)
  - Other (pulp and paper production)
- Transport (Section 15)
  - Road transport
  - Rail transport
  - Aviation
- Waste (Section 16)
- AFOLU (Section 17)

13. The Energy Sector

This section identifies the GHG emissions mitigation potential for the South African energy key sector. The mitigation potential is presented in the form of marginal abatement cost curves (MACCs) for years 2020, 2030, and 2050, ranking available mitigation options in terms of their marginal abatement cost. The mitigation potential presented is considered to be technically achievable assuming that all identified mitigation technologies have been technically proven or will be proven prior to becoming available.

The energy sector comprises exploration and exploitation of primary energy sources, conversion of primary energy sources into more useable energy forms in refineries and power plants and the transmission and distribution of fuels. This includes IPCC emissions sector 1A, fuel combustion activities; 1A1, energy industries; and 1B fugitive emissions from fuels. The energy sectors examined and sources of emissions, as classified by the IPCC categories, are listed in Table 16 below.

Mitigation opportunities for energy sector emissions which are presented in this section focus on four separate sources of emissions, described below:

- Combustion emissions from the use of fuels in stationary combustion. Fuel combustion may be defined as the intentional oxidation of materials within an apparatus that is designed to provide heat or mechanical work to a process, or for use away from the apparatus.
- Fugitive emissions, which escape without combustion (for example, leakage of natural gas and the emissions of methane during coal mining and flaring during oil/gas extraction and refining).
- Process emissions, from production processes, from the use of greenhouse gases in products, and from non-energy uses of fossil fuel.
- Indirect emissions from the consumption of electricity.

The most important sector is power generation, which accounted for 65% of all energy-related emissions in 2009 (DEA, 2011a). Fugitive emissions from the energy sector accounted for around 8% in 2009.

Table 16: Energy subsectors (with IPCC emissions source classifications) included in the mitigation analysis

Energy sector	Subsector	IPCC emissions category	
		Fuel combustion (1A)	Fugitive emissions (1B)
Power	Electricity and heat production	1A1a	
Non-power	Petroleum refining	1A1b	1B2aiii4
	Coal mining and handling	1A1ci	1B1a
	Oil and natural gas	1A1cii	1B2
	Other energy industries	1A1cii	1B3

All of the mitigation measures and associated estimates of abatement potential and marginal abatement costs in the energy sector are presented in Table 32 for each of the three snapshots in time considered in this study: 2020, 2030 and 2050. The identifier associated with each measure is used in the legend of the MACC summaries per sector shown below. These identifiers are used consistently throughout the report and can be used to look up measures and associated values in Table 32.

A detailed discussion of GHG emission projections and mitigation opportunities for the energy sector is provided in Technical Appendix C: Energy Sector.

13.1 Power Sector

The analysis of mitigation potential in the power sector has sought consistency with the range of measures established under the IRP 2010 Policy-Adjusted Scenario (DoE, 2011). Therefore, the choice of mitigation measures was influenced by the technologies defined in this report. Most of the options analysed are advanced generation technologies and energy generation from renewable sources. The final set thus excludes options such as conversion or efficiency improvements of existing power plants.[8] Similarly, assumptions regarding costing and implementation rates flow directly from the IRP 2010 report. All assumptions are documented in detail in Technical Appendix C.

Some additional measures have however been added to the mix of measures considered in the energy sector mitigation analysis. These include power generated from methane capture at landfill sites, and energy from waste – measures not considered under the waste sector for this reason.

13.1.1 Marginal abatement cost curves

In 2020 (Figure 14), there are no measures that have a negative marginal abatement cost. The least expensive and also the measure with the highest abatement potential is wind power. Landfill gas (LFG), concentrated solar power and biomass provide small but still relatively inexpensive contributions to emissions savings (all under R450/tCO_2e). Using combined cycle gas turbines (CCGT) could save a further 3,000 ktCO_2e in 2020, while more expensive concentrated solar photovoltaic (PV) can deliver further significant emissions savings.

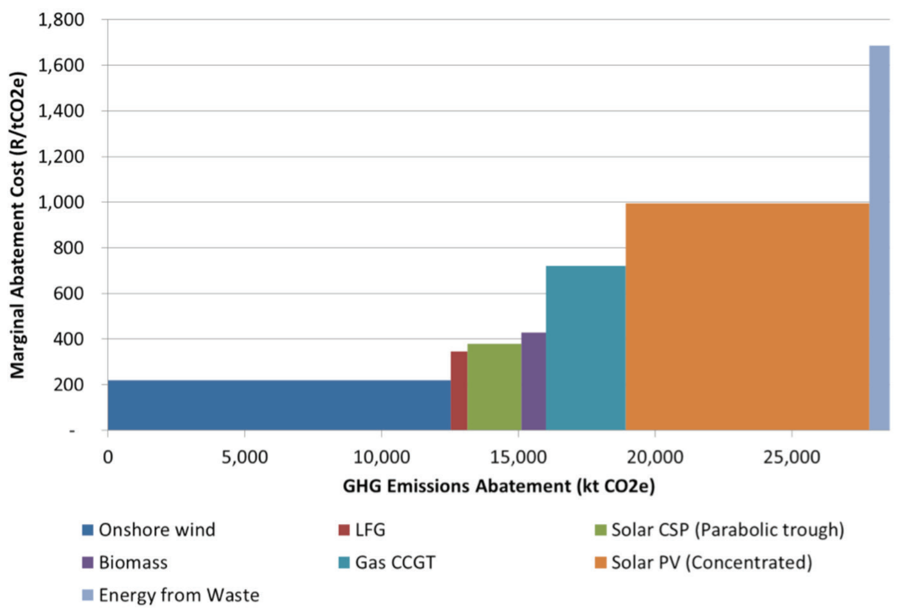


Figure 14: Marginal abatement cost curve for the power sector in 2020

8. Note that reference case emissions (WOM and WEM) projections for the power sector are aligned to the Integrated Resource Plan for Electricity 2010–2030 (DoE, 2011). The definition of projections in the power sector is based on planned capacity additions to meet demand (according to the IRP). Accordingly, the WOM projection is represented by coal generation. It assumes that all base-load capacity comes from coal with mainly gas turbines, using diesel, providing peaking capacity. Some pumped storage hydro is also included, but there is no wind, solar, or waste generation. The WEM projection is represented by the IRP 2010 base case to 2030. Post 2030, the relative shares of the plant capacity observed in 2030 are held at consistent proportions to 2050.

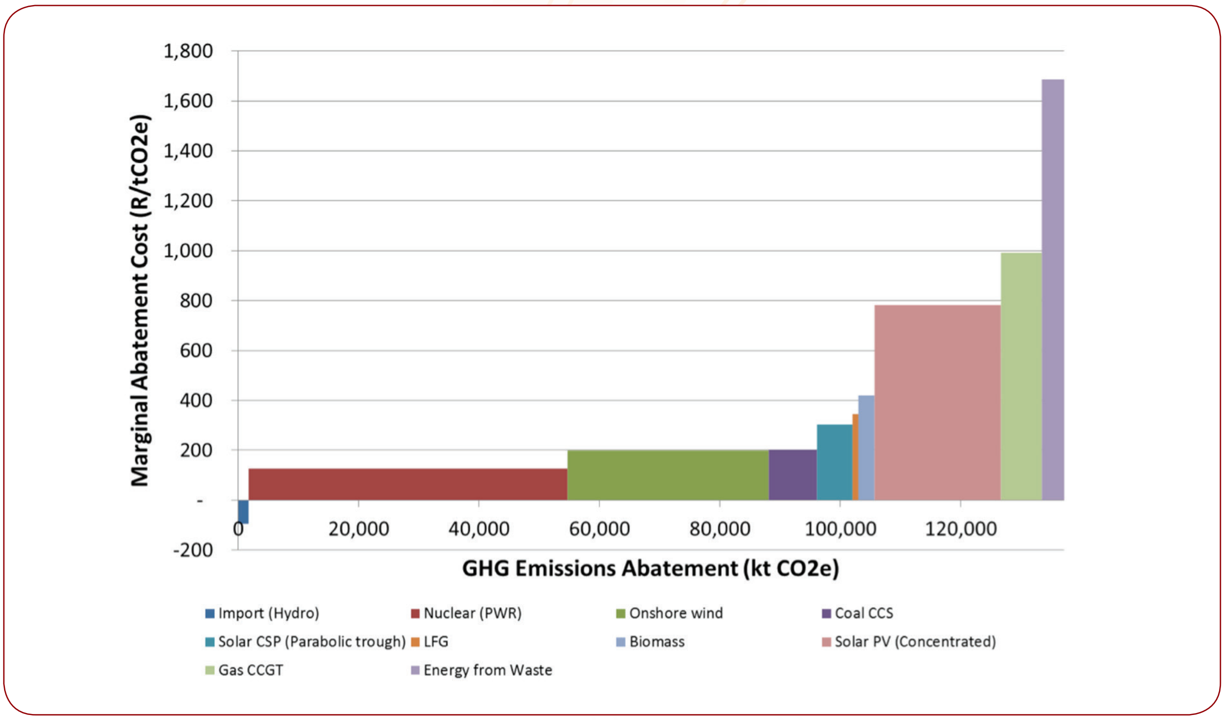


Figure 15: Marginal abatement cost curve for the power sector in 2030

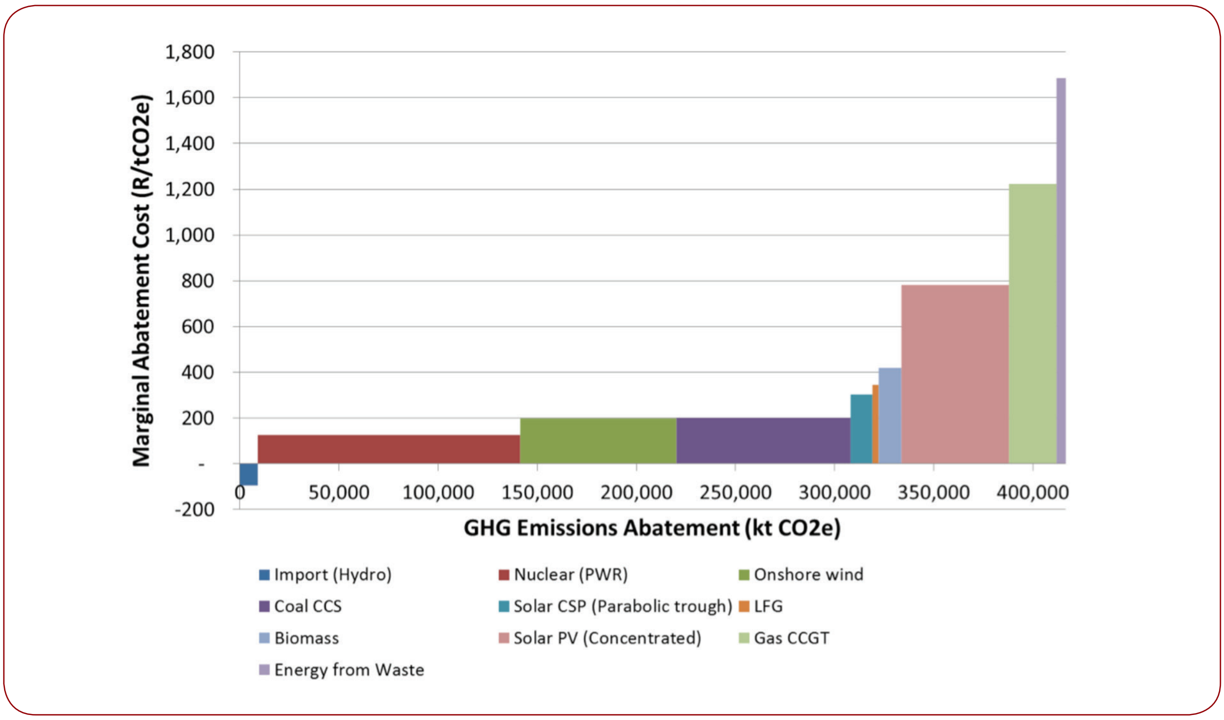


Figure 16: Marginal abatement cost curve for the power sector in 2050

In 2030 (Figure 15), three new technologies appear which together could deliver savings of more than 60,000 ktCO_2e. Imported hydropower could deliver abatement of 1,700 ktCO_2e,[9] at a negative marginal abatement cost, while nuclear power would provide abatement of a further 53,000 ktCO_2e and coal power plants with carbon capture and storage (CCS) could deliver 8,000 ktCO_2e[10]. The remaining technologies would deliver a similar abatement profile as in 2020, each technology delivering more abatement than before, with potential total abatement of 137 MtCO_2e.

Finally, in 2050 the total potential abatement for the WEM projection exceeds 400 MtCO_2e (Figure 16). The largest part of this is delivered by nuclear energy, followed by coal CCS and onshore wind. Imported hydro has a negative marginal abatement cost and is expected to deliver GHG savings of almost 9,000 ktCO_2e. The nuclear energy option provides the largest single abatement from any measure considered in this study (132 MtCO_2e). Despite the relatively large costs associated with building a nuclear plant, and because of the large mitigation potential, the marginal abatement costs are still lower than the other technologies.

13.2 Non-Power Sector

The non-power energy sector includes four subsectors comprising petroleum refining, coal mining and handling, oil and natural gas production and other energy industries. Summary MACCs for the non-power sector are shown below. MACCs have been developed for each of the three snapshots (2020, 2030 and 2050) and are presented in the sections which follow. Table 32 shows a summary of abatement potential and marginal abatement costs for all measures.

In all cases, detailed assumptions for each mitigation measure are documented in Technical Appendix C. These assumptions include:

- The emissions reduction potential and energy saving potential for each measure
- The costs, availability and lifetime of the mitigation measures
- The starting point, penetration rate and uptake of each measure

13.2.1 Marginal abatement cost curves

Marginal abatement cost curves for the non-power energy sector for the 2020, 2030 and 2050 snapshots are shown in Figure 17 to Figure 19.[11]

In 2020, a total of 4.5 MtCO_2e of abatement potential has been identified in the non-power sector. A total of 79% of the available mitigation potential (3.5 MtCO_2e) has a negative marginal abatement cost. In 2030, a total of 35.4 MtCO_2e of abatement potential has been identified; 17.6% (6.2 MtCO_2e) can be achieved through measures that have a negative marginal abatement cost. In 2050, a total of 50.6 MtCO_2e of abatement potential has been identified, 14% (7.3 MtCO_2e) can be achieved through measures which have a negative marginal abatement cost.

9. The price assumptions and timing of imported hydro power are optimistic. These costs are subject to negotiation, and might in reality be substantially higher.

10. The current marginal abatement cost estimates for nuclear power do not include fuel costs.

11. Note that the sectoral MACC summaries presented here do not include all mitigation measures that have been identified. Certain measures, which generally indicate very small mitigation potential but are associated with large marginal abatement costs, have been excluded as outliers in the impact assessment component of the study. These measures (including, for example, all measures for the oil and gas sector), have thus been excluded from the calculations on technical mitigation potential and national emission reduction pathways. In all cases, subsectoral MACCs including all measures are shown in the relevant sector appendices.

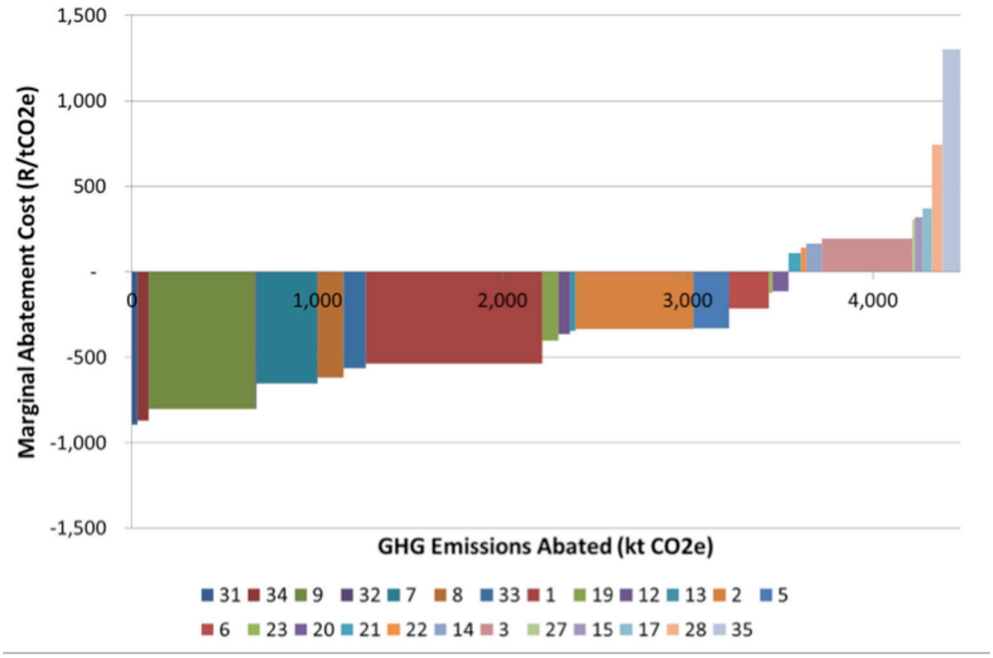


Figure 17: Marginal abatement cost curve for the non-power sector in 2020

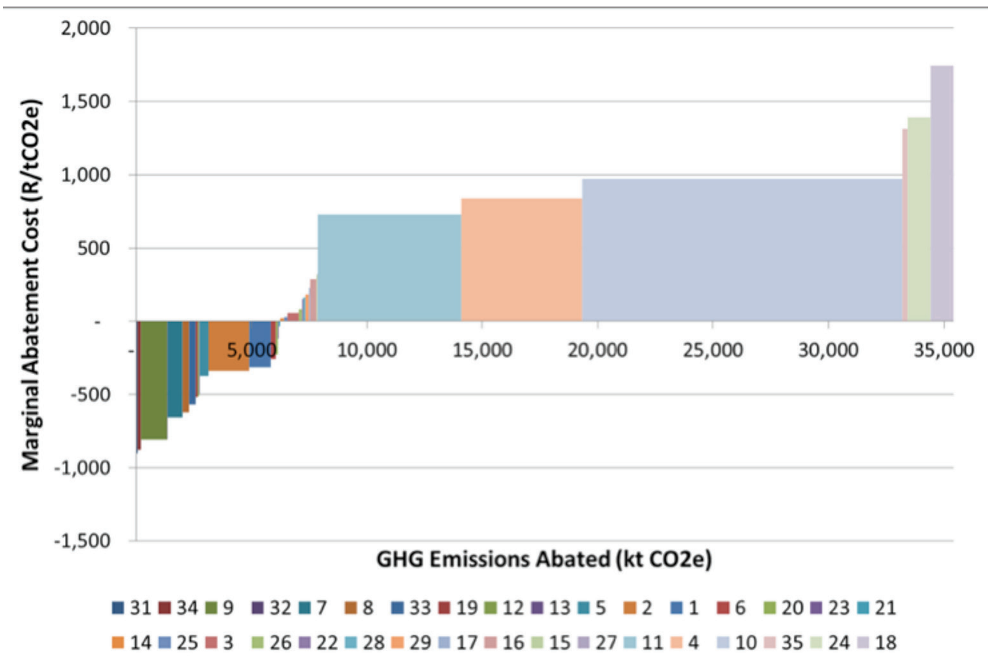


Figure 18: Marginal abatement cost curve for the non-power sector in 2030

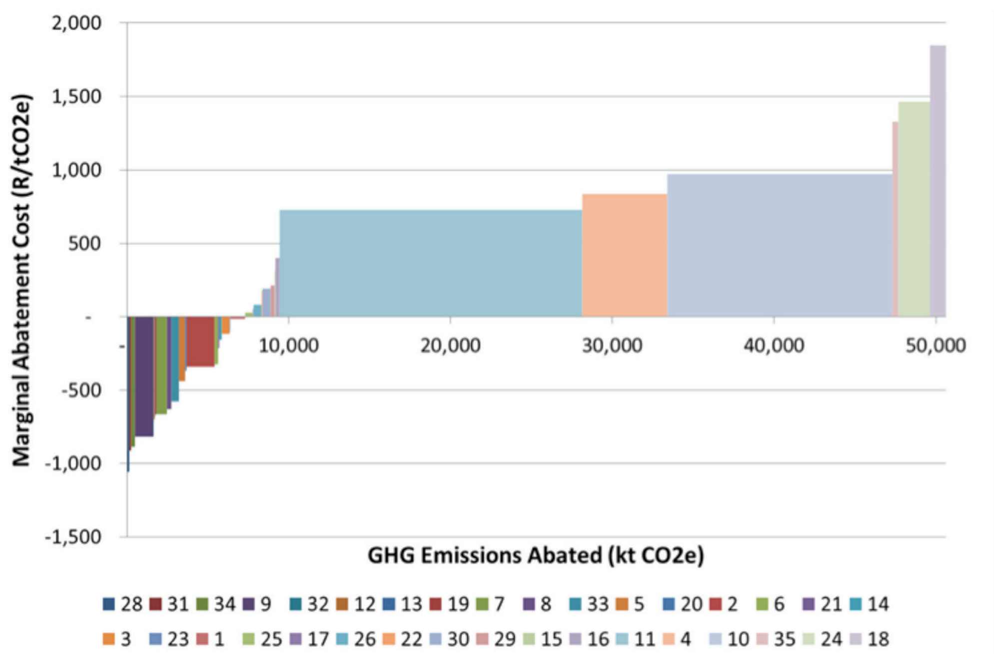


Figure 19: Marginal abatement cost curve for the non-power sector in 2050

13.2.1.1 Petroleum refining

The MACC analysis for petroleum refining makes the following general assumptions.

Production, energy and GHG emissions projections are split for existing and new production capacity. New capacity is assumed to be added in 2030 and 2050.

The measure of crude oil refined by existing refineries is based upon the "sources of crude oil for SAPIA members" provided in the 2010 SAPIA Annual Report (SAPIA. 2010). It is noted that this may not be an entirely accurate measure of oil refined due to changes in crude stock levels.

Sector growth is based upon supply estimates necessary to meet forecasted national liquid fuel demand in line with South African Government energy security targets, provided by TWG-M members and SAPIA members. New facilities with capacity of 250,000 barrels per day (bpd) of liquid fuel are assumed to be added in 2030 and 2050, adding an additional 500,000 bpd by 2050 (SAPIA, 2013).

With the aim of reducing emissions, the MACCs assume that 50% of refining facilities implement efficient onsite power energy production equipment by 2030 (for example, combined cycle gas turbines and combined heat and power) capable of meeting at least 60% of a refinery's electricity demand and reducing equivalent indirect emissions from imported power.

New refineries added in 2030 and 2050 are assumed to have lower emissions factors and to be more energy efficient compared to existing plants in 2010, reflecting the more modern design and adoption of best available technologies. Overall energy efficiency is assumed to improve by 20% compared to existing operations in 2010. These improvements are based on the assumption that all identified measures except CCS would be implemented in a new facility.

Carbon capture and storage (CCS) capital and operational costs for capture, transport and storage of CO_2 are based upon IEA benchmark costs (ETSAP, CCS, 2010). The additional annual costs of onshore storage assume US\$5/tCO_2e transport and US\$10/tCO_2e onshore storage cost. Storage offshore assumes US\$10/tCO_2e for transport and US\$20/tCO_2e for offshore storage cost. For CCS transport costs, 100km is selected as the default transport distance for CO_2 storage onshore within coal fields and 400km is selected for CO_2 storage in offshore geological formations. It is noted that some sources may be located closer or further than the selected distances. To compensate for this uncertainty, the high IEA cost estimate for CO_2 transport is selected as above.

CO_2 storage capacity is not considered to be limited for the levels of CO_2e storage proposed by the MACCs based upon assessments of onshore and offshore storage resources in South Africa. The estimated capacity of geological storage in South Africa is at least 150 Gt (150,000 Mt) of CO_2, for example. The storage potential lies mainly in the capacity of saline formations associated with the oil- and gas-bearing sequences in the Outeniqua, Orange and Durban/Zululand basins (Council for Geoscience, 2010). It should be emphasised that the estimated geological storage volume (150 Gt) is theoretical. Through extensive basin exploration and site characterisation activities, effective (actual) storage capacity can be established and may be lower than initial theoretical estimates.

For storage of CO_2 from existing plants, injection into either coal fields or saline formations can begin from 2025 and two (out of the four) refineries can be retrofitted. New refineries which come online in 2030 and 2050 have CCS installed (at 75% of the assumed benchmark capital cost for existing plants). The MACCs assume injection of CO_2 into saline reservoirs in offshore basins can begin as early as 2030.

The cost of refinery fuel gas (RFG) is based on the assumption that 5% of crude feedstock is converted into RFG and production costs are 2.5% of total refinery product energy consumption giving an RFG production cost of approximately R8/GJ in 2010.

The assumed fugitive emissions for an existing refinery are based upon data on flaring of RFG submitted to the Greenhouse Gas Inventory for South Africa (GHGI) by one oil refinery equivalent to 666 GJ/day in 2012. The equivalent sector fugitive GHG emissions assume the same emissions for all four existing conventional oil refineries (approximately 1% of total emissions). The assumptions and sector estimate for years 2009 to 2012 are shown in Table 18 of Technical Appendix C: Energy Sector. The minimise flaring and utilise flare gas as fuel mitigation measure aims to abate these fugitive emissions and assumes that a 75% reduction in emissions is technically possible for existing refineries. For new refineries it is assumed that a 75% reduction and improvement is built in to reflect improvements in design.

The lowest-cost mitigation options in 2020 (Figure 17) are the installation of advanced energy management and monitoring systems, improvement of existing steam generating boiler efficiencies and the improvement of process heater efficiencies. These all have negative marginal abatement costs of less than -R100/tCO_2e. Improved process control, improved heat exchanger efficiencies and recovery and utilisation of waste heat within the process all offer good abatement potential at varying cost levels. Minimising flaring activity and use of flare gas as fuel is the only option proposed to abate fugitive emissions and has a positive marginal abatement cost of over R300/tCO_2e.

The 2030 MACC assumes the availability and uptake of CCS technology in the sector (Figure 18, option 18). Implementing CCS on existing refineries can mitigate 998 kt CO_2e/year. The cost of retrofitting existing refineries with CCS is estimated at over R1,750/ tCO_2e. This is considerably more expensive compared to the cost of CCS in other sectors due to the complicated process, many sources of CO_2 (e.g. process emissions and flue gas emissions) and higher energy overhead required to capture the CO_2 (e.g. as much as 6.2 GJ of energy per tCO_2 captured). This is much more than the energy needed for CO_2 capture in power plants. Despite this high cost, implementing new refining capacity with CCS is capable of mitigating another 17% of the petroleum refining subsector emissions. The marginal abatement cost of including CCS in new refineries is estimated at R1,392/tCO_2e. Implementing efficient energy generation techniques, including CCGT and combined heat and power (CHP), mitigates an additional 5% of total subsector emissions at a cost of R289/ tCO_2e.

The rank order of mitigation measures remains the same in 2050 with the bulk of mitigation action achievable only at positive costs (i.e. above the x-axis in the MACC) as shown by Figure 19. Efficient onsite energy generation continues to show good mitigation potential. However, CCS remains the dominate mitigation option. The wider uptake of CCS in new refining capacity increases overall mitigation to 3,885 ktCO_2e/ year or 54% of the reference emissions from the petroleum refining subsector.

13.2.1.2 Coal mining and handling

For the purpose of GHG mitigation, the coal mining MACC calculations assume that 2.5% of total coal mining operations in South Africa can be equipped for coal mine methane recovery and use for power and/or heat generation by 2030, increasing to 5% by 2040. The analysis also assumes that 7.5% of total coal mining operations in South Africa can be equipped for coal mine methane recovery and destruction by flaring by 2030, increasing to 10% by 2040. It is noted that the TWG-M sector experts stated that this technology may only be applicable to mining operations at a depth in excess of 200 metres and only with certain site-specific conditions due to a low inherent methane concentration in coal seams in South Africa, resulting in sporadic volumes and fluctuating concentrations released.

For the implementation of biodiesel mitigation measures, the MACCs assume that a maximum of 50% of the mining fleet can be fuelled by biodiesel. This assumes that first generation 5% biodiesel (B5) is available from 2010 and second generation 50% biodiesel (B50) is available from 2020. In both cases, it is assumed that the infrastructure and planning is in place to ensure 50% of the fleet can be supplied.

Sector growth ranges from 2.2% per annum on average from 2010 to 2050, in line with the emissions projection assumptions and the underlying macroeconomic model.

In 2020 (Figure 17), there are several low-cost energy efficiency measures available with negative abatement costs, including the implementation of process, demand and energy management systems, optimisation of existing electric motor systems (with improved controls and variable-speed drives (VSDs) where suitable), installation of energy efficient lighting, installation of energy-efficient electric motor systems (replacing old inefficient units) and the improvement of mine haul and transport energy efficiency (via training, behaviour change and improved transport management and operation). There is also potential for the use of first generation biodiesel (B5) for transport and handling equipment to reduce emissions from transport albeit at a higher positive abatement cost.

In 2030 (Figure 18) low-cost energy efficient measures continue to show the greatest potential for mitigation, capable of abating 11% of total emissions from coal mining when combined. A proportion of fugitive emissions (equal to 5% of sector total emissions) can be abated by the assumed implementation of coal mine methane recovery and destruction by flaring, and by coal mine methane recovery and use for power and/or heat generation at relatively low marginal abatement costs of R30 and R83/tCO_2e, respectively. The development of onsite clean power generation also contributes to GHG mitigation (for example, solar PV) by replacing imported power and reducing indirect emissions. However, this measure has a high marginal abatement cost of over R1,300/tCO_2e.

In 2050 (Figure 19) notably significant and low-cost mitigation options include the implementation of process, demand and energy management systems, optimisation of existing electric motor systems and installation of energy-efficient electric motors. These are all energy efficiency measures which reduce electricity consumption and associated indirect emissions. The availability of second generation biodiesel to supply 50% of the coal mining fleet can cut total fleet emissions by half, and reduce coal mining subsector-wide emissions by 6%, at a modest positive abatement cost.

13.2.1.3 Oil and Natural Gas

Based upon forecasted growth from the subsector representative, existing gas exploration and production is expected to cease in 2020. No production is planned beyond 2020 so only measures for the 2020 MACC are presented. The marginal abatement costs for the mitigation measure identified for this sector are high in comparison to other sectors, due to the very short technology lifetime of a maximum of seven years (over which to annualise the investment cost) and the relatively low absolute mitigation potential. Due to the low abatement potential and high marginal abatement costs, the oil and natural gas mitigation measures are not included in the MCA analysis and are hence also excluded from the technical mitigation potential and emissions reduction pathways shown in the rest of the main report.

13.2.1.4 Other energy industries

The MACC analysis for other energy industries makes the following assumptions.

Production, energy and GHG emissions projections are split for existing and new production capacity (added in 2030, 2040 and 2050).

The underlying production, energy consumption and emissions data is based upon data submitted by industry stakeholders to the GHGI and data submitted directly by the stakeholders from the other energy industries sector.

Sector growth is based upon energy supply estimates required to meet forecasted national liquid fuel demand in line with South Africa's Energy Security Master Plan targets, provided by TWG-M members and SAPIA members. New facilities with capacity of 80,000 barrels per day (bpd) of liquid fuel are assumed to be added in 2030, 2040 and 2050, adding an additional 240,000 bpd by 2050 (SAPIA, 2013).

New facilities added in 2030, 2040 and 2050 are assumed to have lower emissions factors and to be more energy efficient, reflecting a more modern design and adoption of best available technologies. Overall carbon intensity is assumed to decrease by 30% compared to existing operations in 2010. The improvement has been allocated proportionally to fugitive, fuel/energy emissions and electricity emissions. These improvements are based on the assumption that all identified measures would be implemented in a new facility (except CCS).

CCS capital and operational costs for capture, transport and storage of CO_2 are based upon IEA benchmark costs (ETSAP, CCS, 2010). The additional annual costs of onshore storage assume US$5/t$CO_2$e transport and US$10/tCO_2e onshore storage cost. Storage offshore is assumed to be possible by 2030 and assumes additional annual costs of US$10/t$CO_2$e for transport and US$20/tCO_2e for offshore storage cost. For CCS transport costs, 100km is selected as the default transport distance for CO_2 storage onshore within coal fields and 400km is selected for CO_2 storage in offshore geological formations. It is noted that some sources may be located closer or further than the selected distances. To compensate for this uncertainty, the high IEA cost estimate for CO_2 transport is selected.

CO_2 storage capacity is not considered to be limited for the levels of storage proposed by the MACCs based upon assessments of onshore and offshore storages resources in South Africa. The estimated capacity of geological storage in South Africa is at least 150 Gt (150,000 Mt) of CO_2. The storage potential lies mainly in the capacity of saline formations associated with the oil- and gas-bearing sequences in the Outeniqua, Orange and Durban/Zululand basins. Offshore storage assumes storing in the Zululand Basin with an estimated effective capacity of 460 million tonnes located within 400 km from South Africa's major emissions sources (Council for Geoscience, 2010). It should be emphasised that the estimated geological storage volume is theoretical. Through extensive basin exploration and site characterisation activities, the effective (actual) storage capacity can be established and may be lower than initial estimates.

Injection of process CO_2 emissions from existing plants into onshore coal fields can begin from 2025. New plants which come online in 2030, 2040 and 2050 have CCS installed (at a cost of 60% of the assumed benchmark cost for existing plants). The MACCs assume injection of CO_2 for new facilities into saline reservoirs in offshore basins can begin as early as 2030.

The MACC for 2020 (Figure 17) shows the wide portfolio of mitigation measures that are available. All but one of the identified measures has negative marginal abatement costs. Improved heat systems (using waste heat for maximising existing onsite steam turbine electricity generation capacities), improved existing electric motor system controls and VSDs (matching motor revolutions with load requirements and thus minimising electricity use) and the installation of energy efficient utility motor systems (for example, lighting, compressed air and refrigeration) all have costs of less than -R600/tCO_2e. Waste gas recovery has a positive cost due to the much higher capital cost and lower potential for uptake relative to other energy efficiency measures proposed.

The annual mitigation potential is transformed in 2030 due to the inclusion of CCS technologies to capture and store process CO_2 emissions in existing and new production facilities. The mitigation potential of CCS dwarfs the potential of the other mitigation options available. The 2030 MACC (Figure 18, option 10) shows that CCS for process emissions from existing plants has the largest mitigation potential of 19 $MtCO_2e$ in 2030 at a marginal abatement cost of R838 and R973/tCO_2 for storage of CO_2 in coal fields onshore and in offshore saline formations, respectively. The lower marginal abatement cost CCS option for implementing in new facilities has a lower cost of R729/tCO_2 (assuming transport and storage costs for offshore storage) and has potential to mitigate an estimated 6.2 $MtCO_2e$ in 2030.

As the production of synthetic fuel increases from new facilities built after 2030, so does the potential uptake of CCS resulting in 18.5 $MtCO_2e$ of process emission mitigated in 2050 (Figure 19). Combined, CCS technologies can potentially mitigate 38 $MtCO_2e$. The marginal abatement costs of the CCS measures remain constant compared to 2030, whilst the marginal abatement costs of the energy efficiency measures drop as assumed underlying energy prices and cost savings increase over time.

13.3 Technical Mitigation Potential

A summary of technical mitigation potential in 2020, 2030 and 2050 for all sectors and subsectors covered in the assessment of the energy sector is shown in Table 17 below.

In calculating total technical mitigation potential for the energy sector, abatement estimates for the other energy industries and petroleum refining sectors show only the impact of measures which can be implemented in the sector. The estimates do not show savings which might occur due to a reduced need for new capacity in the sector if demand for liquid fuel is reduced as a result of successful implementation of mitigation options in the transport sector. If all transport mitigation options were to be successfully implemented then emissions in the energy sector could be reduced by a further 20.3 $MtCO_2$ in 2050. This interaction between the transport and energy sectors is fully taken account of in the national level analysis carried out in Chapter V of this report.

Table 17: Summary of technical mitigation potential for the energy sector, including a breakdown by sector and subsector and showing results for 2020, 2030 and 2050 (ktCO$_2$e)

Sector	Subsector	2020	2030	2050
Power		28,585	137,149	416,555
% of total mitigation potential		**86.47%**	**79.48%**	**89.16%**
Non-power	Coal mining	385	1,284	3,112
	Oil and gas[12]	0	0	0
	Other energy industries	3,529	31,181	43,630
	Petroleum refining	558	2,951	3,891
	Subtotal	**4,472**	**35,415**	**50,632**
	% of total mitigation potential	**13.53%**	**20.52%**	**10.84%**
Total mitigation potential		**33,057**	**172,565**	**467,186**

In summary, abatement options for the power sector dominate abatement potential for the energy sector, accounting for between 79% and 89% of total mitigation potential. The second largest contributor is the other energy industries sector, representing 3.5, 31.2 and 43.6 MtCO$_2$e in 2020, 2030 and 2050, respectively.

Mitigation potential expressed relative to the reference case WEM projection is shown for each sector and subsector in Table 18. Results indicate an 8.8%, 34.9% and 49% reduction relative to the WEM projection in 2020, 2030 and 2050, respectively.

Table 18: Percentage reduction in reference WEM emissions for the energy sector, assuming all technical mitigation potential is implemented

Sector	2020	2030	2050
Power	7.6%	27.8%	43.7%
Non-Power	1.2%	7.2%	5.3%
Energy Sector Total	**8.8%**	**34.9%**	**49.0%**

A similar analysis conducted for the sub-sectors which comprise the non-power energy sector is shown in Table 19. Results indicate a total mitigation potential of 7%, 43% and 42% relative to the reference case projection. The vast majority of these potential savings originate from the other energy industries subsector.

Table 19: Percentage reduction in reference WEM emissions for the non-power energy sector, assuming all technical mitigation potential is implemented

Sector	2020	2030	2050
Coal Mining	0.6%	1.5%	2.6%
Oil and Gas	0.0%	0.0%	0.0%
Other Energy Industries	5.5%	37.6%	36.1%
Petroleum Refining	0.9%	3.6%	3.2%
Non-Power Energy Sector Total	**7.0%**	**42.7%**	**41.9%**

13.4 WAM Projection

Assuming that all available mitigation measures are implemented (that is, that all technically-feasible mitigation potential is implemented according to estimates provided in the sectoral MACCs), the resulting WAM abatement projection for the energy sector is shown in Figure 20. A similar graphic showing a breakdown between subsectors within the non-power energy sector is shown in Figure 21. Note that emissions from the power sector have been reallocated to end users and electricity related emissions savings have been adjusted for the progressive reduction of carbon intensity of the electricity supply over time.

12. Mitigation potential for measures in the oil and gas sector have been excluded as outliers from this portion of the analysis. Please refer to Technical Appendix C: Energy Sector for details of abatement and marginal abatement costs.

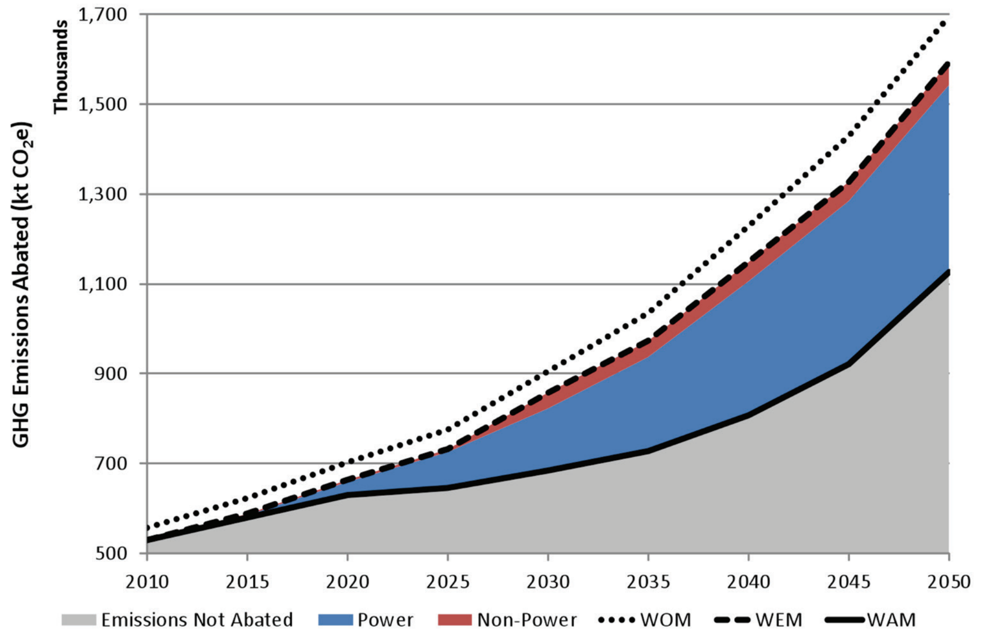


Figure 20: WAM scenario for the energy sector, showing a breakdown between the power and non-power sectors. Emissions from the power sector have been reallocated to end users and electricity related emissions savings have been adjusted accordingly. Reference case WOM and WEM emission projections are also shown.

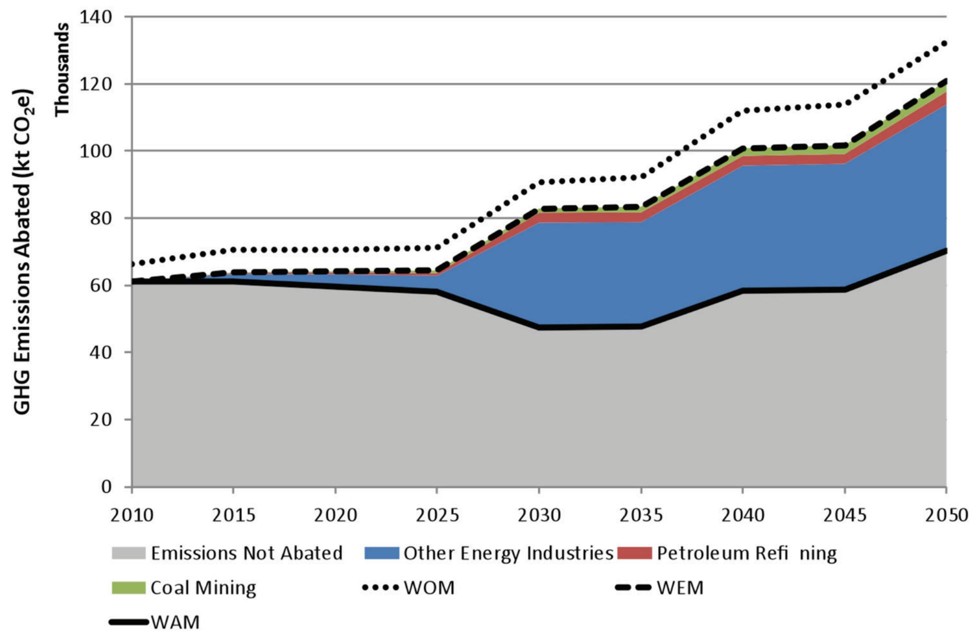


Figure 21: WAM scenario for the non-power sector, showing a breakdown between subsectors. Emissions from the power sector have been reallocated to end users and electricity related emissions savings have been adjusted accordingly. Reference case WOM and WEM emission projections are also shown.

14. The Industry Sector

This chapter identifies the GHG emissions mitigation potential for the South African industry key sector. The mitigation potential is presented in the form of marginal abatement cost curves (MACCs) for the years 2020, 2030, and 2050 ranking available mitigation options in terms of their marginal abatement cost. The mitigation potential presented is considered to be technically achievable assuming that all identified mitigation technologies have been technically proven or will be proven prior to becoming available. The GHG emissions sources for the sector include IPCC emissions sector 1A2, combustion emissions from manufacturing industries and construction, and the relevant parts of IPCC sector 2, industrial process emissions. Mitigation opportunities for emissions associated with fuel combustion in residential and non-residential (commercial and institutional) buildings, IPCC sector 1A4, are also included in this chapter at the request of the TWG-M. The industry sectors examined and sources of emissions, as classified by the IPCC categories, are listed in Table 20 below.[13]

Table 20: Industrial subsectors (with IPCC emissions source classifications) included in the mitigation analysis

Industry sectors (and buildings)	Subsector	IPCC emissions category	
		Fuel combustion (1A)	Process Emissions (2)
Metals Production	Iron and steel production	1A2a	2C1
	Ferroalloy production	1A2a	2C2
	Primary aluminium production	1A2b	2C3
Minerals Production	Cement production	1A2f	2A1
	Lime production	1A2f	2A2
Chemicals Production	Chemicals production (including ammonia, nitric acid, carbide, titanium dioxide, petrochemical and carbon black production)	1A2c	2B (including 2B1, 2B2, 2B5, 2B6 2B8)
Mining	Underground and surface mining (non-coal products)	1A2i	
Buildings	Commercial/institutional	1A4a	
	Residential	1A4b	
Other	Pulp and paper production	1A2d	

13. Note that reference case projections cover all subsectors under IPCC emissions sector 1A2, combustion emissions from manufacturing industries and construction, and are discussed in Technical Appendix D. Only a subset of those sectors has been covered in the mitigation potential assessment discussed below, due to data availability.

Reference GHG emissions projections are based on all activities identified in the national GHGI for 2010 and mitigation opportunities are presented for all sectors listed in Table 20. Emissions from the use of electricity have been allocated to the end use sectors. GHG mitigation opportunities are presented that cover emissions from three separate sources, described below:

- Emissions from industrial processes, from the use of greenhouse gases in products, and from non-energy uses of fossil fuel.
- Emissions from the use of fuels in stationary combustion. Emissions result from the combustion of fuels in order to provide heat or mechanical work.
- Indirect emissions from the consumption of electricity, where fossil fuels are consumed in order to generate the electricity.

A detailed assessment of mitigation and the key assumptions driving these estimates is provided in Technical Appendix D: Industry Sector. The summaries provided below are drawn directly from that appendix.

All of the mitigation measures and associated estimates of abatement potential and marginal abatement costs in the industry sector are presented in Table 32 for each of the three snapshots in time considered in this study: 2020, 2030 and 2050. The identifier associated with each measure is used in the legend of the MACC summaries per sector shown below. These identifiers are used consistently throughout the report and can be used to look up measures and associated values in Table 32.

In all cases, detailed assumptions for each measure are documented in the technical appendix. These assumptions include:

- The emissions reduction potential and energy saving potential for each measure
- The costs, availability and lifetime of the mitigation measures
- The starting point, penetration rate and uptake of each measure

14.1 Sectoral Growth Assumptions

A key assumption driving the reference emissions projections and hence the estimates of abatement potential is the sector growth rate. These growth rates are based on the moderate growth rate defined by National Treasury. The moderate growth scenario forecasts real GDP growth of 4.2% per annum over the medium-term and 4.3% per annum over the long-term (2021–2050) according to the 2012 Medium Term Budget Policy Statement (National Treasury, 2012). In agreement with guidance provided by the TWG-M, all sector growth rates are aligned to the national growth target. For each of the subsectors considered within the metals sector, the average growth rates between 2010 and 2050 are shown in Table 21.

Table 21: Average GDP growth rates for industry subsectors (per annum)

Sector	Subsector	Sectoral growth rate
Metals	Aluminium production	4.2%
	Ferroalloys production	4.2%
	Iron and steel production	3.9%
Minerals	Cement production	4.2%
	Lime production	4.2%
Chemicals	Chemicals production	4.1%
Mining	Surface and underground mining	3.8%–4.3%[14]
Buildings	Residential	Not based on macro-economic modelling[15]
	Commercial/institutional	
Other	Pulp and paper production	3.8%

As stated above, GDP growth in individual industry subsectors is aligned to targeted levels of national economic growth and projections of growth in individual sectors driven by the INFORUM model. It is noted that actual growth in the manufacturing and mining sectors has been lagging overall GDP growth for some time and is likely to continue to do so in the future, particularly in the period to 2020. As both the process emissions and those arising from energy use allocated to each sector are proportional to the GDP growth, the overestimation of emissions in these sectors as a result of the methodology needs to be taken into account when interpreting the estimates of mitigation potential and marginal abatement costs provided below.

14.2 Metals Sector

14.2.1 Marginal Abatement Cost Curves

Marginal abatement cost curves for the metals sector for the 2020, 2030 and 2050 snapshots are shown in Figure 22 to Figure 24.

In 2020 a total of 12.2 $MtCO_2e$ of abatement potential has been identified in the metals sector. A total of 39% of the available mitigation potential (4.8 $MtCO_2e$) can be achieved through measures which have a negative marginal abatement cost. In 2030, a total of 35.9 $MtCO_2e$ of abatement potential has been identified, 48% (17.2 $MtCO_2e$) of which can be achieved through measures with a negative marginal abatement cost. In 2050, a total of 86.5 $MtCO_2e$ of abatement potential has been identified, 49% (42 $MtCO_2e$) of which can be achieved through measures which have negative marginal abatement costs.

14. Sector growth ranges from 3.8 to 4.3% per annum on average from 2010 to 2050 for various mined products, in line with the emissions projection assumptions and the underlying macroeconomic model.

15. The emissions projections for the commercial sector are based on building stock growth and historical energy activity data in the sector."

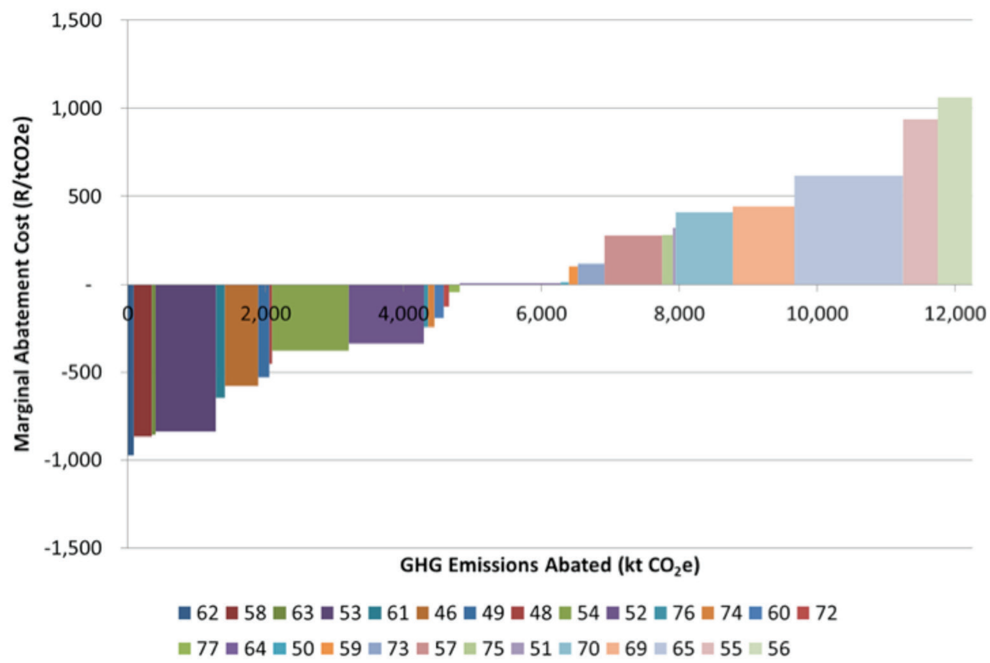


Figure 22: Marginal abatement cost curve for the metals sector in 2020

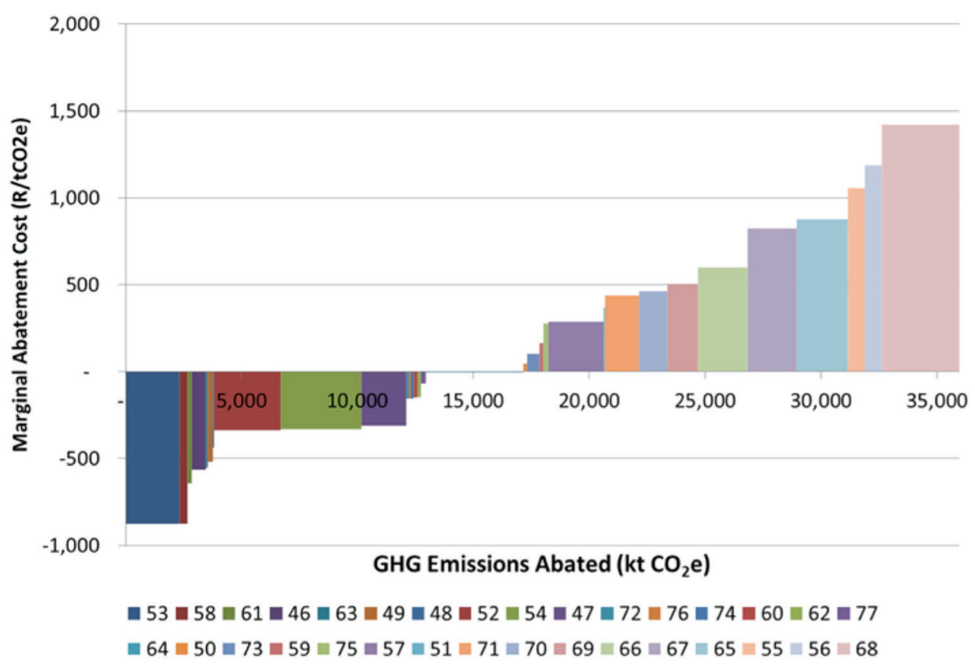


Figure 23: Marginal abatement cost curve for the metals sector in 2030

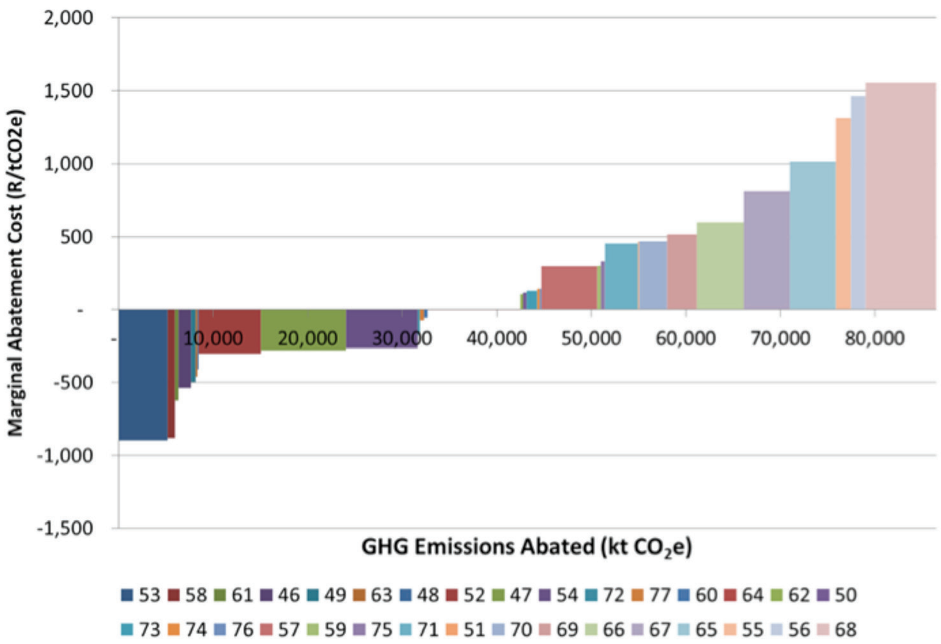


Figure 24: Marginal abatement cost curve for the metals sector in 2050.

14.2.1.1 Primary aluminium production

For the objective of reducing energy consumption and GHG emissions, the mitigation analysis assumes that a 20% production switch from primary operations to secondary production techniques is possible by 2030 by increasing recycling.

The process emission factors applied for prebake production technology are based upon IPCC guidelines and are in line with the South Africa GHGI assumptions. It is noted that these are higher than the emission factors proposed by the TWG-M members representing the primary aluminium sector.

The scope for emissions reductions in primary aluminium production is not as extensive when compared to the steel making and ferroalloy industries. This is largely due to the fact that 100% of the industry in South Africa uses centre worked prebake (CWPB) technology with point feeding – the most energy efficient option available. Further, significant measures have already been taken to reduce process emissions caused by the anode effect. Also, a large proportion of production facilities already uses best available production techniques and advanced process controls.

Sector growth is assumed to be 4.2% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

In 2020, the total abatement potential amounts to just over 844 ktCO_2e (4% of the WEM emissions projection) with best process selection for primary aluminium smelting and advanced process control techniques offering the best scope for mitigation at the least marginal abatement cost.

In 2030, the progressive switch from primary production techniques and replacement with secondary production (option 47 in Table 32) contributes to total abatement potential of 3 MtCO_2e/year (11% of the reference WEM emissions projection for the primary aluminium production subsector), as shown in Figure 23. Secondary aluminium production using recycled scrap raw material requires significantly less energy compared to primary aluminium production and offers mitigation potential of almost 1.9 MtCO_2e/year at a negative marginal abatement cost of -R311/tCO_2e.

Switching to less electricity intensive secondary production techniques in 2050 increases the mitigation potential (Figure 24). Of course, shifting from the primary to the secondary production pathway is limited by access to scrap aluminium and would take place gradually as production facilities reach the end of their lives and are replaced.

12.1.1.2 Iron and steel production

To reduce sector emissions, it is assumed that 40% of crude steel can be produced from the secondary production route of electric arc furnaces (EAF) and scrap material by 2030 (an increase of 11% from 29% in 2010). This measure assumes a gradual shift from the primary production pathway of blast furnace (BF) and basic oxygen furnace (BOF) over a 20-year period starting in 2010. It is also assumed that the increased demand for scrap metal can be met. Again, for the purposes of abatement, it is assumed that 40% of crude steel is produced from the smelting of direct reduced iron (DRI) within EAFs by 2030 (an increase of 27% from 13% in 2010). The increase in DRI production assumes that the necessary additional supplies of gas are available. The remaining 20% of production in 2030 is assumed to come from the BF and BOF route (a reduction of 38% from 58% of total production in 2010).

Sector growth is assumed to be 3.9% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

Energy efficiency measures, such as implementation of BOF waste heat and gas recovery, energy monitoring and management system, and top gas pressure recovery turbines are the lowest-cost measures in 2020 (Figure 22). These measures have negative marginal abatement costs due to their significant energy cost saving potential and relatively low capital cost. The most significant and low-cost abatement option is to shift from traditional energy-intensive primary production processes of iron ore reduction using blast furnaces to secondary techniques using EAFs and maximising scrap raw material. This has the potential to mitigate some 1,465 ktCO_2e in 2020 (although the uptake of this measure is limited by the availability and price of scrap metal).

Replacing further production from the counterfactual BF and BOF route to DRI and EAF could mitigate over 1,700 ktCO_2e in 2020 (for example, by implementing Midrex and HYL technologies that produce DRI from pellets by gas-based direct reduction in a shaft furnace). However, this has an abatement cost of over R410/tCO_2e and uptake may be limited by access to natural gas or coke oven gas. Building state-of-the-art power plants has significant abatement potential (by installing advanced, high-efficiency power generation equipment to use waste process gas to generate electricity and thus replace grid power). However, this also has a positive abatement cost of over R600/tCO_2e.

The wider portfolio of available mitigation technologies in the iron and steel sector in 2030 (Figure 23) is apparent in the introduction of DRI – ULCORED (a more cost effective DRI production technique) and CCS technologies (capable of capturing and storing process and fuel combustion CO_2 emissions). The total mitigation potential of 19,500 ktCO_2e in 2030 or 41% of total projected emissions is considered to be technically achievable. The DRI and EAF alternative to the BF and BOF steelmaking pathway has a combined abatement potential of almost 8,200 kt CO_2e in 2030 at marginal abatement costs of less than R505 and -R4/tCO_2e, respectively. Capturing CO_2 at the blast furnace (for example, by implementing top gas-recycling blast furnace and post-combustion technologies has the potential to abate over 4,260 ktCO_2e in 2030, at a cost of R600 and R825ktCO_2e, respectively (top gas-recycling blast furnace also saves energy and is therefore the cheaper option). Implementing state-of-the-art power plant with CCS is the most expensive mitigation option at over R1,400/tCO_2e.

In 2050 (Figure 24), retrofitting CCS to blast furnaces combined with top gas-recycling blast furnaces offers a realistic solution for maximising energy efficiency whilst minimising emissions from the blast furnace primary production pathway with marginal abatement costs of R600/tCO_2e. However, CCS for power plants is more costly and emphasises the associated high investments costs. The clear leaders in terms of abatement potential are the shift away from energy intensive primary techniques to the more energy efficient secondary techniques (EAFs and use of scrap metal) and increased production using DRI. The option with the highest marginal abatement cost is implementing state-of-the-art power plants (with and without CCS).

14.2.1.3 Ferroalloys production

The share of furnace technology in operation across the sector is assumed to be 40% semi-closed and 60% closed type in 2010. For the objective of increasing energy efficiency and GHG abatement, the analysis assumes that a production switch of 25% from semi-closed to the more energy efficient closed furnace type is technically possible by 2030, giving a split of 15% semi-closed and 85% closed. The mitigation analysis also assumes a 20% switch from carbon reductants (for example, coke and coal) to biocarbon sources (for example, charcoal and woodchips) is possible by 2030.

Sector growth is assumed to be 4.2% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

Several low-cost mitigation options are available in 2020 (Figure 22). The replacement of submerged arc semi-closed furnaces with closed type furnaces offers the lowest marginal abatement cost to reduce emissions by 877 ktCO_2e/year at a marginal abatement cost of -R840/tCO_2e. Implementation of best available production techniques and waste gas recovery and power generation (on closed furnace types) also offer negative marginal abatement cost options to reduce carbon intensity.

In 2030 (Figure 23), the deployment of waste heat recovery and power generation projects adopting Rankine Cycle and Organic Rankine Cycle technologies is unlikely as other low-cost effective energy efficiency options are available. The option to use bio-carbon reductants instead of coal/coke offers a zero-carbon solution capable of abating almost 2,400 $ktCO_2e$/year at a relatively modest marginal abatement cost of R290/tCO_2e.

By 2050 (Figure 24), the total annual mitigation potential from the ferroalloys sector has increased to over 30 million tCO_2e/year or 28% of the reference WEM emissions projection with the notable options being the replacement of submerged arc semi-closed furnaces with the closed type, implementation of best available production techniques and using CO_2 gas from closed furnaces to generate power onsite and reduce electricity imports (and associated indirect emissions).

14.3 Minerals Sector

14.3.1 Marginal Abatement Cost Curves

Marginal abatement cost curves for the minerals sector for the 2020, 2030 and 2050 snapshots are shown in Figure 25 to Figure 27.

In 2020, a total of 1.6 $MtCO_2e$ of abatement potential has been identified in the minerals sector. A total of 67% of the available mitigation potential (1 $MtCO_2e$) can be achieved through measures which are cost effective (that is, their marginal abatement cost in R/tCO_2e is negative). In 2030, a total of 4.5 $MtCO_2e$ of abatement potential has been identified, 57% (2.5 $MtCO_2e$) can be achieved through measures which have a negative marginal abatement cost. In 2050, a total of 22 $MtCO_2e$ of abatement potential has been identified, 24% (5.2 $MtCO_2e$) of which can be achieved through measures which have a negative marginal abatement cost.

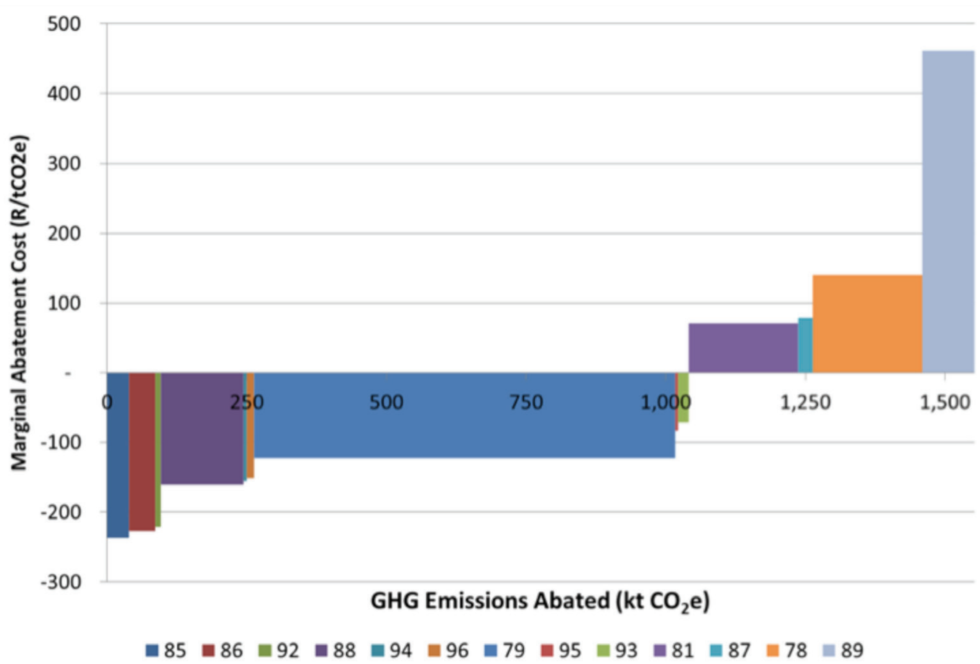


Figure 25: Marginal abatement cost curve for the minerals sector in 2020

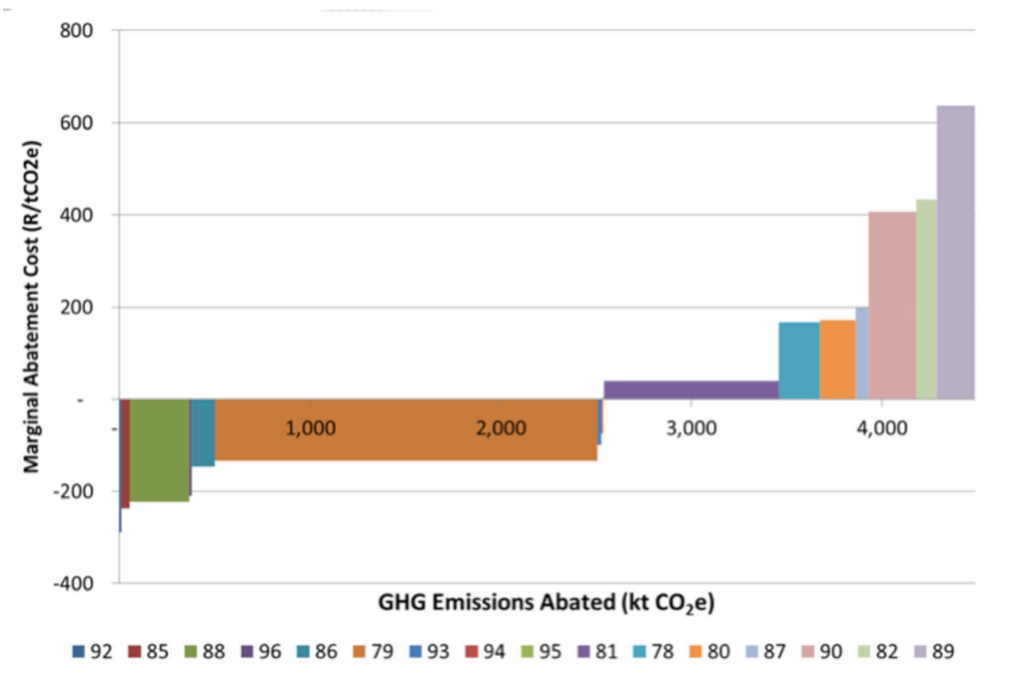


Figure 26: Marginal abatement cost curve for the minerals sector in 2030

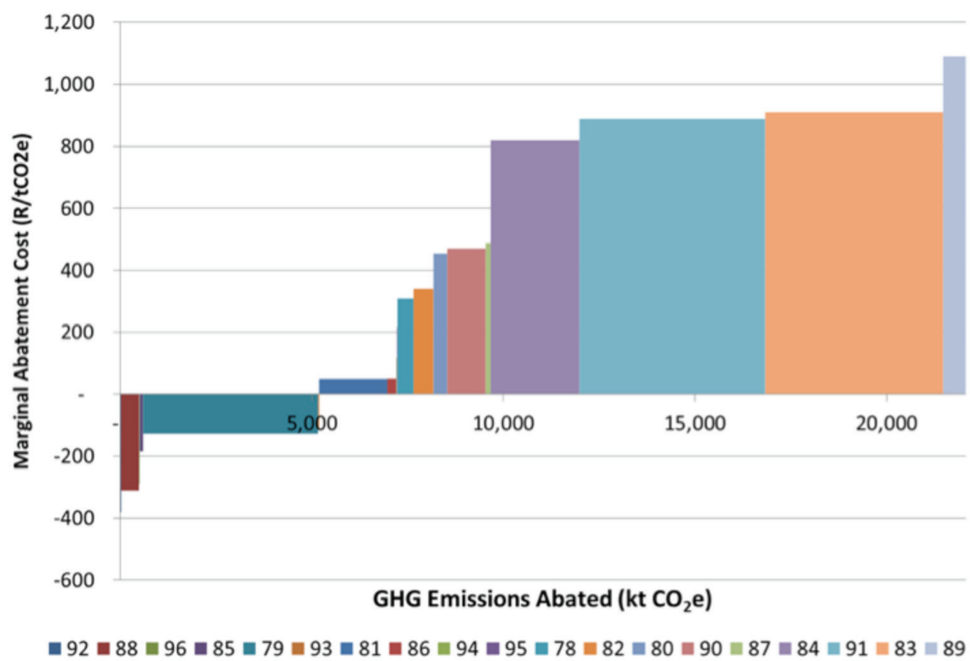


Figure 27: Marginal abatement cost curve for the minerals sector in 2050

14.3.1.1 Cement production

For the objective of reducing emissions, the analysis assumes that a 25% fuel switch from fossil fuels to zero-carbon waste and biomass fuels is technically possible by 2030 (the proportional split of fuel is assumed to be 99% fossil and 1% waste/biomass in 2010). The analysis assumes a reduction in clinker content of cement is possible from 69% on average in 2010 down to 60% on average by 2030. The MACCs also assume that 2.5% of total cement production can be supplied by geopolymer production techniques by 2040. Sector growth is assumed to be 4.2% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

The abatement option with the lowest marginal abatement cost in 2020 (Figure 25) is the reduction of clinker content of cement products to 66% on average (capable of mitigating 754 ktCO_2e/year at a negative marginal abatement cost of -R122/tCO_2e). Improved electric motor system controls and VSDs and advanced energy management systems also have negative marginal abatement costs of -R227 and R -237/tCO_2e, respectively.

By 2030 (Figure 26), more technologies become available, thereby increasing the total annual mitigation potential. These include the implementation of waste heat recovery from kilns and coolers and the production of geopolymer cement (replacing standard Portland cement), with marginal abatement costs which range from R172/tCO_2e to over R434/tCO_2e, respectively. Using waste materials as fuel also shows good potential with a lower marginal abatement cost compared to 2020.

By 2050 (Figure 27), the availability of CCS technologies including back-end chemical absorption and oxyfuel (with marginal abatement costs of R910 and R820/tCO_2e, respectively) offers a much wider opportunity to reduce emissions of over 15 million tCO_2e/year in total compared to the reference case WEM projection.

14.3.1.2 Lime production

For the objective of reducing emissions, the analysis assumes that 90% of fuel consumed in 2010 is from fossil sources and 10% is waste/biomass fuel. By 2040, a 40% fuel switch from fossil fuel to zero-carbon waste and biomass fuels is assumed to be technically possible (that is, by 2040, 50% of fuel is from fossil sources and 50% from waste/biomass). The MACCs also assume that by 2050, 80% of all kilns are vertical/parallel flow regenerative kiln (PFRK) types and the remaining 20% are rotary/other type (in 2010, it is assumed that 100% are of rotary or other non-vertical kiln types).

Sector growth is assumed to be 4.2% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

In 2020, the identified technical mitigation potential for lime production is almost 295 ktCO_2e/year or 7% compared to the WEM emissions projection scenario. The MACC displayed in Figure 25 shows that implementing shaft preheaters is the most significant option, with negative abatement costs of -R33/tCO_2e. The replacement of rotary kilns with vertical shaft kilns or PFRKs also offers a significant abatement option, albeit, at a much higher marginal abatement cost.

In 2030 (Figure 26), the mitigation potential increases to 822 ktCO_2e/year equivalent to 15% of the WEM reference emissions projection, with the use of alternative fuels including waste and biomass increasing the opportunity for mitigation. The implementation of advanced energy monitoring and management systems, improved heat systems including heat exchanger efficiencies and improved electric motor system controls and VSDs are all mitigation options with low marginal abatement costs, although their impact is limited. The implementation of shaft preheaters is still the most significant mitigation option. The replacement of rotary kilns with vertical kilns or PFRK type again shows significant potential for abatement, albeit still at a much higher cost.

The MACC for 2050, displayed in Figure 27, shows the availability of CCS at a cost of over R800/tCO_2e significantly increases the mitigation potential to 7 million tCO_2e/year. This is equivalent to 56% of the WEM reference emissions projection. The marginal abatement cost of replacing rotary kilns with vertical kilns or PFRKs increases from R800 in 2030 to over R1,300/tCO_2e in 2050. This is the result of an increased use of alternative fuels (including waste and biomass) in 2030 and 2050 which reduces the carbon intensity of lime production and therefore reduces the carbon reduction potential of other energy saving measures, thereby increasing their marginal abatement cost.

14.4 Chemicals Production Sector

The chemical sector as covered in this report includes the production of basic chemicals and other chemicals including production of ammonia, nitric acid, carbide, titanium dioxide, petrochemicals and carbon black. Disaggregated product data is only available for these chemicals and not for all chemicals produced in the basic and other chemicals subsectors. For the purposes of the study, energy efficiency measures have been assumed to apply equally to all production processes.

Mitigation potential of product specific measures in the chemical sector was difficult to assess due to a lack of energy consumption and direct fuel/indirect electricity emissions data broken down by chemical product. In particular it was not possible to estimate the mitigation potential associated with the implementation of tail-gas energy recovery for combined heat and power plants (CHP) within carbon black production. It should also be noted that ammonia production in South Africa is integrated with synthetic fuels and chemicals production and most of the potential for emissions reduction and mitigation associated with ammonia production is captured in the other energy industries sector. Therefore, conventional measures used to assess mitigation potential for ammonia are not applicable to existing facilities but will be applicable to new facilities on the assumption that they adopt conventional technology.

The difficulties in projecting emissions for the chemicals sector mean that the current WEM projection is likely to underestimate total emissions and brings into question the integrity of the underlying data based on two difference sources (industry data reported to the Chemical and Allied Industries' Association (CAIA) and the DoE 2009 Energy Balance(DoE, 2013b)). Action should be taken to improve the quality, coverage and granularity of production, energy and emissions data where possible.

Sector growth is assumed to be 4.1% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

14.4.1 Marginal Abatement Cost Curves

Marginal abatement cost curves for the chemicals production subsector for the 2020, 2030 and 2050 snapshots are shown in Figure 28 to Figure 30.

In 2020, a total of 938 ktCO_2e of abatement potential has been identified in the chemicals sector. A total of 68% of the available mitigation potential (641 ktCO_2e) can be achieved through measures with negative marginal abatement costs. In 2030, a total of 2.6 MtCO_2e of abatement potential has been identified, 66% (1.7 MtCO_2e) can be achieved through measures with negative marginal abatement costs. In 2050, a total of 6.2 MtCO_2e of abatement potential has been identified; 24% (1.5 MtCO_2e) can be achieved through measures with a negative marginal abatement cost.

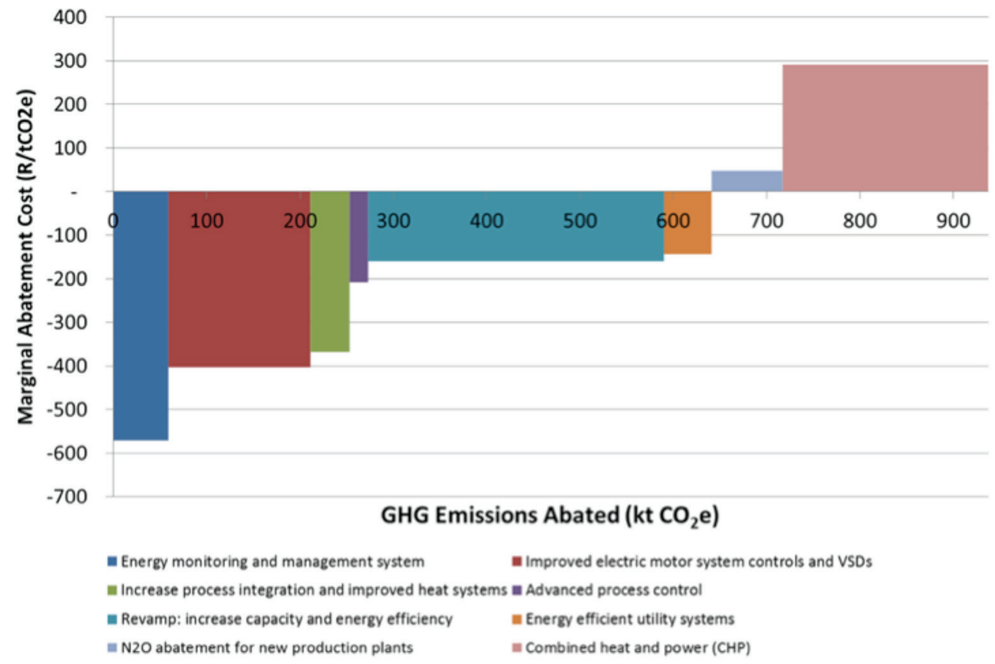


Figure 28: Marginal abatement cost curve for the chemicals sector in 2020

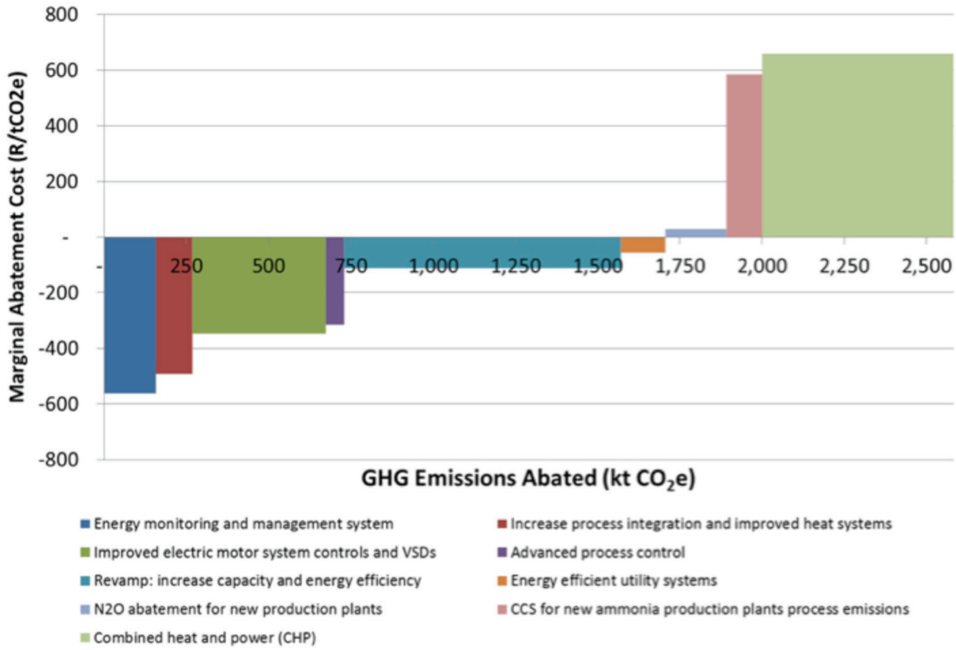


Figure 29: Marginal abatement cost curve for the chemicals sector in 2030

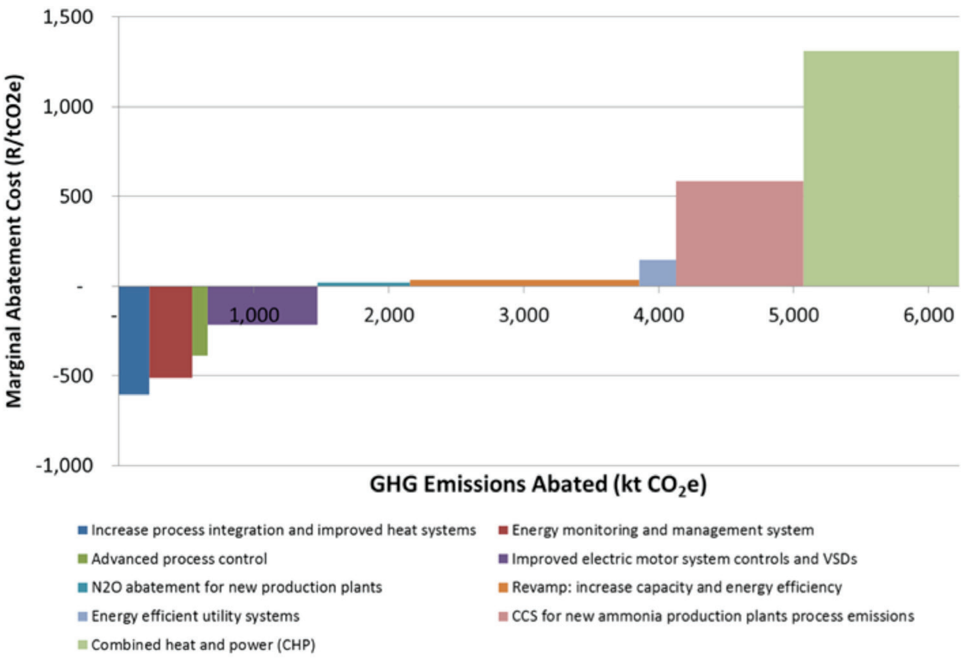


Figure 30: Marginal abatement cost curve for the chemicals sector in 2050

In 2020 (Figure 28), there are a number of opportunities with negative marginal abatement costs available to mitigate both process and fuel combustion emissions. These include energy efficiency measures to implement advanced energy monitoring and management systems, improved electric motor system controls and installation of variable speed drives (VSDs), where appropriate, and increased process integration and revamping of old facilities to improve overall production and energy efficiency. Implementing onsite CHP generation systems also offers major scope for emission reductions but at a positive abatement cost.

In 2030 (Figure 29), the priority order of mitigation options in terms of marginal abatement cost remains similar to 2020. The identified technical mitigation potential increases to almost 2.6 $MtCO_2e$/year compared to the WEM emissions projection or 13% of total emissions due to wider uptake of technologies. Energy management systems and improved electric motor systems remain the options with the lowest marginal abatement costs while complete waste site revamps and CHP offer the biggest scope for mitigation. Nitrous oxide (N_2O) abatement is only applicable to new production facilities as most nitric acid production plants in South Africa have already implemented N_2O abatement projects partially financed under the UNFCCC's Clean Development Mechanism (CDM). Carbon capture and storage (CCS) for ammonia production becomes available and provides an option to reduce process emissions.

The mitigation potential in 2050 increases to over 6.2 million tCO_2e/year compared to the WEM emissions projection or 15% of total emissions. CCS is fully implemented across new production facilities and capable of reducing process emissions by 945 tCO_2e/year by 2050 (Figure 30). The marginal abatement cost of R585/tCO_2e for this measure is lower than the cost of CCS in other industries due to the high purity of the CO_2 in the process emissions resulting in lower capture and compression costs. The portfolio of energy efficiency measures available together offer the largest mitigation opportunity at negative marginal abatement costs.

14.5 Mining Sector

The mining sector encompasses mined materials from surface and underground mines, including gold, platinum group metals (PGMs), diamonds, iron ore, chromite, manganese and other mined materials. This sector does not include coal mining. GHG emissions from coal mining and handling are included in the energy sector.

For the implementation of biodiesel mitigation measures, MACCs assume that a maximum of 50% of the mining fleet can be fuelled by biodiesel. This assumes that first generation biodiesel is available from 2010 and second generation biodiesel is available from 2020. In both cases, it is assumed that the infrastructure and planning is in place to ensure 50% of the fleet can be supplied.

Sector growth ranges from 3.8 to 4.3% per annum on average from 2010 to 2050 for various mined products, in line with the emissions projection assumptions and the underlying macroeconomic model.

14.5.1 Marginal Abatement Cost Curves

Marginal abatement cost curves for the mining sector for the 2020, 2030 and 2050 snapshots are shown in Figure 31 to Figure 33.

In 2020, a total of 5.6 $MtCO_2e$ of abatement potential has been identified in the mining sector. A total of 66% of the available mitigation potential (3.7 $MtCO_2e$) can be achieved through measures which have negative marginal abatement costs. In 2030, a total of 16.8 Mt CO_2e of abatement potential has been identified; 65% (10.9 $MtCO_2e$) of which can be achieved through measures which have negative marginal abatement costs. In 2050, a total of 45.8 $MtCO_2e$ of abatement potential has been identified; 64% (29 $MtCO_2e$) of which can be achieved through measures which have negative marginal abatement costs.

For the implementation of biodiesel mitigation measures, it is assumed that a maximum of 50% of the mining fleet can be fuelled by biodiesel. This assumes that first generation biodiesel is available from 2010 and second generation biodiesel is available from 2020. In both cases, the estimates assume that the infrastructure and planning is in place to ensure 50% of the fleet can be supplied.

In 2020 (Figure 31), several energy efficiency measures are available with negative abatement costs including the implementation of process, demand and energy management systems, installation of energy-efficient electric motor systems, optimisation of existing electric motor systems (with improved controls and VSDs, where suitable), installation of energy efficient lighting and the improvement of mine haul and transport energy efficiency (via training, behaviour change and improved transport management and operation).

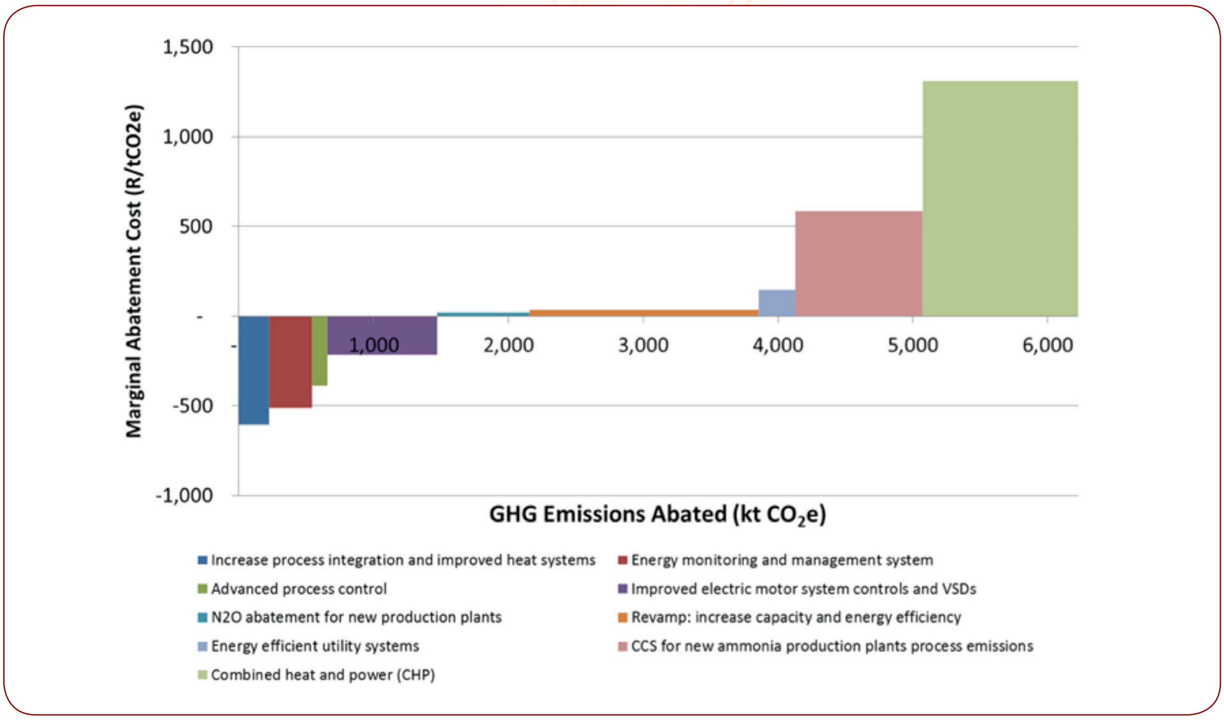


Figure 31: Marginal abatement cost curve for the mining sector in 2020

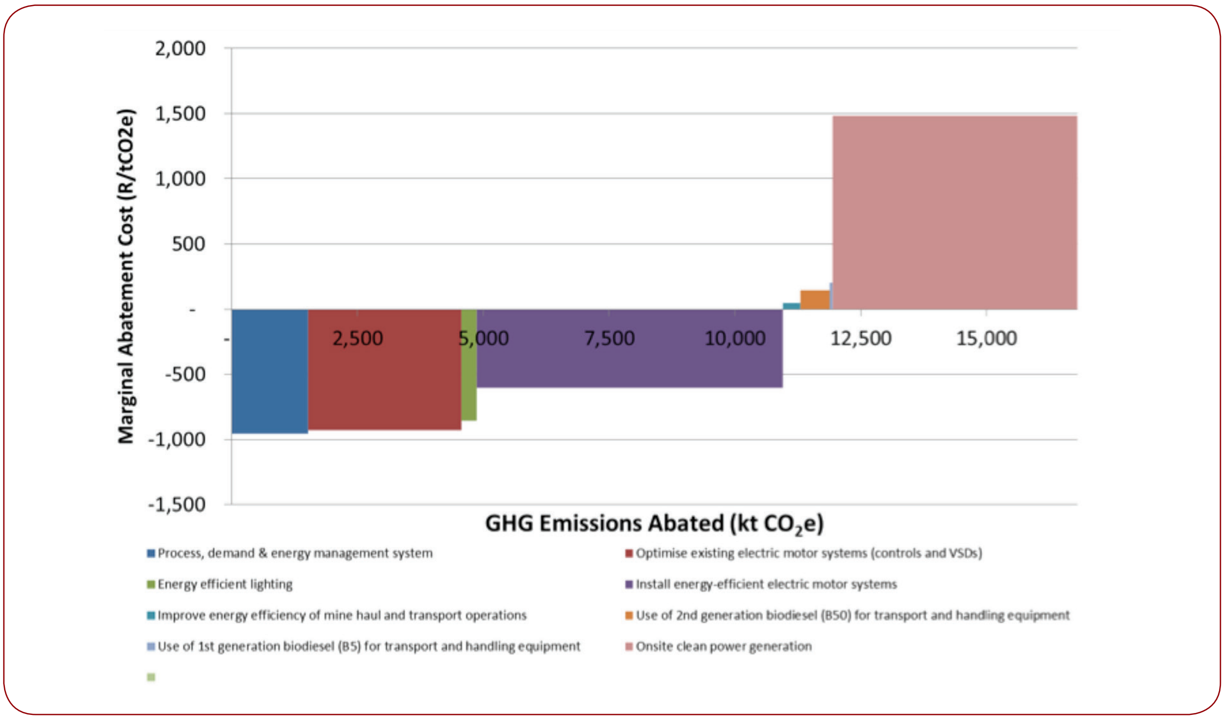


Figure 32: Marginal abatement cost curve for the mining sector in 2030

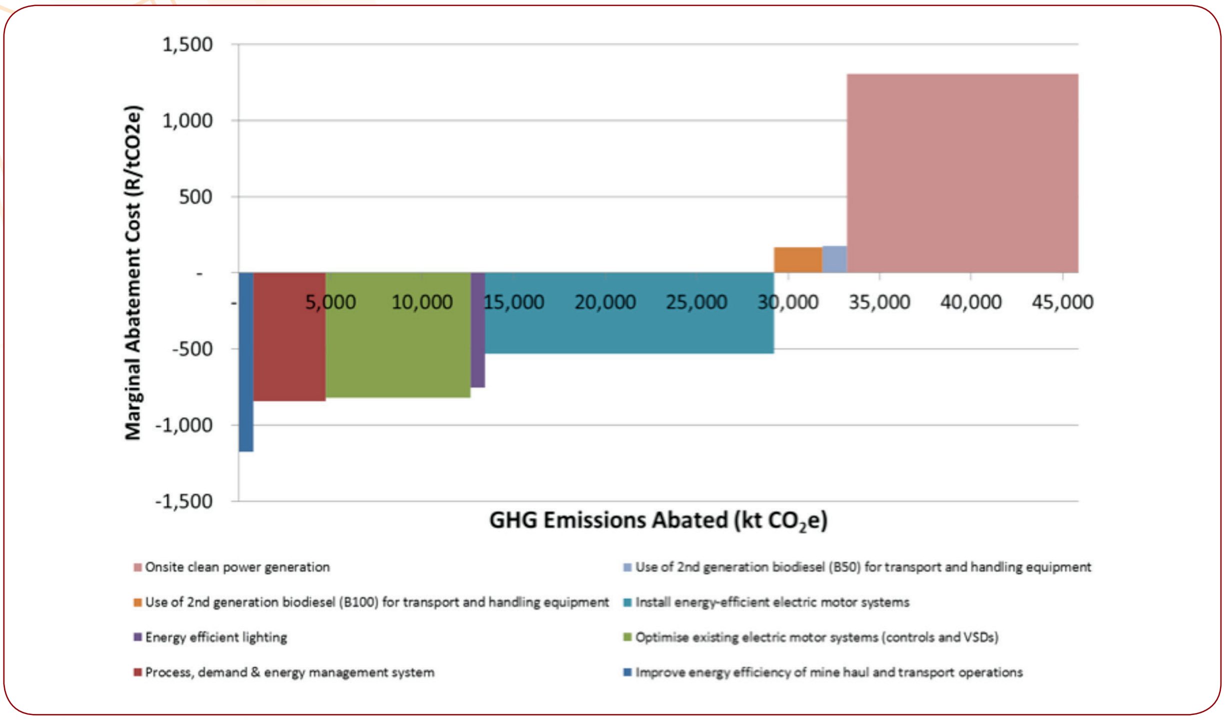


Figure 33: Marginal abatement cost curve for the mining sector in 2050

In 2030 (Figure 32), the mitigation potential in the mining sector increases to 16,807 ktCO_2e/year. This is equivalent to 23% of the reference WEM emissions projection driven largely by energy efficiency measures with negative marginal abatement costs. The development of onsite clean power generation also contributes to GHG mitigation (for example, solar PV) by replacing imported power and reducing indirect emissions. However, this measure has a high marginal abatement coast of over R1,000/tCO_2e.

The overall abatement potential in 2050 (Figure 33) increases to 45,847 ktCO_2e/year – equivalent to 24% of the reference emissions projection for the mining subsector. The mitigation options with large potential (and negative marginal abatement costs) are the implementation of process, demand and energy management systems, installation of energy-efficient electric motor systems and optimisation of existing electric motor systems. These are all energy efficiency measures which reduce electricity consumption and associated indirect emissions. The availability of biodiesel for reducing fleet emissions has a much smaller impact in comparison.

14.6 Buildings Sector

In the case of emission projections and estimates of mitigation from the residential, commercial and institutional buildings subsectors, the starting point, penetration rate and uptake of each measure are all based on the technology proposed by the South African TIMES energy model (SATIM) 'upper bound' scenario (ERC, 2013).

14.6.1 Marginal Abatement Cost Curves

14.6.1.1 Commercial/institutional buildings

The identified mitigation potential for commercial and institutional buildings in South Africa is estimated at 7.5 MtCO_2e in 2020 compared to the reference WEM emissions projection (equivalent to 13% of total projected emissions). Several mitigation options with negative marginal abatement costs (MACs) are available to reduce emissions from commercial and institutional buildings, as shown by the MACC in Figure 34. Installation of heating, ventilation and air conditioning (HVAC) systems with heat recovery in new buildings have the lowest marginal abatement costs, followed closely by efficient lighting, energy efficient appliances and HVAC equipment with variable speed drives (VSDs). Construction of passive buildings with improved thermal design offers the largest single mitigation potential, but at a much higher marginal abatement cost (as the total cost of the building is included in the marginal abatement cost calculation).

In 2030 (Figure 35), the overall mitigation potential increases to over 15 MtCO_2e, 22% of the reference emissions projection for the commercial/institutional buildings subsector. The overall mitigation potential increases to more than 43 $MtCO_2e$ in 2050. This is equivalent to 45% of reference emissions. This is fuelled by both the growth in buildings and the reference emissions and the increases in uptake of mitigation technologies or (Figure 36).

14.6.1.2 Residential buildings

The identified mitigation potential in the residential building subsector is 14.5 $MtCO_2e$ in 2020 compared to the reference WEM emissions projection (equivalent to 20% of total projected emissions for the subsector). Figure 34 shows there are a number of mitigation options available for residential buildings in South Africa which have negative marginal abatement costs. The measure with the lowest marginal abatement cost is the installation of high efficiency lighting and energy efficient appliances in new and old buildings. The implementation of solar water heating, geyser blankets and improved insulation in new buildings also offer large potential savings at negative marginal abatement costs. Constructing passive buildings with improved thermal design has the highest marginal abatement cost (as this includes the total cost of the new building). The overall mitigation potential in 2030 (Figure 35) increases to over 23 $MtCO_2e$/year compared to the reference WEM emissions projection (equivalent to 29% of total projected emissions from residential buildings).

The rank order of mitigation measures in the residential buildings sector (order from lowest to highest marginal abatement cost) remains largely the same across all three snapshots. With the continued uptake of mitigation technologies, the overall mitigation potential increases in 2050 to over 42 $MtCO_2e$/year or 46% of the reference emissions projection (Figure 36).

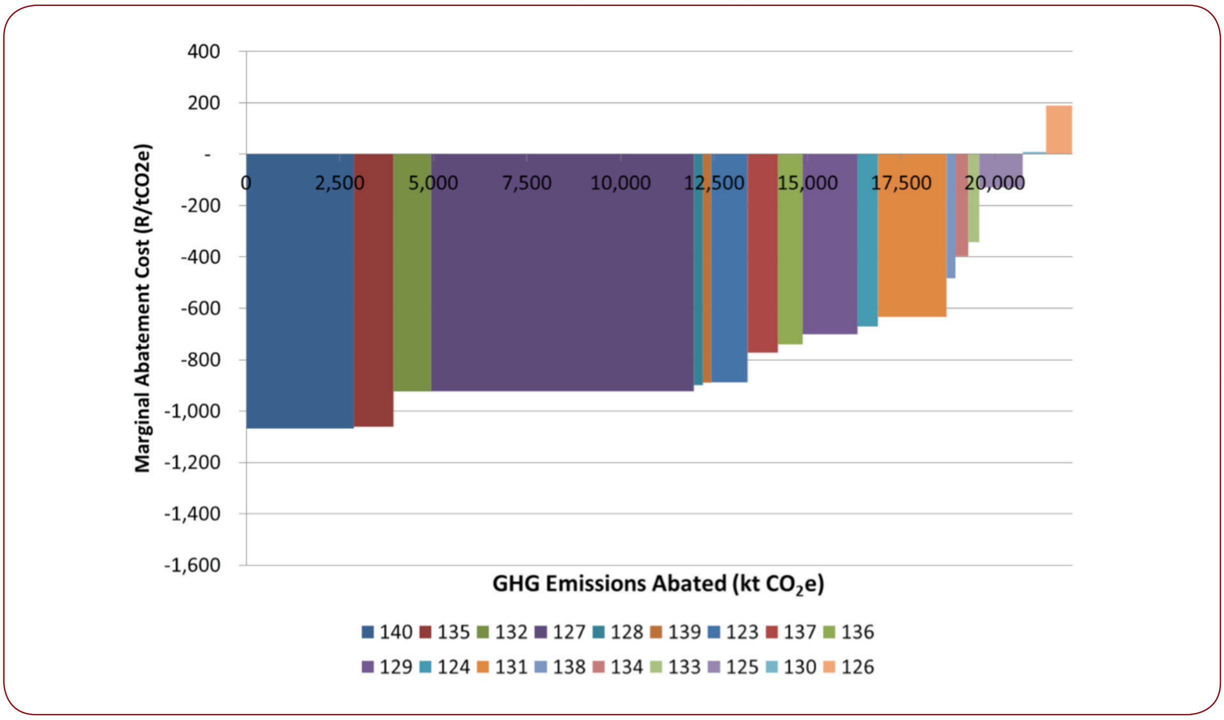


Figure 34: Marginal abatement cost curve for the buildings sector in 2020

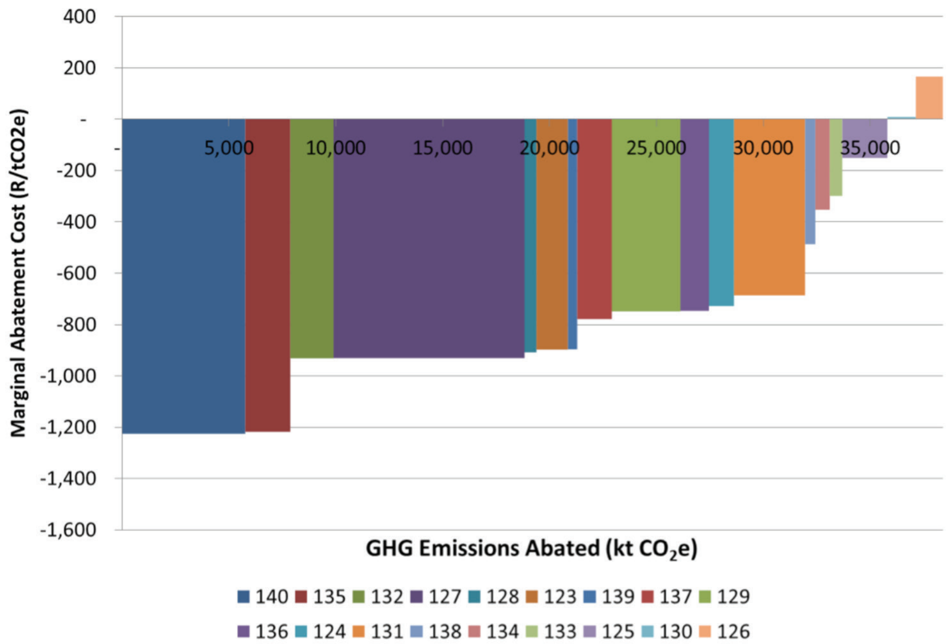


Figure 35: Marginal abatement cost curve for the buildings sector in 2030.

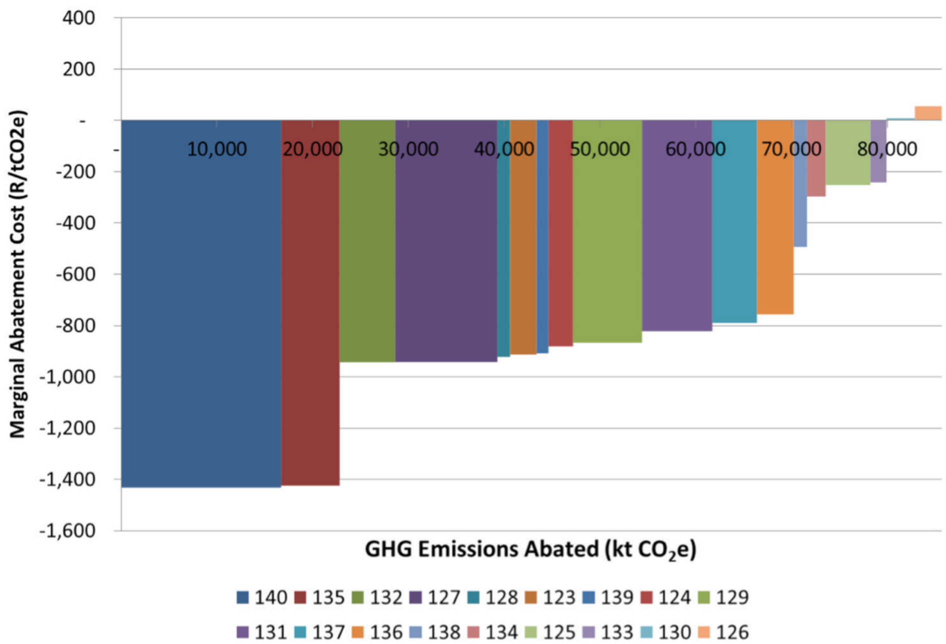


Figure 36: Marginal abatement cost curve for the buildings sector in 2050.

14.7 Mitigation Potential from Other Sectors

The other sectors include an assessment for the pulp and paper production industry only. Marginal abatement cost curves have been developed for pulp and paper production in 2020, 2030 and 2050.

14.7.1 Key Assumptions

For the objective of reducing emissions, the analysis assumes that a 45% switch from fossil fuels to zero-carbon residual wood waste and biomass fuels is technically possible by 2030 (i.e. by 2030, 55% of fuel is from fossil sources and 45% is waste/biomass). The MACCs also assume that 300 MW of combined heat and power (CHP) is installed by 2030 (with 85% fuel utilisation/ efficiency).

Sector growth is assumed to be 3.8% per annum on average from 2010 to 2050 in line with the emissions projection assumptions and the underlying macroeconomic model.

14.7.2 Marginal Abatement Cost Curves

The technical mitigation potential for the pulp and paper subsector in 2020 is 2.4 $MtCO_2e$ or 32% compared to the reference WEM emissions projection for the subsector. There are several mitigation options available, as shown in the 2020 MACC in Figure 37. The implementation of advanced energy management systems and energy efficient electric motors, improved controls and variable speed drives all have negative abatement costs. However, their overall abatement potential is low. The most significant abatement measures available to the pulp and paper industry is the conversion of fuel from coal to biomass/residual wood waste in conjunction with the implementation of combined heat and power (CHP) systems to replace imported grid power. Both options have positive abatement costs with CHP the most expensive at R1,400/tCO_2e.

In 2030 (Figure 38), continued switching from coal to biomass and residual wood waste fuels and uptake of CHP increases mitigation potential to 5,618 $ktCO_2e$ or 54% compared to the reference WEM emission projection.

The mitigation potential in 2050 increases in absolute terms to over 12 $MtCO_2e$ influenced by the sector growth and increasing reference emissions (Figure 39). However, in percentage terms, the mitigation drops slightly to 54% compared to the reference WEM emission projection. The fuel switch option from coal to biomass remains the largest mitigation opportunity.

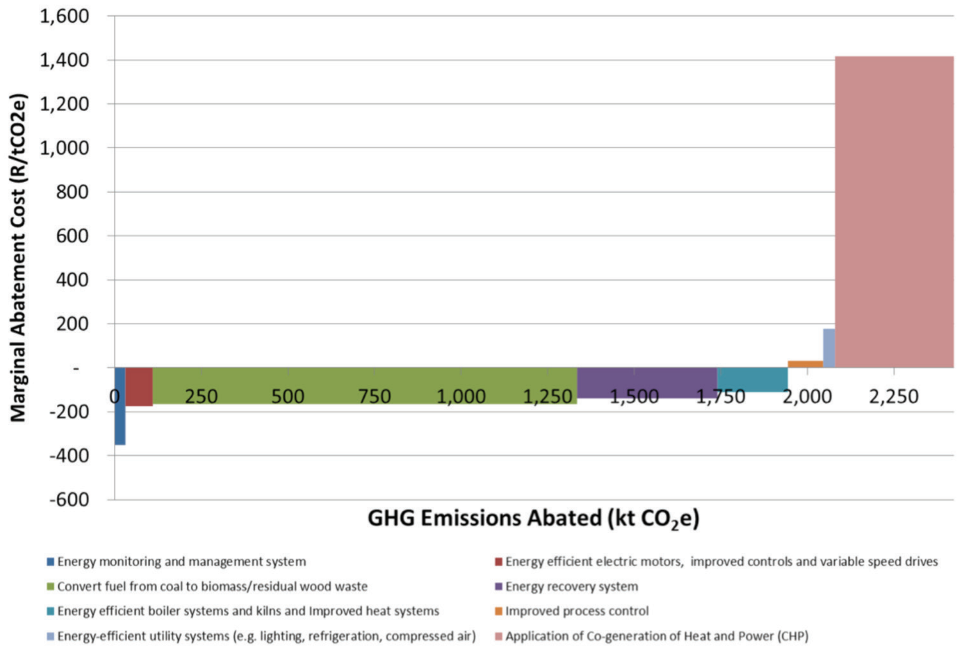


Figure 37: Marginal abatement cost curve for the pulp and paper sector in 2020

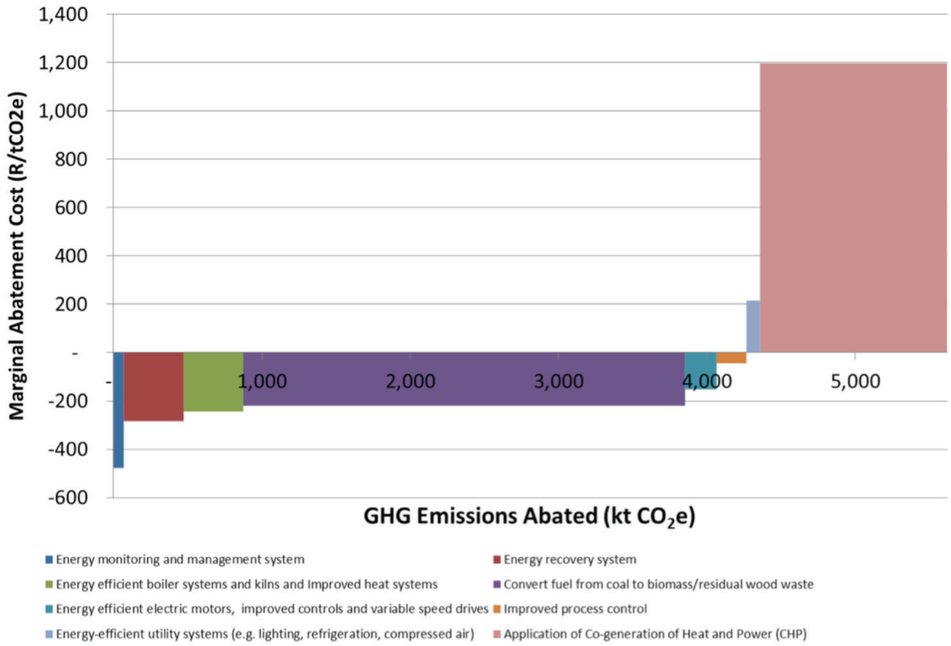


Figure 38: Marginal abatement cost curve for the pulp and paper sector in 2030

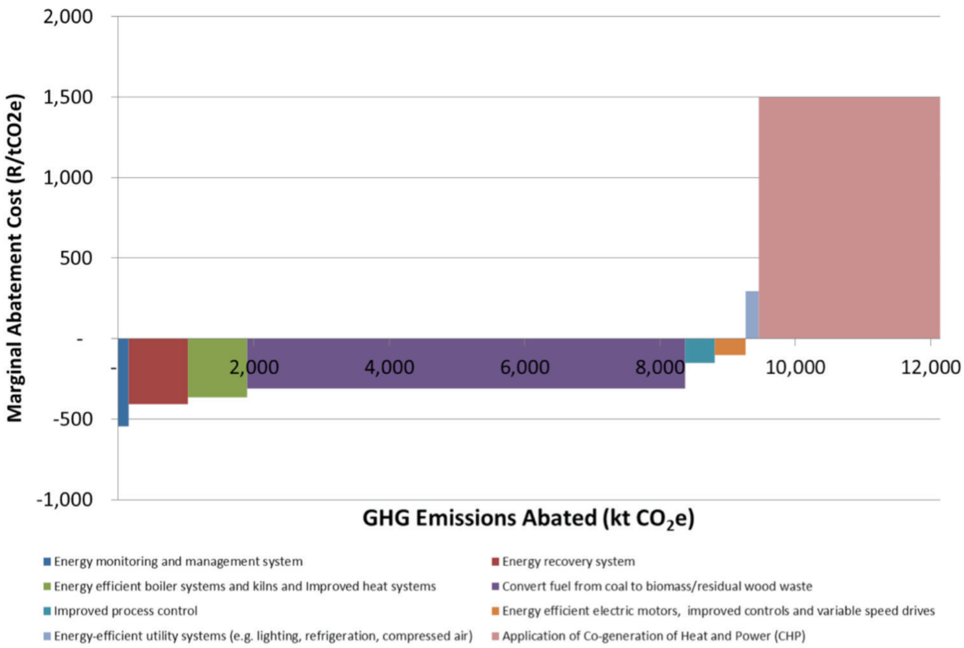


Figure 39: Marginal abatement cost curve for the pulp and paper sector in 2050

14.8 Technical Mitigation Potential

A summary of technical mitigation potential in 2020, 2030 and 2050 for all sectors and subsectors covered in the assessment of the industry key sector is shown in Table 22 below.

In 2020, the metals sector accounts for just over one quarter of mitigation potential for the industry sector (12,249 $ktCO_2e$, 27%). This rises to 86,502 $ktCO_2e$ (33%) in 2050. The proportion of total mitigation potential accounted for by the minerals sector rises from 3.5% in 2020 (1,553 $ktCO_2e$) to 8.5% (22,072 $ktCO_2e$) in 2050. By comparison, the buildings sector contribution to total mitigation potential drops from 49% (22,066 $ktCO_2e$) in 2020 to 30% (85,668 $ktCO_2e$) in 2050. The mining sector contribution to total mitigation potential is relatively stable, rising slightly from 12.5% (5,613 $ktCO_2e$) in 2020 to 17.7% (45,847 $ktCO_2e$) in 2050.

Mitigation potential expressed as a percentage of the reference WEM projection is shown for each sector and subsector in Table 23.

Table 22: Summary of technical mitigation potential for the industry sector, including a breakdown by sector and subsector and showing results for 2020, 2030 and 2050 ($ktCO_2e$)

Sector	Subsector	2020	2030	2050
Metals	Aluminium production	844	3,045	11,445
	Ferroalloys	5,579	13,407	30,392
	Iron and steel	5,825	19,507	44,665
	Subtotal	**12,249**	**35,959**	**86,502**
	% Total	**27.32%**	**34.63%**	**33.47%**
Minerals	Cement	1,258	3,666	15,059
	Lime	295	820	7,014
	Subtotal	**1,553**	**4,486**	**22,072**
	% Total	**3.46%**	**4.32%**	**8.54%**
Chemicals	Chemicals production	938	2,582	6,226
	% Total	**2.09%**	**2.49%**	**2.41%**
Pulp and Paper	Pulp and paper	2,423	5,618	12,137
	% Total	**5.40%**	**5.41%**	**4.70%**
Other Mining	Surface and underground mining	5,613	16,807	45,847
	% Total	**12.52%**	**16.18%**	**17.74%**
Buildings	Residential	14,551	23,375	42,303
	Commercial	7,515	15,023	43,365
	Subtotal	**22,066**	**38,398**	**85,668**
	% Total	**49.21%**	**34.70%**	**30.30%**
Total		**44,842**	**103,850**	**258,453**

Table 23: Percentage reduction in reference WEM emissions for the industry sector, assuming all technical mitigation potential is implemented

Sector	2020	2030	2050
Metals	8%	18%	21%
Minerals	1%	2%	5%
Chemicals	1%	1%	2%
Mining	4%	8%	11%
Buildings	15%	19%	21%
Other: Pulp & paper	2%	3%	3%
Total	**30%**	**52%**	**63%**

14.9 WAM Projection

Assuming that all available mitigation measures are implemented (that is, that all technically feasible mitigation potential is implemented), the resulting WAM abatement projection is shown in Figure 40. Note that emissions from the power sector have been reallocated to end-use sectors and hence electricity-related emissions savings in industry end-use sectors have been adjusted for the progressive reduction of the carbon intensity of electricity supply over time. In the case of the industry sector, no early mitigation actions were identified and consequently there is no difference between the reference case WOM and WEM projections (please refer to Box 1 and Table 6). Consequently, only the WEM projection is shown in Figure 40.

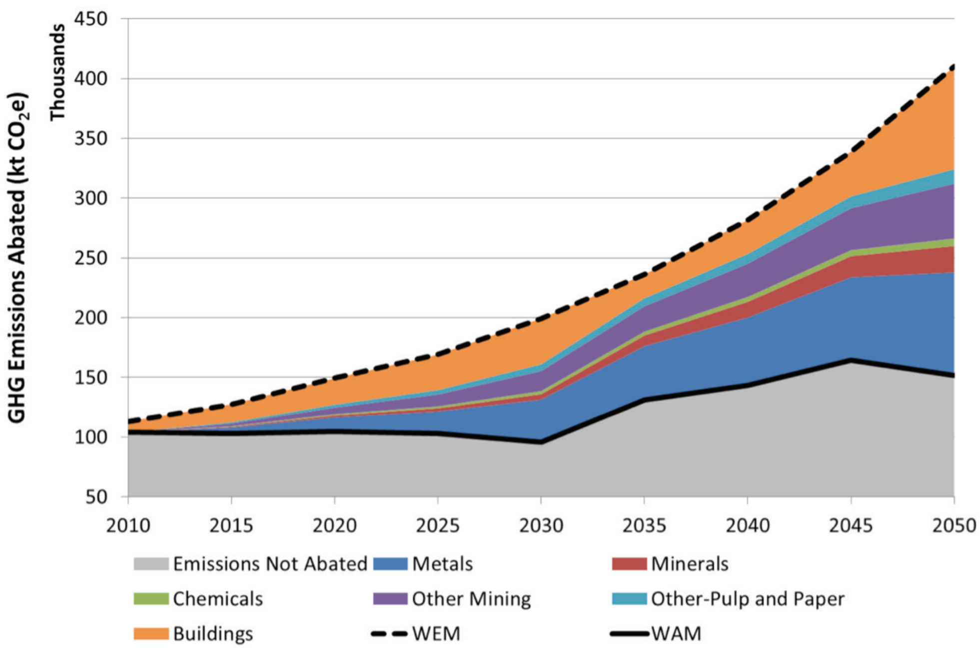


Figure 40: WAM scenario for the industry sector, showing a breakdown per sector. Emissions from the power sector have been reallocated to end-use sectors and electricity-related emissions savings have been adjusted accordingly. The reference case WEM emission projection is also shown

15. The Transport Sector

The assessment of mitigation potential in the transport sector covers road and rail transport as well as civil aviation. The corresponding IPCC emission categories are:

- 1A3a civil aviation
- 1A3b road transportation
- 1A3c railways

For maritime transport, insufficient information was available on the emissions associated with inland navigation and coastal and short sea shipping was estimated to represent less than 1% of total freight transport (Aurecon, 2012). The sector was excluded as a consequence. Transportation of certain products (for example, primary fuels) can also be made using pipelines. In the GHGI, the emissions associated with energy used in pipeline transportation and fugitive releases are allocated to other sectors, and are not discussed in this sector.

A range of potential mitigation measures were identified that could potentially be applied to the transport sector to deliver emissions reductions by 2050. These were discussed and agreed with the transport task team. The list of mitigation opportunities were categorised into the following types:

- modal shift
- demand reduction measures
- more efficient vehicle technologies
- more efficient operations
- alternative lower-carbon fuels

A final list of mitigation options was discussed and agreed with the transport sector task team. The measures are described in Table 24.

The approach to estimating mitigation potential and building MACCs for the transport sector has been summarised in Chapter III, Section 10.2.7 and is described in detail in Technical Appendix E: Transport Sector.

Table 24: List of mitigation opportunities identified in the transport sector

Subsector	Measure	Type	Measures description
Road transport	Shifting passenger transport from passenger cars to public transport	Modal shift	These measures would involve increased use of public transport. The cost and effectiveness of these measures are extremely site-specific, therefore more uncertain in a national context. It was nevertheless considered important to capture these measures, albeit on a more illustrative basis.
	Shifting freight from road to rail	Modal shift	This measure would involve increased use of rail to transport freight. The cost and effectiveness of this measure is also extremely site-specific, therefore more uncertain in a national context. It was nevertheless considered important to capture this measure, albeit on a more illustrative basis.
	More fuel efficient vehicles	More efficient vehicle technologies	Improving the fuel efficiency of gasoline/diesel vehicles through engine efficiency improvements, hybridisation, lightweighting, reducing rolling resistance, reducing aerodynamic drag.
	Alternative fuel vehicles	Alternative lower-carbon fuels	Switching to vehicles powered by electricity, gas (e.g. compressed natural gas (CNG)) or hydrogen fuel cells.
	Biofuels	Alternative lower-carbon fuels	Blending biofuels into road transport fuels to reduce carbon intensity.
Rail transport	More energy efficient trains	More efficient vehicle technologies	Technology applications have the potential to improve the energy efficiency of new trains.
	Alternative fuel vehicles	Alternative lower-carbon fuels	This measure involves the application of alternative engine technologies and/or fuels including natural gas and biofuels.
	Voltage upgrade	More efficient vehicle technologies	This measure would involve switching from 3000V AC to 25kV DC on the Metrorail system to reduce efficiency losses on the system.
Aviation	Fleet management	More efficient vehicle technologies	Certain fleet management measures open to airlines have the potential to influence emissions including, for example, aircraft retirement.

15.1 Key Assumptions

Actions 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 in the WAM scenario, this may be sufficient to delay a requirement for new investment in refinery capacity, which would be expected in the reference case WEM scenario. This in turn would reduce the overall emissions associated with liquid fuel production.[16]

15.1.1 *Road Sector*

In the road sector, the marginal cost calculations rely on fuel prices and three other key metrics: capital costs of new cars, their fuel efficiency and maintenance costs. The capital costs and fuel efficiency used in the modelling are shown in Technical Appendix E: Transport Sector. Maintenance costs are typically between 0.5% and 2% of the capital costs. In the reference case WOM projection, conventional petrol and diesel engine vehicles are the default option (the counterfactual) for new vehicles.

15.1.2 Rail Sector

The rail sector mitigation options are based on differing uptake of improved efficiency train fleets, fleet replacement and the use of alternative fuels. The main driver of the marginal abatement cost (MAC) analysis here is therefore the cost associated with each measure.

15.1.3 Aviation

Two separate measures have been quantified for the aviation sector. In both cases the key technical data, including cost assumptions, has drawn upon international benchmarks. Since the market for aircraft is global the measures data is assumed to be applicable to the South African context. In practice, the capital cost estimates are very sensitive to the specific aircraft concerned, and the operating costs are sensitive to the assumed efficiency of the measures, the use of the aircraft (for example, routes deployed) and the assumed fuel prices. Insufficient data on the South Africa fleet was available to assess these variables separately, and the cost estimates are based on generic assumptions published in the literature. Further detail is provided in Technical Appendix E.

The estimates of abatement and marginal abatement costs for all measures in the transport sector are presented in Table 32 for each of the three snapshots in time considered in this study: 2020, 2030 and 2050.

15.2 Road Transport

15.2.1 Marginal Abatement Cost Curves

As shown in Figure 41 to Figure 43, a number of measures have a negative marginal abatement cost. In particular, the uptake of compressed natural gas (CNG) vehicles which show a negative marginal abatement cost in all years is an attractive measure. It should be noted that the large scale uptake of CNG vehicles requires the necessary supporting infrastructure, along with the necessary supplies of gas.

Other measures have a high marginal abatement cost in earlier years, but the marginal abatement cost reduces in future years. This is the case with plug-in and full electric vehicles as well as passenger modal shift (shifting passengers from cars to public transport). The marginal abatement cost of hybrid electric vehicles also improves over time, although not to the extent where the marginal abatement cost becomes negative.

15.2.2 Modal Shifts

The modal shift scenarios were the most complex to analyse. The marginal abatement costs of modal shift programmes are highly site dependant, making it difficult to derive an estimate applicable to the national level. A particular uncertainty relates to the level of capital investment, which unlike some of the other abatement measures will vary considerably from one case to another.

The analysis of passenger model shift has been based upon a single case study for the Western Cape Province (PDG, 2013) scaled up to a national estimate. The result should therefore be interpreted with care. In the short term (to 2020) the marginal abatement cost associated with the measure is positive, but this decreases towards 2050. This is largely due to increasing demand over time as well as an increase in fuel prices. This conclusion is broadly similar to results from other research. The IPCC, for example, suggests that a GHG reduction potential of 25% through passenger modal shift can be achieved with a marginal abatement cost of US\$30/tCO_2e.[17]

For freight modal shift, the analysis is based on data provided by Transnet. This has the advantage of being based upon

16. These adjustments implicitly assume that the abatement measures identified for the transport sector will be fully implemented. In practice, the level of implementation may be lower than this, or other factors may influence growth in fuel demand from transport, which will in-turn influence the level of liquid fuel demand and the emissions from the other energy industries and petroleum refining sectors.

17. Table 5.6 (http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch5s5-3-1-5.html)

a national estimate of the potential, so is considered more robust that the estimate for passenger transport. The abatement potential has been estimated by overlaying the data from Transnet on the model shift potential in the rail sector, with the demand data from the ERC (Merven et al., 2012). Infrastructure (capital) cost data is sourced from a Transnet annual report (Transnet, 2012) and from this a cost of R1 bn per 1 bn tonne km shifted was assumed. Results of the analysis can be seen in Table 25.

Table 25: Modal shift mitigation potential, showing abatement ($ktCO_2e$) and marginal abatement cost (MAC) estimates (R/tCO_2e)

	2020		2030		2050	
	$ktCO_2e$	R/tCO_2e	$ktCO_2e$	R/tCO_2e	$ktCO_2e$	R/tCO_2e
Road - shifting passengers from cars to public transport	820	3,105	3,087	729	9,396	-1,128
Road - shifting freight from road to rail	1,840	1,375	2,729	2,085	2,997	1,497

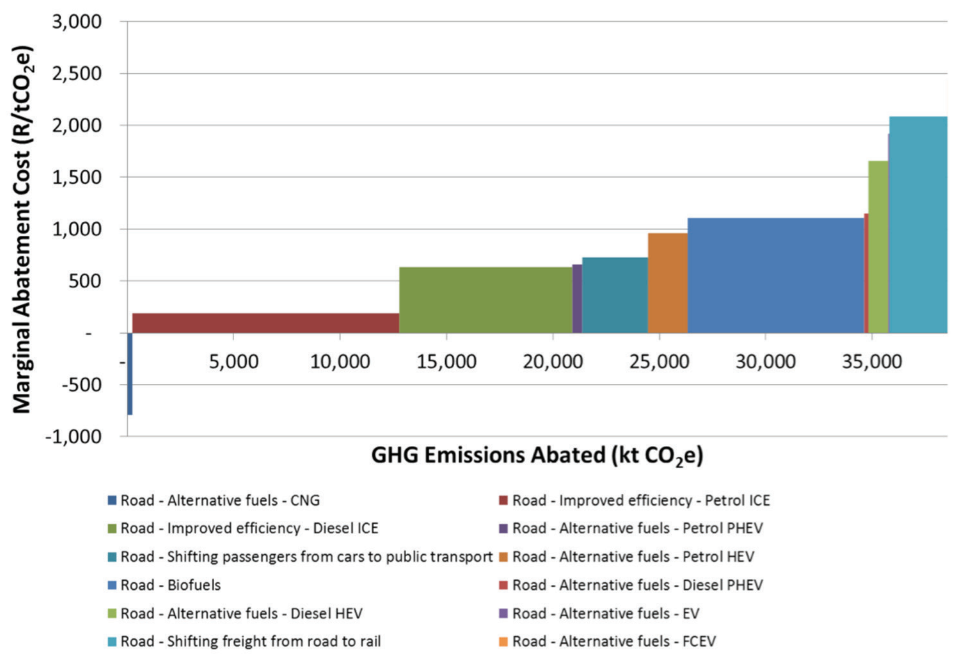


Figure 41: Marginal abatement cost curve for the road sector in 2020

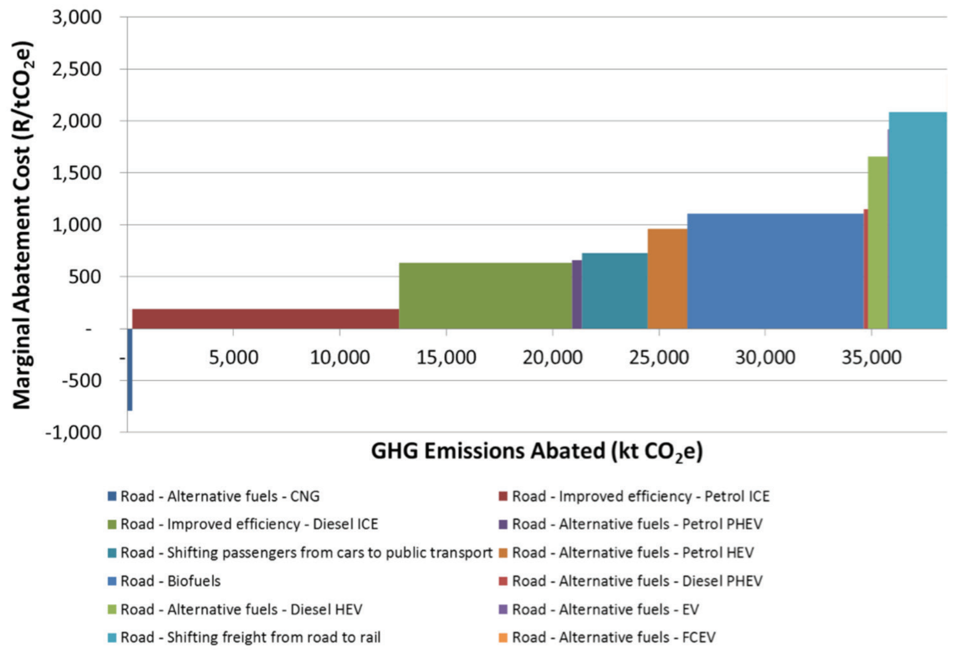


Figure 42: Marginal abatement cost curve for the road sector in 2030

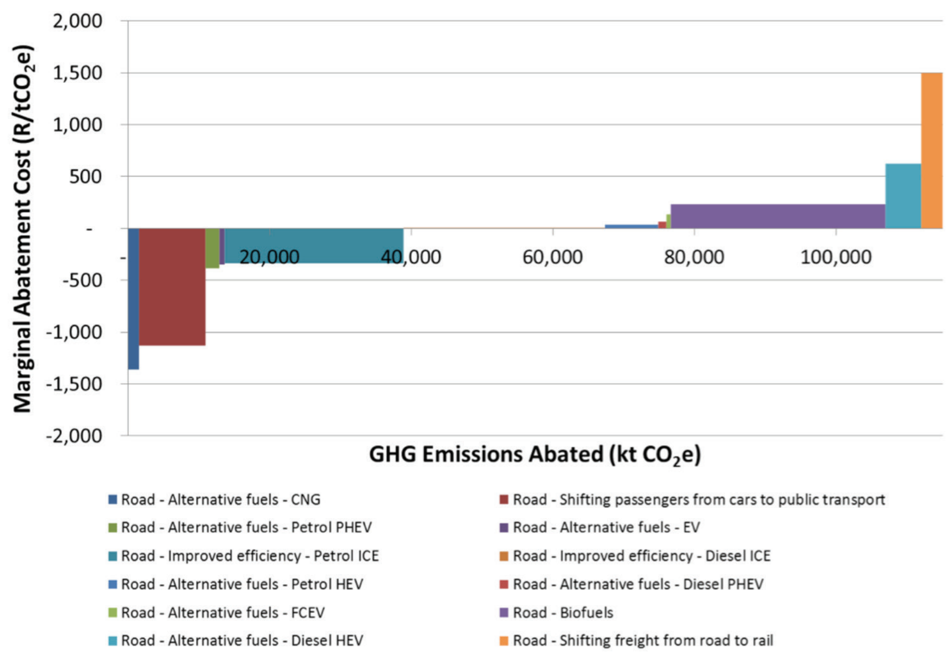


Figure 43: Marginal abatement cost curve for the road sector in 2050

15.3 Rail Transport

15.3.1 Marginal Abatement Cost Curves

Marginal abatement cost curves for the rail sector in 2020, 2030 and 2050 are shown in Figure 44, Figure 45 and Figure 46, respectively. The abatement and marginal abatement cost estimates are listed in Table 32.

In the rail sector, improved efficiency of diesel freight and diesel hybrid engines as well as switching to CNG appear as promising options, delivering savings in a cost-effective manner, first appearing on the MACCs in 2020, 2030 and 2050 respectively. Meanwhile improvements to passenger rail either through more efficient electric multiple unit (EMU) train sets, or a voltage upgrade to the network appear much more expensive. However, the cost estimates for these measures are much more uncertain.

With respect to biofuels, the costs and overall potential are both uncertain. First generation biofuels are currently more expensive than conventional fuels and this is likely to remain the case in the future. In contrast, second generation fuels are projected to offer a cost advantage over fossil fuels by 2030. In addition, biofuels provide a large potential for emissions savings despite not having a negative marginal abatement cost in any sector across the time series.

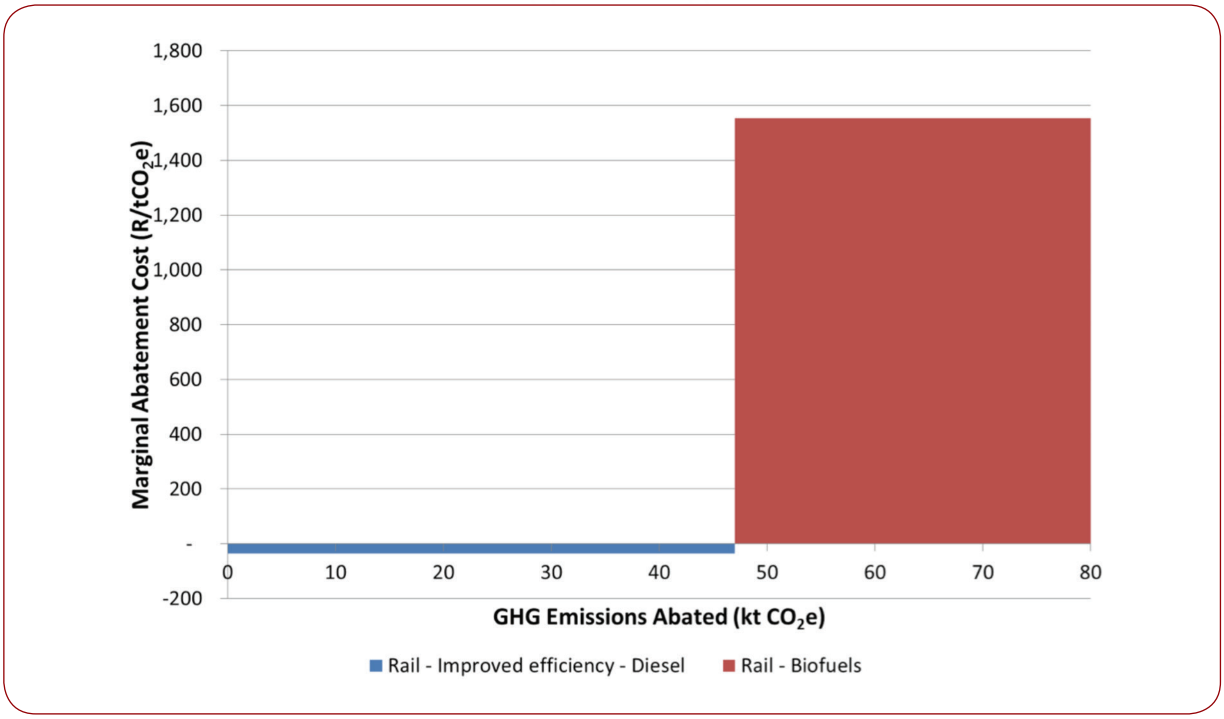


Figure 44: Marginal abatement cost curve for the rail sector in 2020

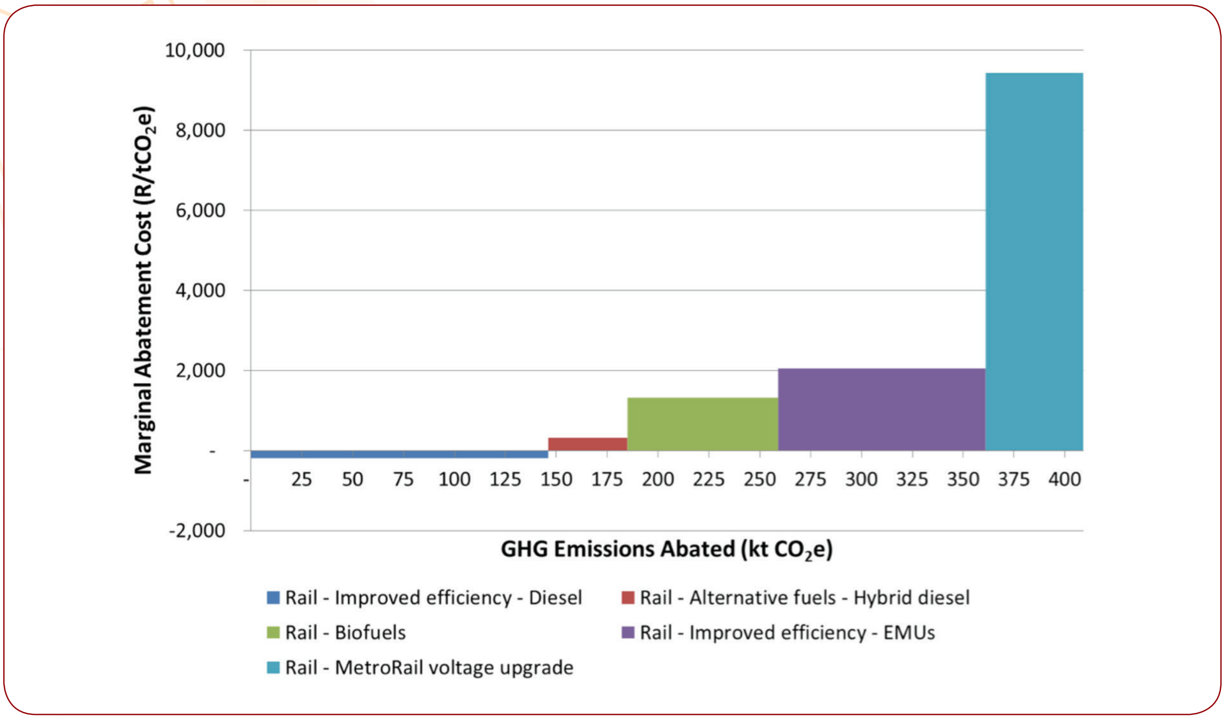


Figure 45: Marginal abatement cost curve for the rail sector in 2030

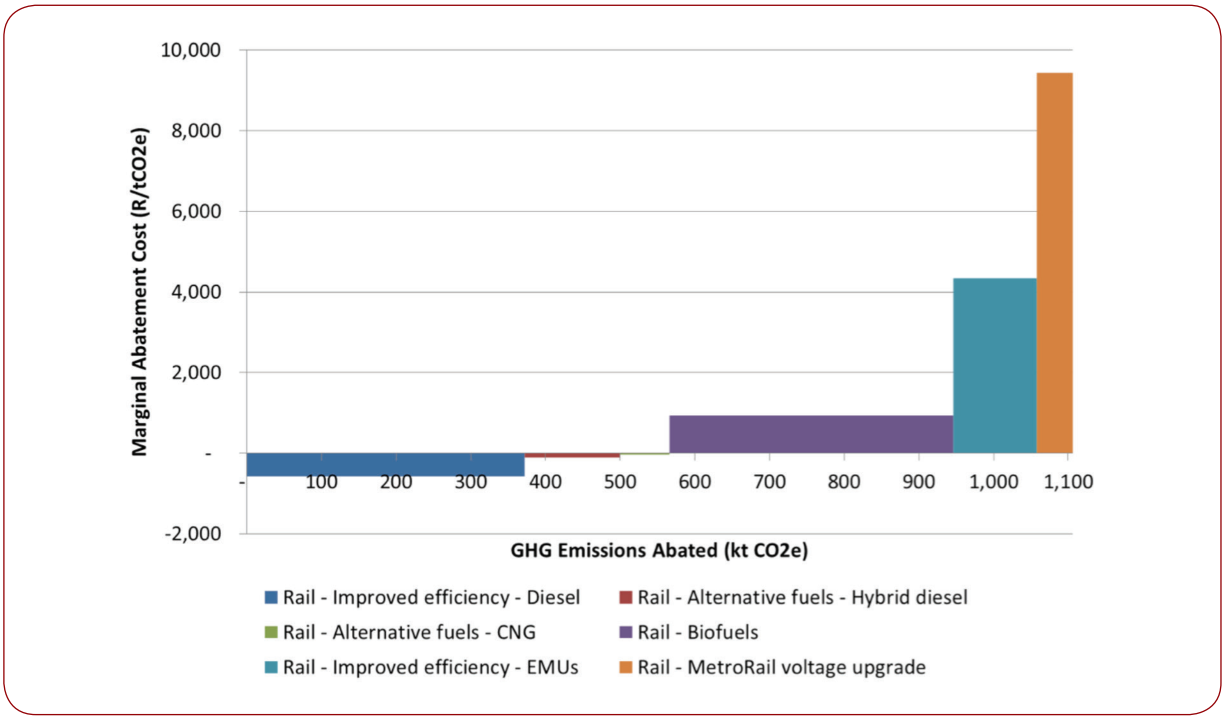


Figure 46: Marginal abatement cost curve for the rail sector in 2050

15.4 Aviation

Given the limited number of abatement options remaining after the existing voluntary sectoral agreement to reduce emissions from the aviation sector has been accounted for, and the dominance (in terms of abatement potential) of the biofuels options in the aviation sector, the MACCs below do not serve an optimal purpose. Technical mitigation potential and the marginal cost of abatement for the aviation sector are identified in Table 32.

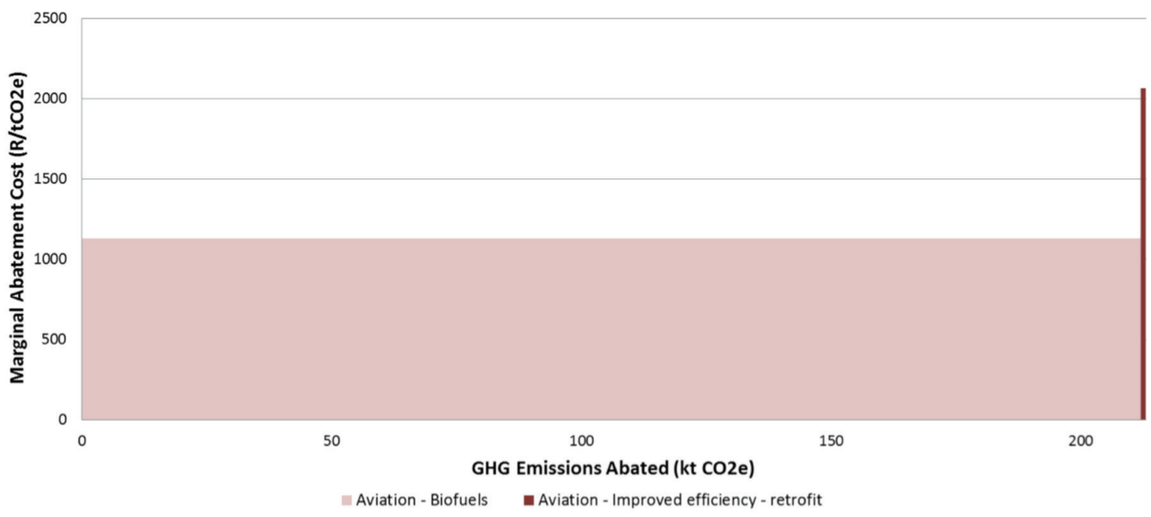


Figure 47: Marginal abatement cost curve for the aviation sector in 2020

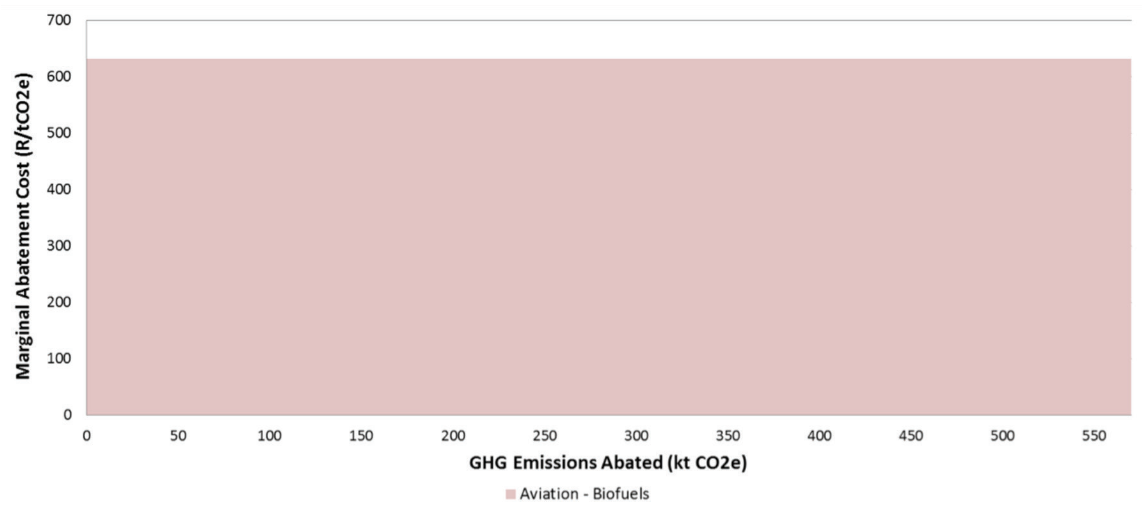


Figure 48: Marginal abatement cost curve for the aviation sector in 2030

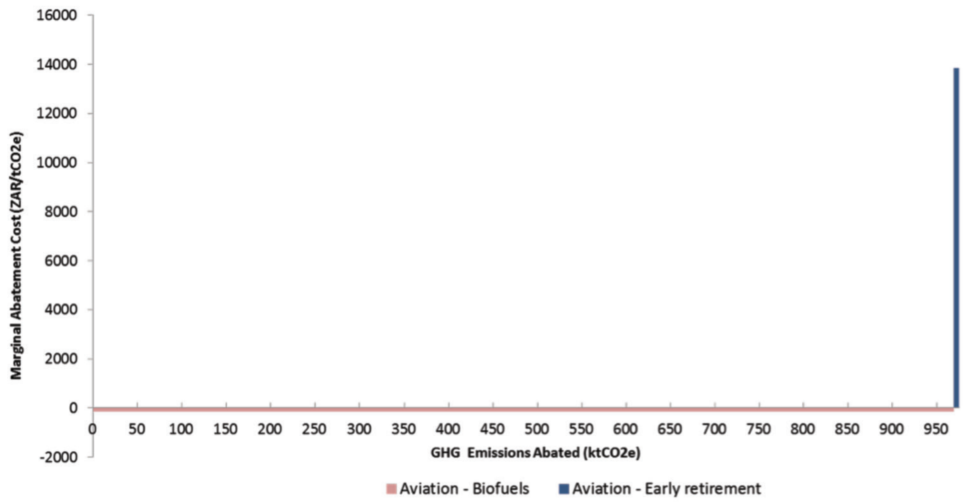


Figure 49: Marginal abatement cost curve for the aviation sector in 2050

15.5 Technical Mitigation Potential

The analysis shows that if all technically available mitigation potential in the transport sector were to be implemented the GHG emissions could be reduced by 11,869 ktCO_2e in 2020, 39,525 ktCO_2e by 2030 and 117,151 ktCO_2e by 2050 (Table 26).

Table 26: Total mitigation potential for the transport sector, assuming all measures are implemented (in ktCO_2e)

Subsector	Measure	2020	2030	2050
Aviation	Aviation – improved efficiency – retrofit	1	-	-
	Aviation – early retirement	-	-	6
	Aviation – biofuels	212	571	969
Subsector Total		**213**	**571**	**975**
Rail	Rail – improved efficiency – electric multiple unit (EMU) train sets	N/A	102	112
	Rail – improved efficiency – diesel	47	147	372
	Rail – alternative fuels – hybrid diesel	N/A	39	128
	Rail - Metrorail voltage upgrade	N/A	48	48
	Rail – alternative fuels – compressed natural gas (CNG)	N/A	N/A	66
	Rail – biofuels	33	74	380
Subsector Total		**80**	**410**	**1,107**
Road	Road – alternative fuels – CNG	20	246	1,579
	Road – alternative fuels – diesel plug-in hybrid electric vehicle (PHEV)	22	202	1,152
	Road – improved efficiency – petrol internal combustion engine (ICE)	4,349	12,538	25,241
	Road – alternative fuels – petrol hybrid electric vehicle (HEV)	450	1,872	7,522
	Road – improved efficiency – diesel ICE	1,875	8,122	28,448
	Road – alternative fuels – petrol PHEV	64	467	1,951
	Road – alternative fuels – fuel cell electric vehicle (FCEV)	-	4	616
	Road – alternative fuels – diesel HEV	176	933	5,041
	Road – alternative fuels – EV	-	57	750
	Road – shifting passengers from cars to public transport	820	3,087	9,396
	Road – shifting freight from road to rail	1,840	2,729	2,997
	Road – biofuels	1,959	8,286	30,374
Subsector Total		**11,575**	**38,545**	**115,068**
TOTAL		**11,869**	**39,525**	**117,151**
TOTAL % Reduction (relative to WEM with indirect emissions included)		**12%**	**30%**	**54%**

Mitigation potential expressed relative to the reference WEM projection is shown for each sector and subsector in Table 27.

Table 27: Percentage reduction in reference WEM emissions for the transport sector, assuming all technical mitigation potential is implemented (%)

Sector	2020	2030	2050
Road	13	32	59
Rail	2	6	11
Aviation	4	8	11
Total	12	30	54

15.6 WAM Projection

Assuming that all available mitigation measures are implemented, the resulting WAM abatement projection is shown in Figure 50. Note that emissions from the power sector have been reallocated to end-use sectors and hence electricity-related emissions savings in industry end-use sectors have been adjusted for the progressive reduction of carbon intensity of the electricity supply over time.

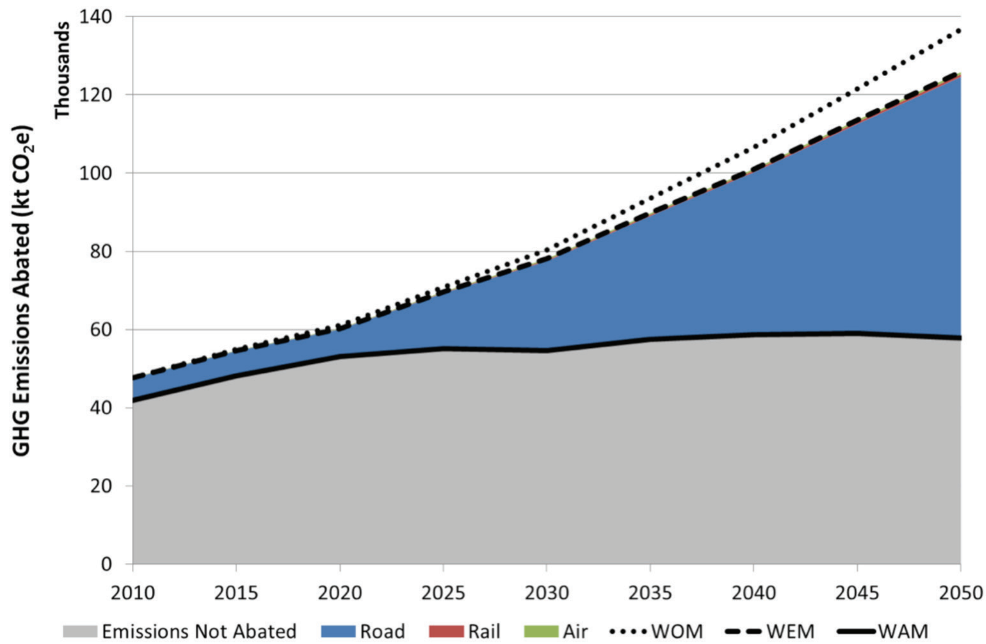


Figure 50: WAM scenario for the transport sector, showing a breakdown per sector. Emissions from the power sector have been reallocated to end-use sectors and electricity-related emissions savings have been adjusted accordingly. Reference case WOM and WEM emission projections are also shown

As described in the introductory section, 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 where implemented in the WAM scenario, this may be sufficient to delay a requirement for new investment in refinery capacity, which would be expected in a WEM scenario. This in turn would reduce the overall emissions associated with liquid fuel production.

16. The Waste Sector

This section provides an overview of mitigation opportunities for the waste sector. The assessment of mitigation opportunities focused on the municipal waste sector (due to a lack of data on industrial waste disposal) and considered emissions from the following IPCC emission sources:

- 4A1 managed waste disposal sites
- 4D wastewater treatment and discharge

Mitigation opportunities from managed waste disposal sites arise from reductions of methane (CH_4) emissions contained in landfill gas which is generated as a result of the anaerobic decomposition of organic waste deposited in the landfill. Wastewater treatment options result from emissions of both CH_4 and nitrous oxide (N_2O) depending on the treatment method.

Options identified for managed waste disposal fall into two categories. Firstly, better management of landfill sites, with recovery and flaring or use of landfill gas and secondly, alternatives to conventional landfill for disposing of organic waste. While landfilling of waste is the primary means of managed waste disposal currently, there is interest in South Africa in exploring other waste management options. For example the government is currently drafting a strategy on composting. While the options being considered focus on municipal solid waste, there may be other opportunities for using waste as a fuel.

The final list of measures considered for the waste sector includes:

- managed waste disposal measures:
  - landfill gas collection to electricity
  - landfill gas collection and flaring
  - anaerobic digestion
  - energy from waste
  - windrow composting
  - home composting
- in vessel composting
- paper recycling

Wherever possible, the assessment of mitigation options and potential has been aligned to the National Waste Strategy (DEA, 2011c), which promotes waste minimisation, reuse, recycling and recovery of waste while ensuring the effective and efficient delivery of waste services. Despite this, a mitigation option for waste minimisation was not evaluated for the purposes of the MACC analysis due to a lack of information to evaluate how this might be achieved in practice, and data on the costs and reductions which might be achieved. Wastewater treatment options were not considered for the purposes of the MACC analysis due to a lack of data to assess mitigation potential and due to the small size of the emissions source in South Africa.

A more detailed overview of emission trends, existing policies and potential future abatement opportunities in the sector is provided in Technical Appendix F: Waste Sector.

16.1 Marginal Abatement Cost Curves

The estimates of abatement and marginal abatement costs for all measures in the waste sector are presented in Table 32 for each of the three snapshots in time considered in this study: 2020, 2030 and 2050.

In 2020 (Figure 51), the landfill gas recovery and generation option is the lowest cost option (at less than R100/tCO_2e). This option also has the greatest abatement potential (4.8 MtCO_2e). Recovery and electricity generation has lower marginal abatement costs than recovery and flaring as the additional cost of generating equipment is more than offset by the value of the electricity produced, and the higher gas recovery rates assumed when recovery involves generation. Abatement for these options is higher than for other options as it is assumed these technologies can be implemented relatively quickly. Paper recycling, home composting and energy from waste have significantly higher marginal abatement costs than landfill gas recovery, (R360–370/tCO_2e), and have less abatement potential. Centralised composting and anaerobic digestion have higher marginal abatement costs again, (R650–900/tCO_2e) and only produce mitigation of 0.6 MtCO_2e. The total mitigation potential identified is just below 10 MtCO_2e.

By 2030 (Figure 52), the total mitigation potential has grown to 22.1 MtCO_2e, mainly due to fuller implementation of the mitigation options, but also as waste quantities generated grow, leading to increased emissions to be abated. While the marginal abatement cost of the landfill gas options remains the same as in 2020, the marginal abatement costs of other options increases slightly, as more implementation of landfill gas recovery reduces the savings the other measures can deliver.

This trend is also seen in 2050 (Figure 53). Landfill gas recovery and generation can still deliver significant abatement of 31 MtCO_2e at low marginal abatement cost, as some residual waste is still assumed to be disposed of to landfill and all sites are assumed to have recovery of gas by 2050. The total reduction in emissions which can be achieved, if mitigation options with higher marginal abatement costs are also implemented, is 39.7 MtCO_2e, or 78% of projected emissions in the sector.

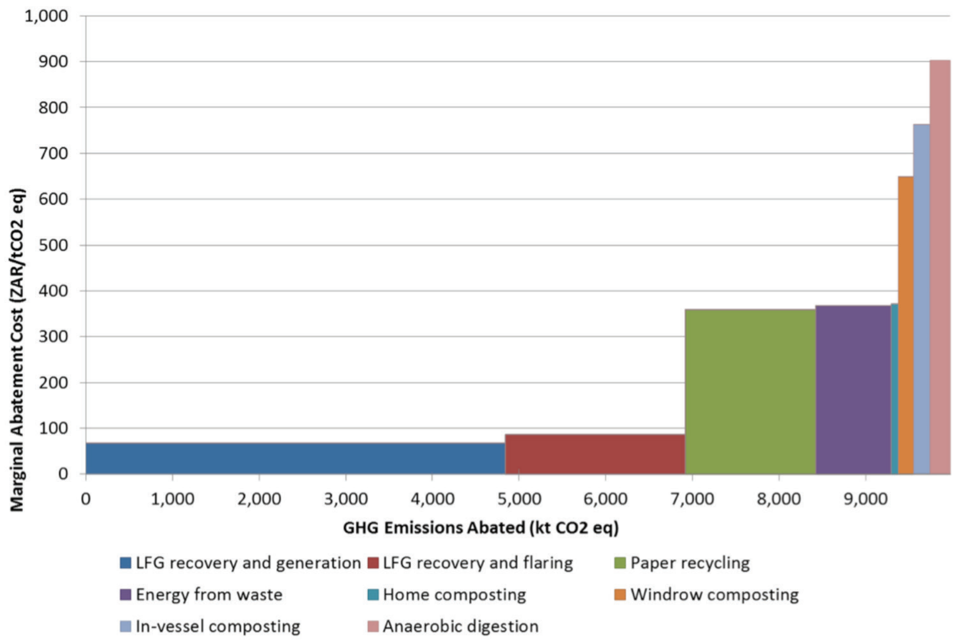


Figure 51: Marginal abatement cost curve for the waste sector in 2020

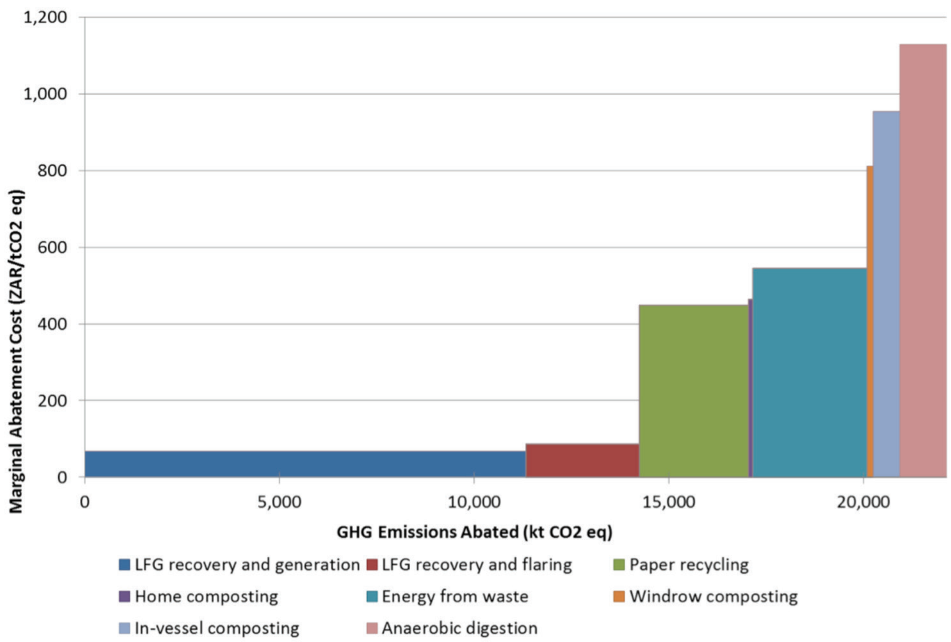


Figure 52: Marginal abatement cost curve for the waste sector in 2030

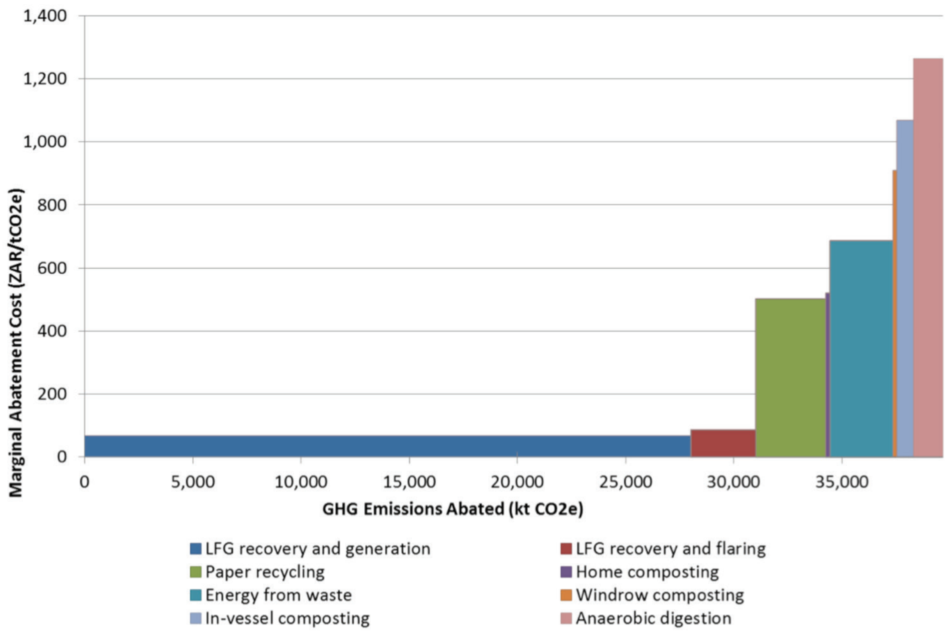


Figure 53: Marginal abatement cost curve for the waste sector in 2050

16.2 Technical Mitigation Potential

If all technically available mitigation potential in the waste sector were to be implemented, then the current analysis shows that GHG emissions could be reduced by 9,977 ktCO$_2$e in 2020, 22,122 ktCO$_2$e by 2030 and 39,658 ktCO$_2$e by 2050. This represents a total potential reduction of 41%, 66% and 78% (respectively) of reference emissions under the WEM projection (Table 28).

Table 28: Total mitigation potential for the waste sector, assuming all measures are implemented (in ktCO$_2$e)

Subsector	Measure	2020	2030	2050
Managed Waste Disposal	LFG recovery and generation	4,843	11,325	28,020
	Paper recycling	1,506	2,802	3,223
	LFG recovery and flaring	2,076	2,912	3,002
	Energy from waste	869	2,935	2,913
	Anaerobic digestion	234	1,198	1,354
	In-vessel composting	83	112	197
	Home-composting programme	189	682	771
	Windrow composting	176	155	176
TOTAL		**9,977**	**22,122**	**39,658**
TOTAL % Reduction (relative to WEM)		**41%**	**66%**	**78%**

17. The Agriculture, Forestry and Other Land Use Sector

Options covering the following IPCC emission categories have been considered in the assessment of mitigation potential for the agriculture, forestry and other land use (AFOLU) sector:

- 3A1 enteric fermentation
- 3A2 manure management
- 3B1 forestry land remaining forestry land and land converted to forest land
- 3B1b land converted to forest land
- 3B1-6b land converted into other land
- 3B2 cropland remaining cropland and land converted into cropland
- 3C4 direct N_2O from managed soils
- 3C1 biomass burning

The final list of mitigation options presented for the AFOLU sector was agreed after correspondence and collaboration with the AFOLU task team and other experts and specialists in the field. The list of measures is as follows:

- treatment of livestock waste
- expanding plantations
- urban tree planting
- rural tree planting (thickets)
- restoration of mesic grasslands
- biochar addition to cropland

Please refer to Technical Appendix G: Agriculture, Forestry and Other Land Use for a more detailed discussion of reference case projections and the assessment of mitigation potential in the sector.

17.1 Marginal Abatement Cost Curves

The estimates of abatement and marginal abatement costs for all measures in the AFOLU sector are presented in Table 32 for each of the three snapshots in time considered in this study: 2020, 2030 and 2050.

In 2020 (Figure 54), the expanding plantations measure is not only cost effective (cost savings estimated to be R91/tCO_2e), but it also mitigates the most emissions (an estimated 2,400 ktCO_2e). The restoration of mesic grasslands has the highest marginal abatement cost (R480/tCO_2e), while the treatment of livestock waste mitigates the least emissions by 2020 (155 ktCO_2e).

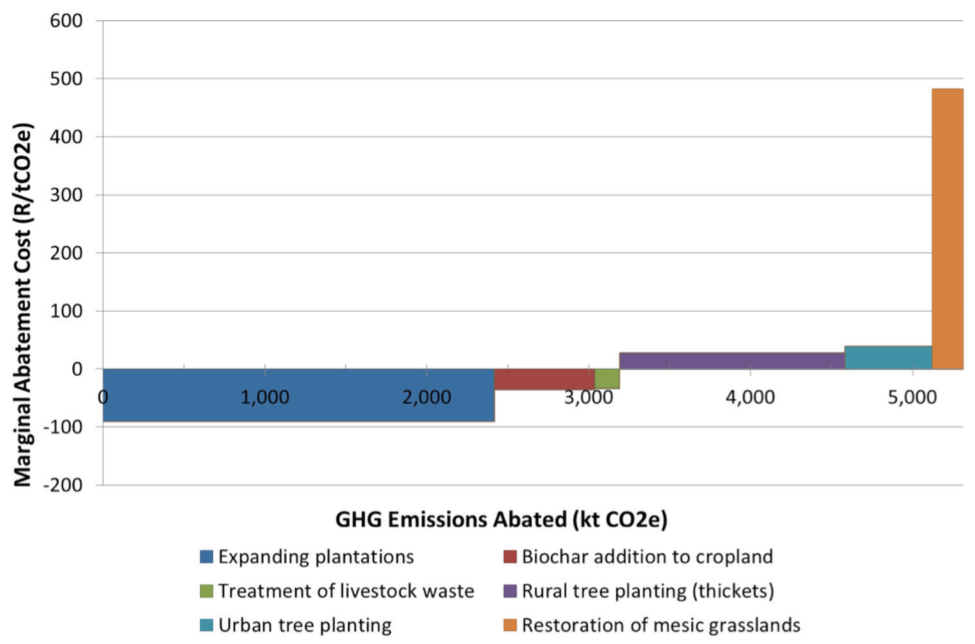


Figure 54: Marginal abatement cost curve for the AFOLU sector in 2020

In 2030 (Figure 55), expanding plantations, the treatment of livestock waste and biochar options are all cost-saving options and together mitigate an estimated 7,100 ktCO_2e. Restoration of mesic grasslands remains the measure with the highest marginal abatement cost. However, while these may be considered relatively easy measures to implement, other impacts need to be considered and are included as part of the multi-criteria analysis (MCA). This changes the relative priorities of these measures considerably, specifically commercial forestry which has high negative impacts under social and environmental criteria, for example.

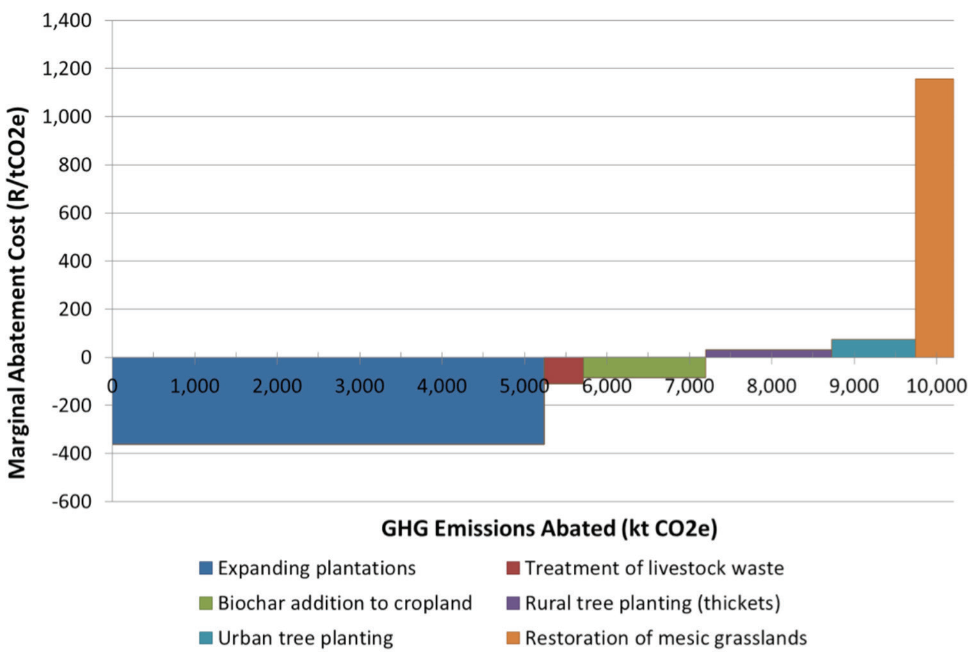


Figure 55: Marginal abatement cost curve for the AFOLU sector in 2030

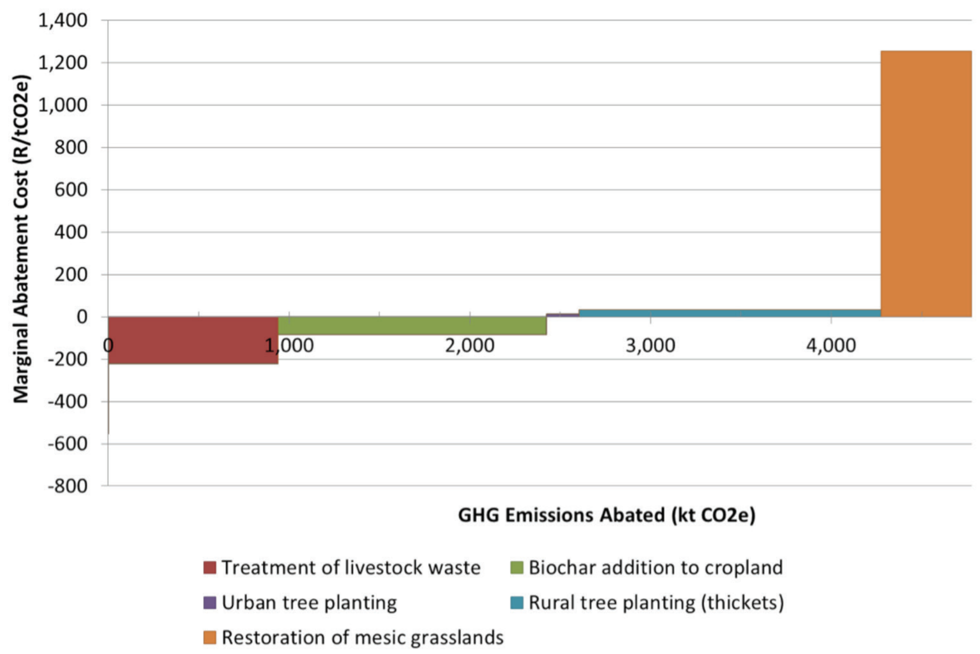


Figure 56: Marginal abatement cost curve for the AFOLU sector in 2050

In 2050 (Figure 56), the expansion of plantations is no longer a mitigation option since plantations can no longer be expanded and the maximum potential of the sector drops to 4,775 ktCO_2e. Rural tree planting and biochar addition to cropland contribute the most, while the mitigation potential from urban tree planting falls to 181 ktCO_2e. The treatment of livestock waste and biochar mitigation options both have negative marginal abatement costs in 2050.

17.2 Technical Mitigation Potential

If all technically available mitigation potential in the AFOLU sector were to be implemented, then these results indicate that GHG emissions could be reduced by 5,315 ktCO_2e by 2020, 10,206 ktCO_2e by 2030 and 4,775 ktCO_2e by 2050. This represents a total potential reduction of 10%, 19% and 9% respectively of emissions relative to the reference WEM projection (Table 29).

Table 29: Technical mitigation potential for the AFOLU sector, assuming all measures are implemented (in ktCO_2e)

Measure	2020	2030	2050
Urban tree planting	539	1,016	1,671
Treatment of livestock waste	155	1,485	1,485
Biochar addition to cropland	619	473	939
Restoration of mesic grasslands	192	461	499
Rural tree planting (thickets)	1,392	1,532	181
Expanding plantations	2,418	5,240	0
TOTAL	**5,315**	**10,206**	**4,775**
TOTAL % Reduction (relative to WEM)	**10.0%**	**19.4%**	**9.2%**

Chapter V: National Mitigation Potential

This chapter presents a national summary of mitigation potential. The chapter includes a national marginal abatement cost curve and a national summary of technical mitigation. The assessment of national mitigation potential continues with a description of national abatement pathways and a discussion of the wider macroeconomic impacts of implementing a range of measures under these pathways.

18. Summary of National Mitigation Potential

18.1 Marginal Abatement Cost Curve

National-scale MACCs are presented for each of the three snapshots considered (2020, 2030, 2050) in Figure 57 to Figure 59.[18] Detailed inputs to the MACCs for each measure are provided in Table 32. The individual measures which comprise the national MACCs are not identified in the figures below as this section focuses on a national summary of results. To this end, abatement estimates and marginal abatement costs are summarised for each of the three snapshots in Table 30. Results are presented per quartile of the total national mitigation estimate.

As illustrated in Figure 57 and summarised in Table 30, the total amount of abatement estimated in 2020 is 105,059 ktCO_2e, at an average marginal abatement cost of R59/tCO_2e. This represents a reduction of 15.8% relative to the reference WEM projection for future GHG emissions. The MACC illustrates that 37.8% of the total mitigation estimate for 2020 (39,716 ktCO_2e) can be achieved through implementing mitigation measures with a negative marginal abatement cost.

In 2030, the national estimate for mitigation potential rises to 348,220 ktCO_2e. This is a 40.6% reduction of emissions, assuming all identified mitigation measures are implemented relative to the reference WEM projection. A smaller proportion (25% or 87,945 ktCO_2e) of mitigation potential can be achieved through implementing mitigation measures with a negative marginal abatement cost.

In 2050, the estimate of national mitigation potential rises further to 887,169 ktCO_2e, or 55.7% of the reference WEM projection. Only 25,5% (226,661 ktCO_2e) of mitigation potential can be achieved through implementing mitigation measures with a negative marginal abatement cost.

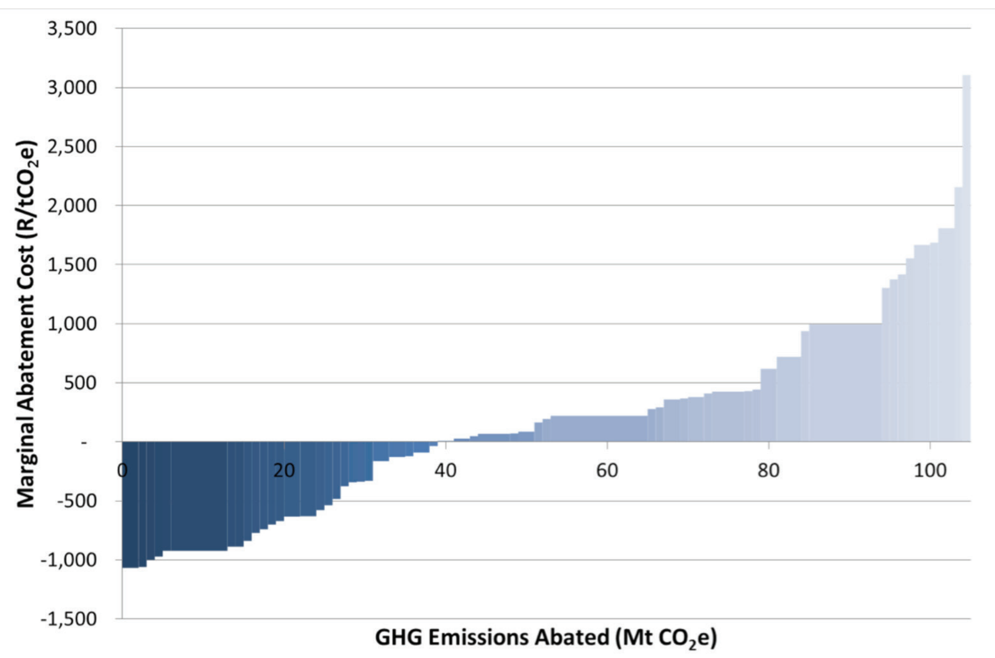


Figure 57: National marginal abatement cost curve for 2020

18. Note the MACCs presented here are not adjusted for direct and indirect saving in the transport sector.

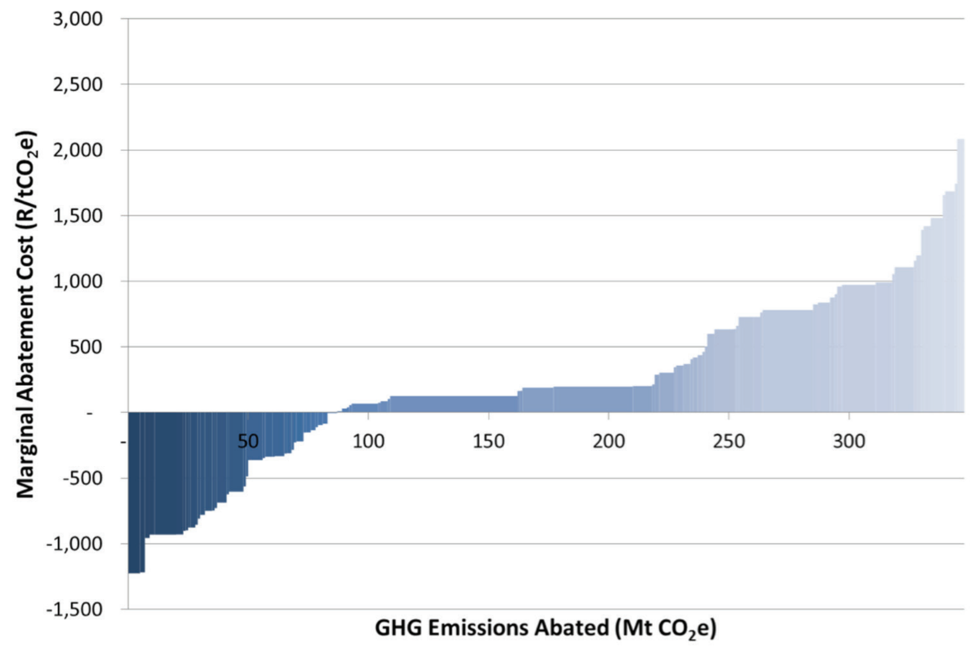


Figure 58: National marginal abatement cost curve for 2030

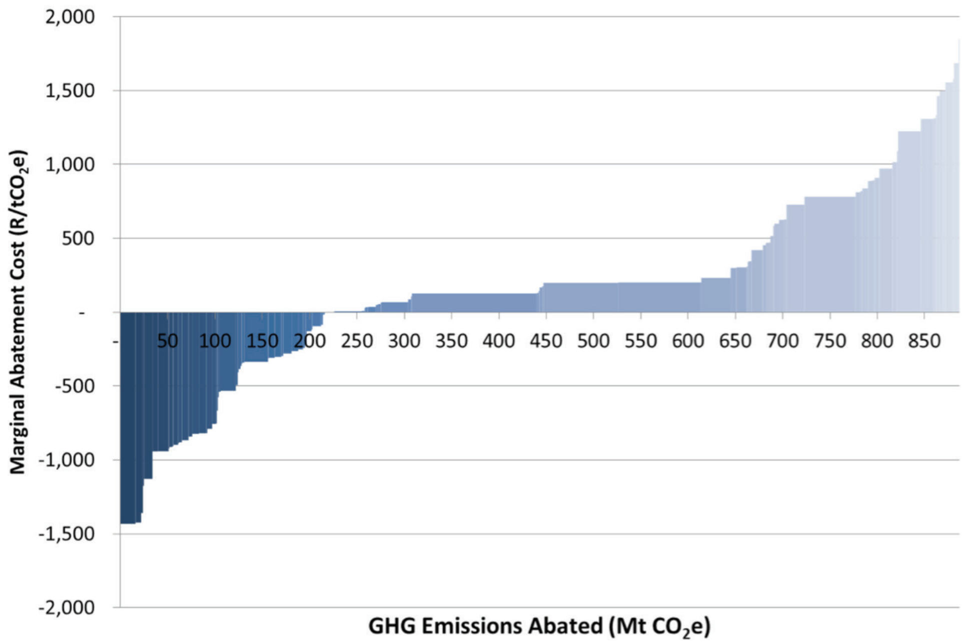


Figure 59: National marginal abatement cost curve for 2050

Table 30: Total national abatement, assuming full implementation of all measures under the WAM projection. Results show abatement ($ktCO_2e$) as well as upper and lower bounds for marginal abatement cost (MAC), (R/tCO_2e) per quartile of total abatement, for 2020, 2030 and 2050.

	2020			2030			2050		
	Total abatement	MAC lower bound	MAC upper bound	Total abatement	MAC lower bound	MAC upper bound	Total abatement	MAC lower bound	MAC upper bound
First Quartile	27,306	-1,068	-402	60,137	-1,226	-337	124,954	-1,432	-408
Second Quartile	11,417	-402	-83	29,501	-337	29	133,124	-406	8
Third Quartile	29,056	-72	346	148,140	30	420	409,519	13	401
Fourth Quartile	37,281	359	3,105	110,442	434	2,445	219,571	420	4,340
Overall	105,059			348,220			887,169		
Reduction compared to WEM	15.84%			40.59%			55.69%		

18.2 Technical Mitigation Potential

The national estimate of technical mitigation potential has already been discussed. In this section, a detailed breakdown per key sector is presented. Results are shown graphically in Figure 60 and in tabular form in Table 31. Also shown in this sector (for completeness) are the remaining emissions (i.e. emissions not abated) under the WAM projection (Figure 61).

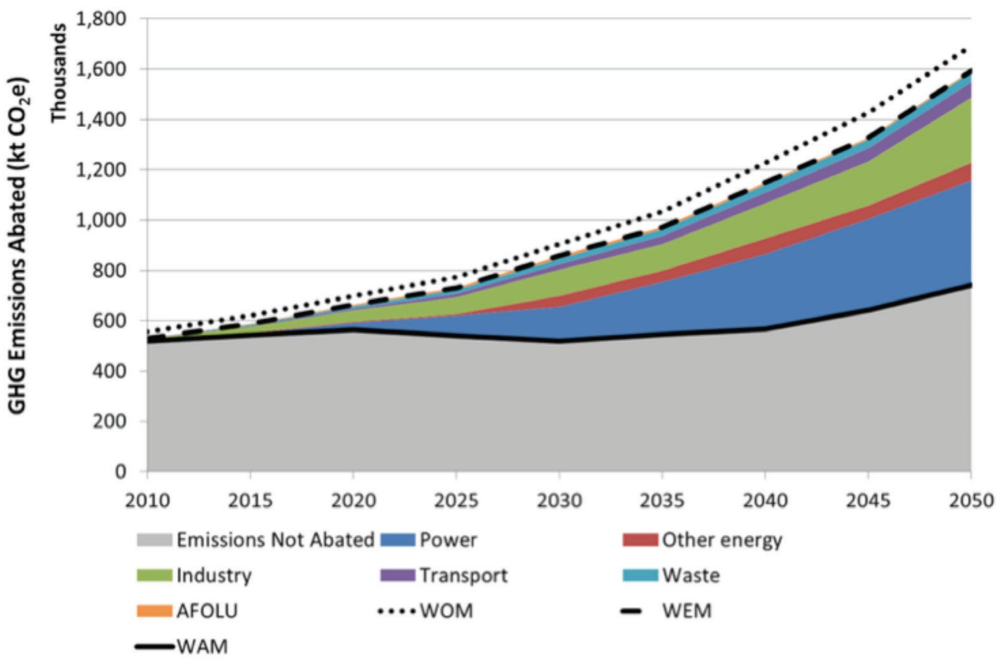


Figure 60: National abatement potential assuming all measures are implemented under the WAM projection. Results are shown for each of the key sectors, and reference projections for the reference case WOM and WEM projections are also shown. The total for all remaining emissions is indicated using grey shading.

When considering the total mitigation which might be achieved across all sectors, it is important to account for the interaction between sectors. For example, implementation of mitigation measures in the power sector will reduce the carbon intensity of electricity supplied, hence reducing the savings achieved by demand side electricity saving measures. Similarly, mitigation measures in the transport sector will reduce demand for liquid fuels, reducing the amount of new capacity and hence emissions in the refining and other energy industries sector. These adjustments are discussed further below. The national estimates of mitigation potential shown in this section allow for these interactions.

The analysis of mitigation potential has included estimates for emission savings related to energy efficiency and reduced electricity consumption. The study has also explicitly considered options for reducing emissions in the power sector by reducing the carbon content of South Africa's electricity supply through a combination of measures, including a switch to renewables and further implementation of nuclear power. As the dependence on coal-based fossil fuels in the electricity supply diminishes over time, the carbon intensity of electricity reduces over time. This effect impacts on estimated savings related to the reduced consumption of electricity in end-use sectors of the economy. To accommodate this, emissions from the power sector have been reallocated to end-use sectors and electricity-related emissions savings have been adjusted for the progressive reduction of carbon intensity of the electricity supply over time.

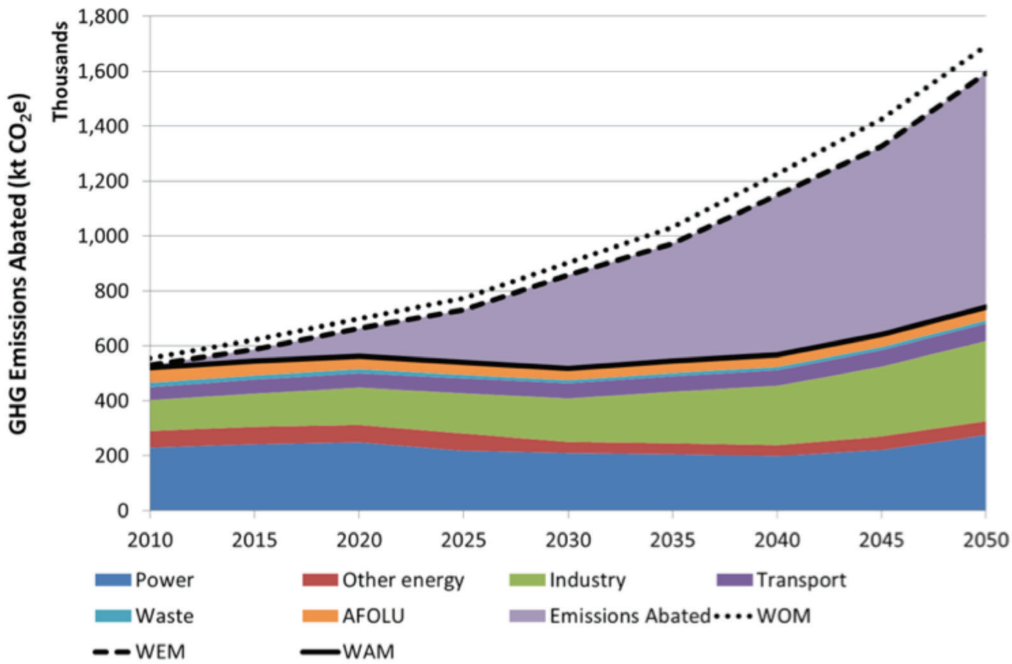


Figure 61: Remaining emissions under the WAM projection. Results are shown for each of the key sectors, and reference projections for the reference case WOM and WEM projections are also shown. Also indicated is the national estimate of mitigation potential (purple shading).

In calculating total technical mitigation potential for the energy sector, abatement estimates for the other energy industries and petroleum refining sectors have been adjusted to account for reductions in the demand for liquid fuels as a result of the implementation of abatement measures identified in the transport sector. In effect, reductions in direct emissions (that is, from fuel combustion) are allocated to the transport sector, and the indirect effects on fuel production are reflected in the other energy industries and petroleum refining sectors. Therefore, emissions (and hence abatement estimates) are adjusted in the other energy industries and petroleum refining sectors to reflect the reduced demand for liquid fuels associated with the implementation of abatement in the transport sector.[19]

The largest contributor to abatement in 2050 is the power sector, (at 416,555 ktCO_2e). This is a 26% reduction of emissions relative to the reference WEM projection. This estimate ramps up significantly after 2030, once a new nuclear power plant is commissioned. Overall, the energy sector accounts for technical mitigation potential of 5% (33,057 ktCO_2e), 21% (181,304 ktCO_2e) and 31% (487,557 ktCO_2e) compared to the reference case WEM projections in 2020, 2030 and 2050, respectively.

The second most significant contributor to national mitigation potential is the industry sector, accounting for 258,453 ktCO_2e in 2050 (a 16.2% reduction relative to WEM). Technical mitigation from the remaining three sectors (transport, waste, AFOLU) reaches 106,534 ktCO_2e in 2050 (a 6.7% reduction of reference WEM emissions).

Table 31: Total technical mitigation potential for the WAM projection (in ktCO_2e). Results are shown per key sector, and also as a percentage reduction of the reference case WEM projection. Total remaining emissions under the WAM projection are also shown.

	2020		2030		2050	
Sector/Projection	Abatement/ reference emissions	% WEM	Abatement/ reference emissions	% WEM	Abatement/ reference emissions	% WEM
WOM (reference)	699,307		903,700		1,692,471	
WEM (reference)	663,270		857,745		1,592,605	
Power	28,585	4.31	137,149	15.99	416,555	26.16
Other energy	4,472	0.67	44,154	5.15	71,002	4.46
Industry	44,842	6.76	103,850	12.11	258,453	16.23
Transport	6,952	1.05	22,530	2.63	62,101	3.90
Waste	9,977	1.50	22,122	2.58	39,658	2.49
AFOLU	5,315	0.80	10,206	1.19	4,775	0.30
Emissions Abated (relative to WEM)	**100,143**	**15.10**	**340,012**	**39.64**	**852,544**	**53.53**
Remaining Emissions (WAM)	**563,127**		**517,733**		**740,061**	

19. This adjustment implicitly assumes that the abatement measures identified for the transport sector will be fully implemented. In practice, the level of implementation may be lower than this, or other factors may influence growth in fuel demand from transport, which will in turn influence the level of liquid fuel demand and the emissions from the other energy industries and petroleum refining sectors.

The national estimates of mitigation potential for 2020, 2030 and 2050 represent a reduction of 15.1%, 39.6% and 53.5%, respectively, relative to the WEM projection. If the same estimates of technical mitigation potential are expressed relative to the WOM reference case projection, they are 14.3%, 37.6% and 50.4%.

Under the Copenhagen Accord, South Africa is committed to reduce its GHG emissions by 34% and 42% below a business as usual (BAU) emissions growth trajectory (by 2020 and 2025, respectively). The WOM reference case is possibly best suited to the description of a BAU emissions growth trajectory. On this basis, the assessment of technical mitigation potential indicates a significant contribution to South Africa's international emission reduction commitments. For reference, estimated emission reductions for 2025 from the current study are 30% of the reference WOM projection and 26% of the reference WEM projection.

The remaining GHG emissions under the WAM projection (563 $MtCO_2e$, 517 Mt CO_2e and 740 $MtCO_2e$) fall within the peak, plateau and decline (PPD) emissions trajectory during the 2010–2040 period. The result is illustrated graphically in Figure 62 and discussed further in the next section.

19. National Abatement Pathways

Having defined national mitigation potential in the previous section, focus now shifts from assessing individual measures to assessing pathways which are essentially groupings of mitigation measures. It is the intention in the remaining section of the report to demonstrate how these pathways can be constructed and what the broader macroeconomic impact of those choices would be, if implemented.

19.1 Level of Implementation of Mitigation Potential

A straightforward way to illustrate a range of different mitigation outcomes for South Africa is simply to implement varying amounts of the total mitigation potential identified in this study. This is shown in Figure 62 which plots four different WAM pathways. The pathways assume varying proportions of implementation of the total mitigation potential over time – 100%, 75%, 50% and 25%. Also plotted on the same figure are the reference case emission projections developed in this study (WOM and WEM) as well as the growth without constraint (GWC) curve and the PPD emission reduction trajectory range (developed under the LTMS study and under the NCCRP, respectively). The comparison indicates firstly that emission reductions achieved by 2050 (with respect to the WEM reference case) are 213, 426 and 639 Mt CO_2e for the 25%, 50% and 75% levels of implementation of mitigation potential, respectively.

The WAM pathway, which assumes all mitigation potential is implemented, achieves emission reductions which fall within the PPD range, between 2010 and 2040. The 75% implementation pathway follows the upper limit of the PPD range between 2010 and 2030. Maintaining emissions reductions which fall within the PPD range after 2040 will require more mitigation potential to be identified and implemented in future than has been estimated in this study.

Lastly, absolute levels of emissions in South Africa do not reduce over the long term. Assuming all identified mitigation potential is implemented, emissions decrease in absolute terms in both 2020 and 2030. But in 2050, and for all other levels of implementation of abatement potential, no absolute emission reductions relative to 2010 are achieved. This result is driven largely by the assumptions driving the decarbonisation of South Africa's electricity supply (given this sector's dominance of both projected emissions and estimated mitigation potential). These assumptions tie reduced dependence on coal-based power and diversification towards other energy sources (such as renewables, biofuels and nuclear power) to modelling conducted under the Integrated Resource Plan (IRP) (DoE, 2011). By definition, the IRP planning horizon was limited to 2030. Beyond this horizon, the share of coal and non-coal-based power in South Africa is effectively held constant – with growth in supply driven by demand from end-use sectors.

This effectively limits the level of diversification of South Africa's power supply which will have to be reconsidered in future. A more aggressive decarbonisation of South Africa's electricity supply will have to be targeted as part of the process of updating the IRP if an absolute reduction in emissions relative to current levels, or a more ambitious emissions reduction target (such as PPD) is to be achieved.

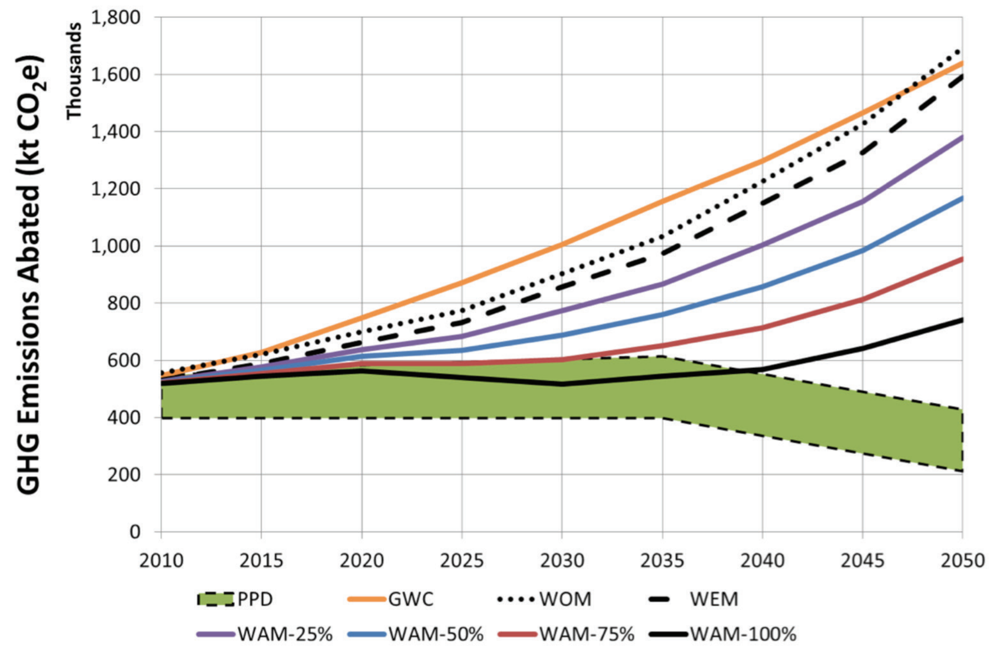


Figure 62: National abatement pathways based on the WAM projection. Pathways indicated assume different levels of implementation of the national mitigation potential (100%, 75%, 50%, 25%). Also shown are the reference case WOM and WEM projections as well as the GWC and PPD scenarios developed under the LTMS study (ERC, 2007) and the NCCRP (DEA, 2011a), respectively

Figure 63 shows how the sector breakdown in mitigation potential changes with different levels of implementation of mitigation potential. This occurs because of the distribution of measures in each sector across the full spectrum of measures under the balanced weighting pathway (assuming all mitigation potential is implemented). For example, it is evident from the graph that energy measures are not well represented in the top 50th percentile of total mitigation. In contrast, transport has a strong representation in the top 50th percentile. This pattern of mitigation by sector is important when applying the economic analysis and implies that the only way to compare impact across pathways and level of implementation of mitigation potential is to normalise the impacts (GDP and employment) by dividing by the amount of mitigation potential for the sector.

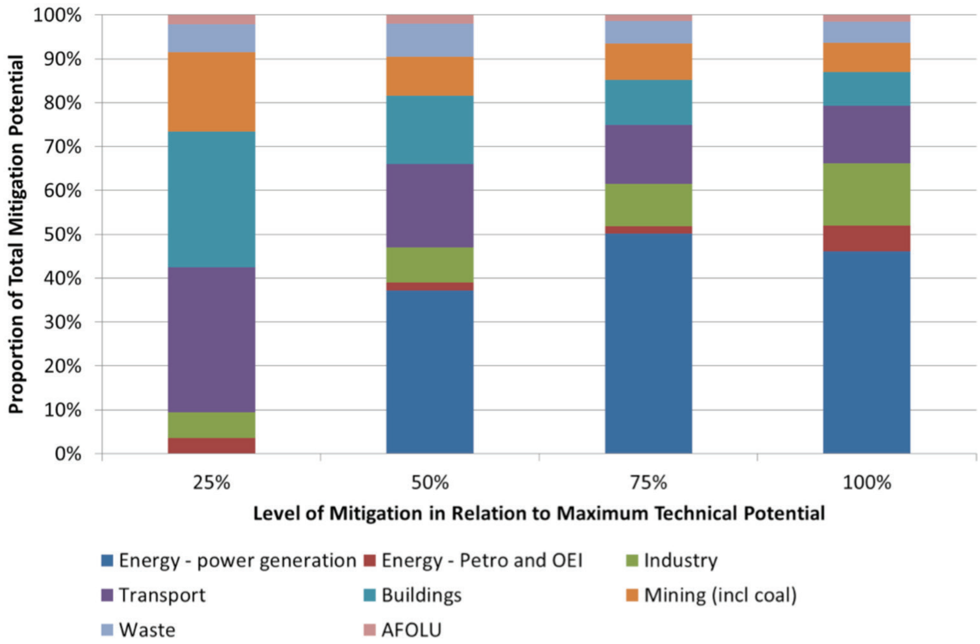


Figure 63: Split in technical mitigation potential between sectors as the level of identified mitigation potential is increased (note: cut-offs are not at exact 25 percentiles)

19.2 Marginal Net Benefit

Three mitigation pathways have already been determined, based on different weightings of the main criteria in the MCA framework (approved by the TWG-M). By definition, the MCA framework is developed to allow decision-making regarding the ranking of measures which considers more than merely abatement potential and marginal abatement cost. The selected pathways are as follows.

- A balanced weighting pathway, which allows for relatively equal consideration of all key factors in the MCA model.
- A pathway which emphasises the cost and implementability of mitigation measures, effectively assigning a larger weight to those measures which have lower marginal abatement costs and are easier to implement.
- A pathway which emphasises social and environmental factors, effectively prioritising measures with lower impacts in these areas

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. The curves for each of the three abatement pathways are shown in Figure 64 to Figure 66.[20] Using these curves, it is possible to read from the horizontal axis how much total mitigation can be achieved (with 25%, 50%, 75% and 100% of total mitigation potential used for illustration purposes) over the 40-year lifetime of the current assessment. Scores for each measure are expressed in percentiles.

Figure 64, Figure 65 and Figure 66 effectively illustrate the marginal net benefit (for the same level of abatement) that can be achieved following different implementation pathways. There are several ways to interpret these graphics. For example, implementing all measures in the top 50th percentile of measures (based on their marginal net benefit score) will yield

20. Note that results for the MCA modelling for all measures are shown in Table 33.

only approximately 25% of total mitigation under the balanced weighting pathway as well as the pathway which seeks to implement first those measures which have relatively lower costs and are easier to implement (Figure 64 and Figure 65, respectively). By comparison, implementing the top 50th percentile of measures according to the pathway which emphasises social and environmental factors will achieve approximately 50% of the available lifetime technical mitigation potential (Figure 66).

Key power sector measures (identified in the figures below) achieve relatively large amounts of abatement (nuclear power and renewables, for example) but generally have marginal net benefit scores which lie in the lower 50th percentile of scores for all measures. As a consequence, once implemented, the proportion of total abatement achieved reaches approximately 75% for all pathways.

Implementing the final quartile of mitigation potential in all three pathways will become harder, as measures become increasingly costly, with more substantially negative social and environmental impacts and also as the limits of technological possibilities are reached.

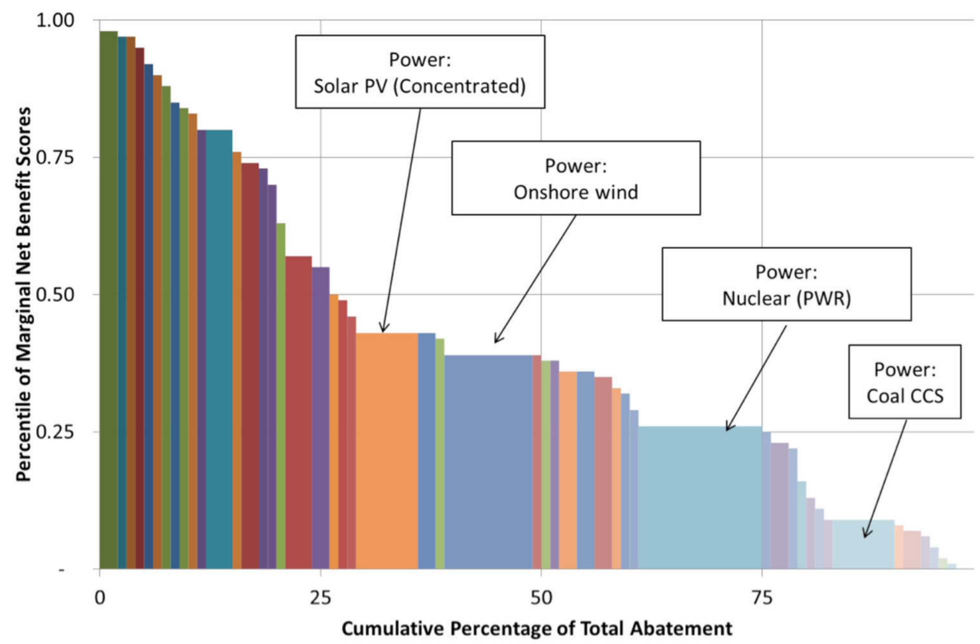


Figure 64: Proportion of total abatement potential nationally plotted against marginal abatement net benefit scores (also shown as percentiles of all scores) for the balanced weighting abatement pathway.

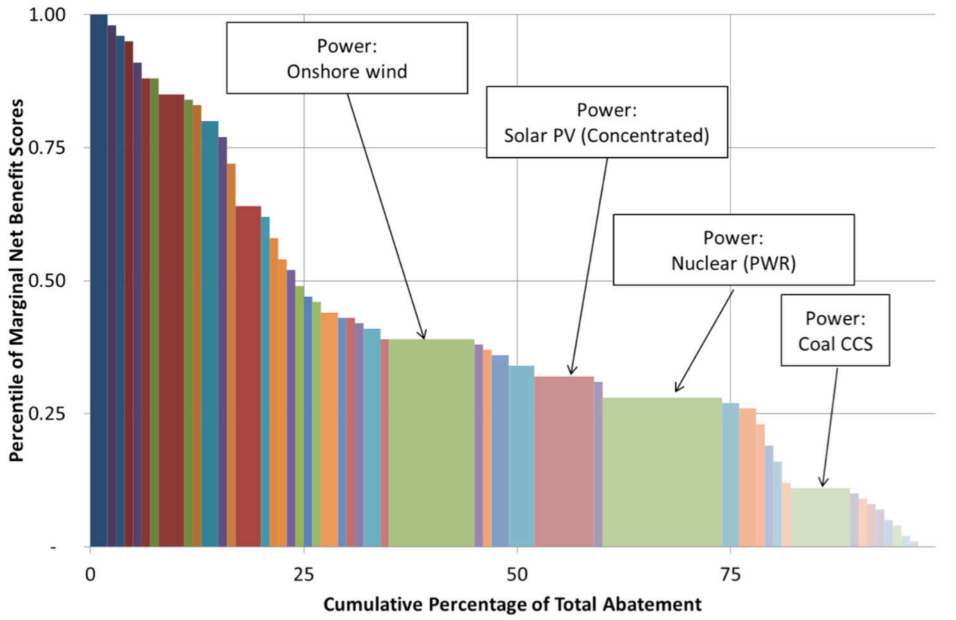


Figure 65: Proportion of total abatement potential nationally plotted against marginal abatement net benefit scores (also shown as percentiles of all scores) for the abatement pathway which emphasises the cost and implementability of mitigation measures

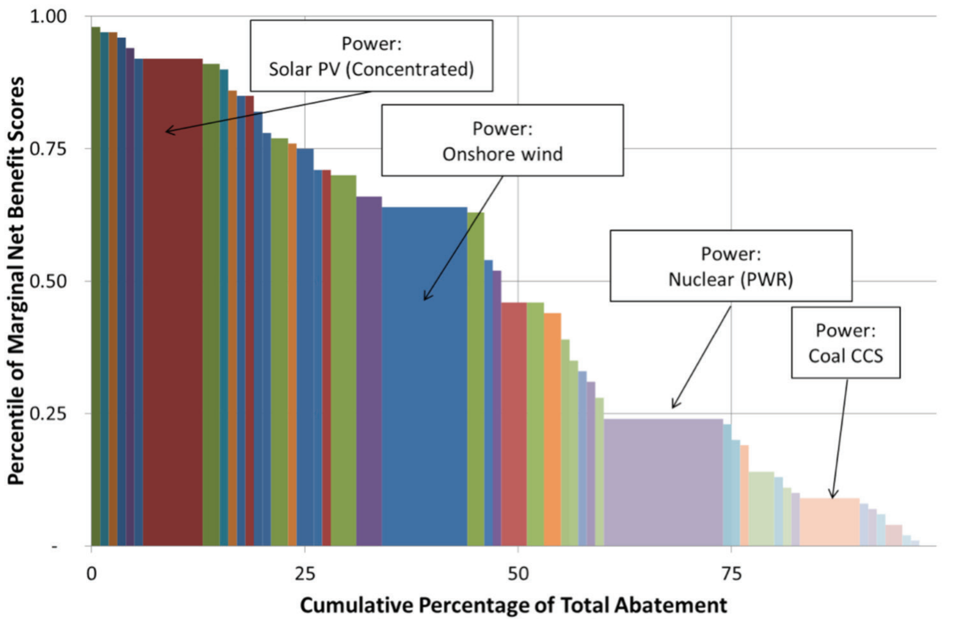


Figure 66: Proportion of total abatement potential nationally plotted against marginal abatement net benefit scores (also shown as percentiles of all scores) for the abatement pathway which emphasises social and environmental factors

20. The Wider Impacts of Implementing the National Abatement Pathway

In Section 12, the importance of the macroeconomic impact assessment in decision-making relating to pathways was described. The structure of the analysis (based on the application of the INFORUM model) is also described there. The analysis is undertaken for the 100% level of mitigation, with all measures applied. The economic modelling gives results for gross GDP and employment. The full sets of results are reported in Technical Appendix B; Macroeconomics, with the key results summarised below. For a full discussion of the macroeconomic impacts modelling methodology and results, please refer to Appendix B.

20.1 Impacts on Gross Domestic Product

The result of the GDP impact analysis indicates that the economy will grow (expressed in terms of GDP, taking the current GDP as the basis) by R48 billion on average, assuming all mitigation measures are implemented. This constitutes approximately 1.5% of current GDP.

In considering this 1.5% figure, the factors which influence both positive and negative changes in the GDP need to be considered. While backward linked impacts are mostly positive (driven by capital expenditure and increased operating expenditure associated with the mitigation measures) the forward linkages often lead to negative GDP changes, driven by increases in prices. The fact that the final outcome gives a positive change in GDP for all sectors is, in itself, a significant conclusion. The impact per sector is shown in Figure 67 below.

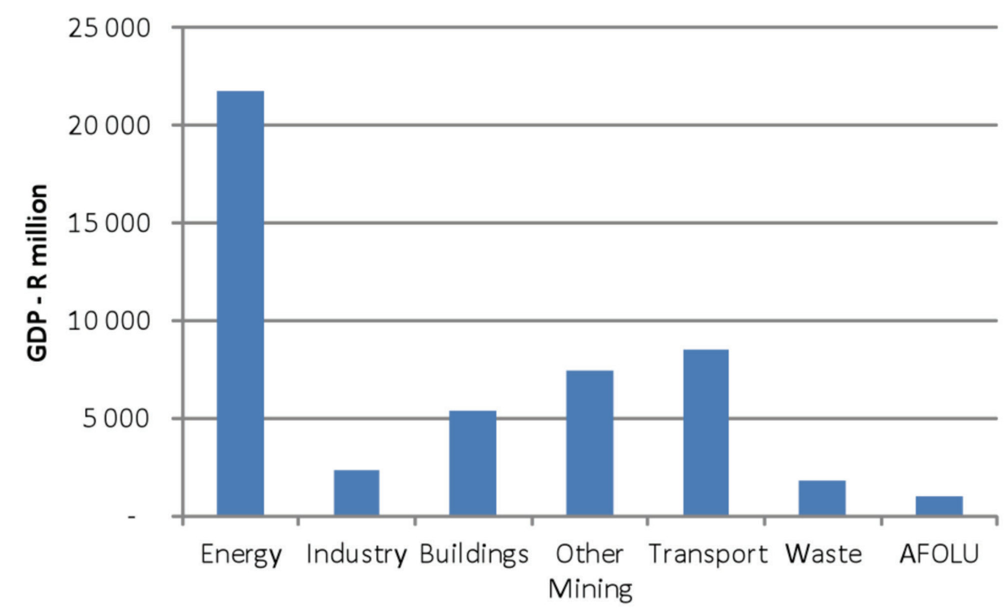


Figure 67: GDP impact per sector (value, R million) assuming 100% of technical mitigation potential is implemented

It is evident that the energy sector dominates. But it is notable that that this dominance is concentrated at the middle and lower end of the mitigation measure priority range (See Figure 63). On the other hand, building and transport measures are also significant but are concentrated at the higher end of the mitigation priority range.

With the INFORUM model the results are analysed over the full 40 year period covered in the mitigation assessment. A plot of the marginal change in GDP over this period is shown in Figure 68 below.

The declining trend over time is due to the inclusion of less economically favourable measures in the later decades. The average marginal impact on GDP is R48 million, with a peak of R70 million in 2025 (Figure 68). The marginal impact in 2010 is zero because no additional mitigation has been implemented yet at the beginning of the projection.

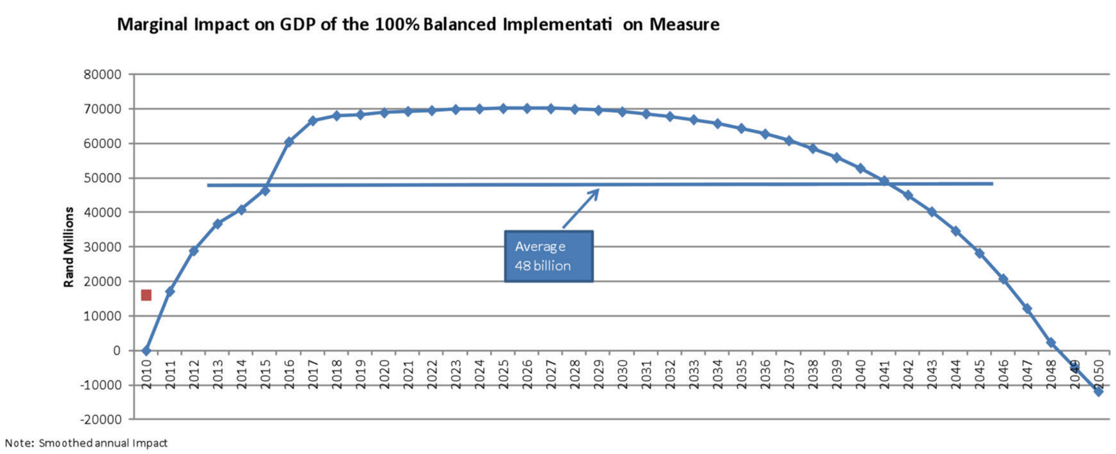


Figure 68: The varying impact over time on GDP, assuming all available mitigation potential is implemented

20.2 Impacts on Employment

The analysis shows that a final total of 195,000 net jobs is created, on average over the 40 year period being assessed.[21] This represents 1.2% of the average of the projected number of jobs in the South African economy over the period 2010 to 2050. The employment gains are, therefore, modest.

The net change in jobs per sector is shown in Figure 69 below, assuming all quantified mitigation potential is implemented.

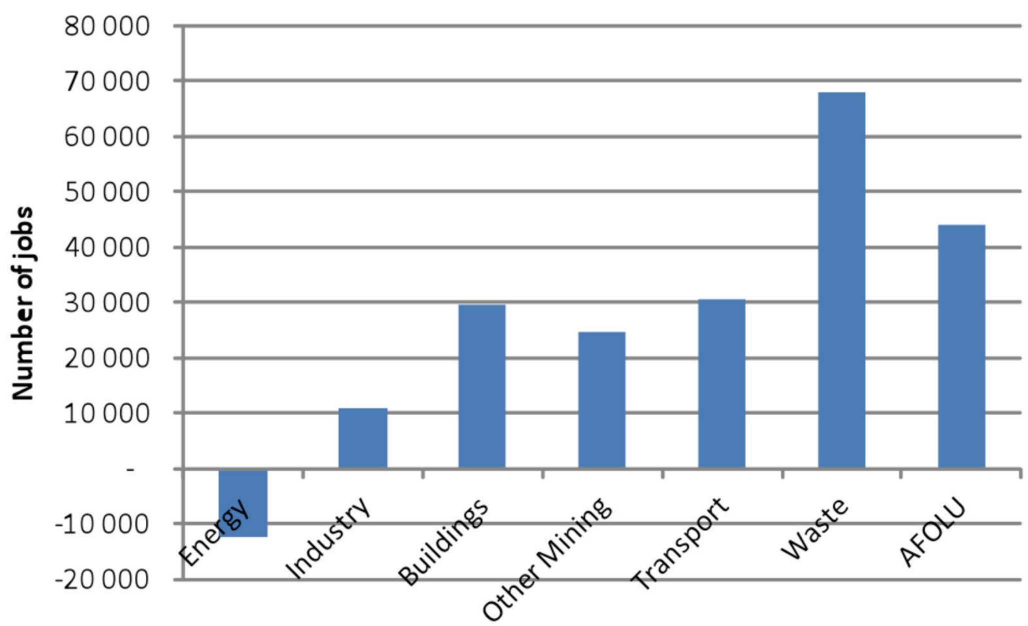


Figure 69: Impact on jobs per sector assuming 100% of technical mitigation potential is implemented

The negative figure for jobs in the energy sector is associated primarily with the structural change in the energy economy as coal-fired power stations, with the associated mining industry jobs, are displaced with less employment-intensive measures. Both the waste and AFOLU sectors include measures which are employment-intensive.

Due to the importance of the waste and AFOLU sectors from an employment point of view, the employment figures from the INFORUM model have been adjusted, taking into consideration that these sectors have different relationships between GDP and employment compared to the standard figures in the model. This adjustment amounts to an average of 98,000 jobs.

The impact of investment is positive in all cases. For energy and transport, the backward linked impact due to operational cost changes is negative but all other sectors have positive impacts. With regard to forward linked impacts on employment, associated with price changes, the pattern is the same as for GDP: negative for all sectors bar mining and buildings.

The trends over time for all employment are shown in Figure 70 below, based on the results of the INFORUM model, with the waste and AFOLU figures adjusted.

The results directly from the INFORUM model and with adjustments for waste and AFOLU sectors are shown. As with GDP the downward trend towards the later decades relates to the inclusion later in the period of analysis of measures with poorer employment characteristics (waste and AFOLU sectors excluded).

21. Includes adjustment of INFORUM results for AFOLU and waste sectors.

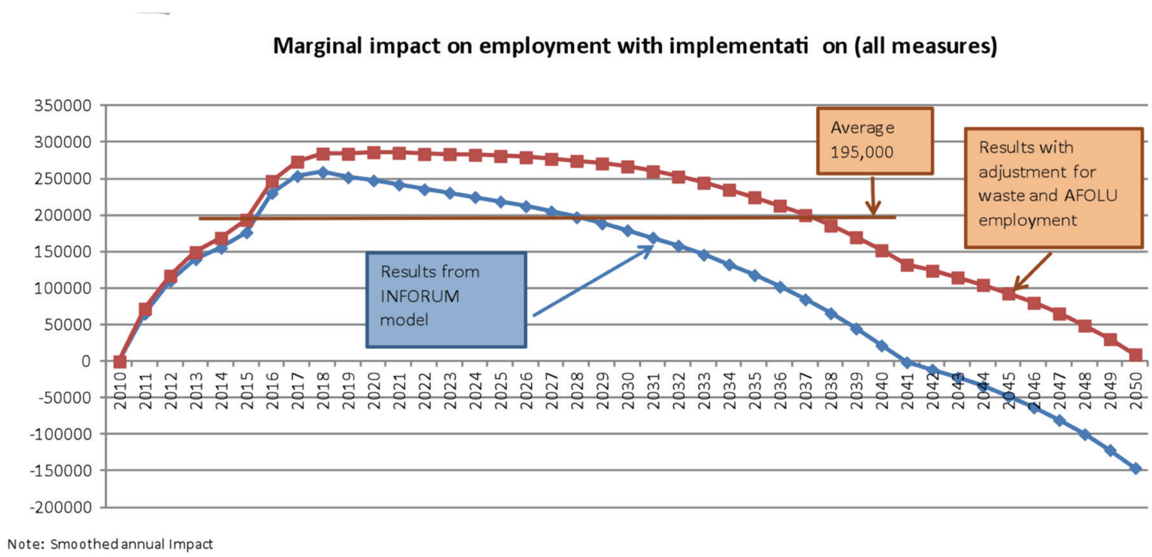


Figure 70: The marginal impact on employment over time, assuming all available mitigation potential is implemented under the balanced weighting pathway

20.3 Conclusions With Regard to Economic Impact

With regard to GDP impact, the modelling shows a positive outcome in terms of backward linkages for all sectors. With regard to forward linked impact the results are negative for energy, transport, waste and AFOLU sectors, associated with increases in net costs and hence the need for price increases on products and services associated with these sectors which reduces economic efficiency. In the case of the mining and buildings sectors, the forward impacts are positive, with industry being neutral. In total, if all mitigation measures are implemented, the marginal impact on GDP is approximately a 1.5% increase. This is a modest impact but is, nevertheless, significant in being positive.

Turning to the impact on employment, with the full implementation of mitigation potential the impact on employment is an increase of about 1.2%, also a modest increase but also significant in that it is positive. The net impact is negative in the case of the energy sector (largely because of the loss of low-skilled jobs in the coal mining sector as the proportion of renewables and nuclear power in South Africa's energy mix grows and hence demand for coal decreases). The impact on employment is positive for all other sectors with the waste sector as the biggest contributor, followed by AFOLU, buildings, transport and mining.

In conclusion, the economic assessment conducted in this analysis aims to illustrate the possible economic impacts from implementation of the range of mitigation measures identified in this study. It shows that there are considerable backward linked GDP and employment gains but these are countered by forward linked effects for many sectors as prices increase due to implementation of mitigation measures with a negative impact on GDP and jobs. It is accepted that no economic model is perfect and that the complexity of the economy combined with the complex set of mitigation measures applied to many sectors of the economy means that the results are useful mainly to show the broad scale and trends with respect to economic impacts.

Further, while the economic analysis has been important for comparing the relative merits of individual mitigation measures, the overall economic impact results are of secondary importance to this particular study. In considering the concept of a lower-carbon economy the GHG mitigation benefit is clearly the most important factor. This presentation of the economic impacts aims to stimulate debate rather than inform policy. Further work will be required to identify the economic costs of climate change and compare them to various adaptation and mitigation options. As part of this further work, there is a need to better understand the drivers and barriers of investment into greener technology.

Chapter VI: Summary

21. Summary of Key Project Outcomes

The following key project outcomes have been achieved:

Reference Case Projection of Future GHG Emissions

Greenhouse gas (GHG) emissions projections developed under this study are based on a targeted level of future economic growth. This target is defined by the moderate growth scenario according to the National Development Plan. Two reference case emission projections have been developed. The first, 'without measures' (WOM) projection, assumes that no mitigation occurs between 2000 and 2050. The second, 'with existing measures' (WEM) projection, explicitly accounts for the impacts of climate change policy and for early mitigation measures implemented before 2010. The WEM projection extends from 2010 to 2050. For the period 2000 to 2010 the projections follow the actual path of observed emissions according to the draft 2010 national Greenhouse Gas Inventory (GHGI), with the exception of the power sector where additional information from Eskom (relating to the net calorific value of coal) was used to revise the emissions estimate in the draft GHGI.

Under the WOM reference case, GHG emissions reach 1,692 $MtCO_2e$ by 2050. Under the WEM reference case, the equivalent figure is 1,593 $MtCO_2e$ by 2050. The WEM projection is used as the reference case for all future mitigation potential because its starting point is aligned to historical emissions and the projection represents the pathway for future emissions assuming no additional mitigation is implemented.

The reference case GHG emissions determined in this study for 2050 resemble results from earlier work conducted under the Long-Term Mitigation Scenarios (LTMS) study. The LTMS 'growth without constraint' reference case projected GHG emissions in 2050 of 1,638 $MtCO_2e$. Given the adjustment for the net calorific value of coal, the emissions projections for 2020 and 2030 in this study are lower than those estimated under the LTMS study.

Accounting for Early Mitigation Action

The study has accounted for early mitigation actions implemented in each sector between 2000 and the present. These were determined through a review of climate change policies and measures, and through consultation with industry in order to understand and quantify the impacts of mitigation measures already implemented within sectors.

For some actions, the impact on the emissions or energy savings achieved was assessed based on information provided directly by industry or the relevant implementing bodies. In some cases, for mitigation measures in industry and the energy sector, the emissions reductions were calculated based on the levels of uptake of the measure in 2010 which were agreed with industry.

Sensitivity Analysis for Emissions

A sensitivity analysis was carried out based on a higher and lower rate of economic growth. The changes in growth were used to derive high and low growth projections for the energy, industry and waste sectors. Emission projections for the transport sector are based on forecasts of transport demand made by an external study; therefore it was not possible to estimate the sensitivity of emissions to macroeconomic growth for the sector. The emissions projection assumes that economic growth is not a driver of emissions in the agriculture, forestry and other land use (AFOLU) sector because the supply of agricultural land is already constrained. For this reason the AFOLU sector was also excluded from the sensitivity analysis. Note that collectively, the transport and AFOLU sectors account for 11% of total emissions in 2050 under the WEM projection, so the exclusion of these sectors (while likely to result in an under-estimate of sensitivity) is not likely to have a significant impact on the overall result.

Low and high growth projections of 3.8% and 5.4% respectively per annum by 2050 were based on inputs provided by National Treasury. Under the low growth scenario, GHG emissions are projected to be 15% lower (1,361 $MtCO_2e$) by 2050 than the reference case WEM projection. Under the higher growth scenario, GHG emissions are projected to be 18% higher (1,882 $MtCO_2e$) by 2050 than the reference case WEM projection.

Updated Assessment of Mitigation Potential for Key Sectors

One of the primary outputs from this study is a comprehensively updated and very detailed assessment of mitigation potential for key sectors of the South African economy. The study has successfully identified a broad range of technically feasible mitigation measures across the energy, industry, transport, waste and AFOLU sectors (172 measures in total). Mitigation opportunities are presented that cover emissions from a variety of different sources including fugitive emissions, process emissions, direct fuel emissions and/or indirect electricity related emissions (as defined by the emissions sources of each key sector).

In all cases, the sectoral and subsectoral mitigation potential estimates have been developed in close consultation with a broad range of stakeholders, including industry, government and civil society, through a mechanism of sector specific task teams established for this purpose.

Nationally, the technical mitigation potential (assuming 100% implementation of all identified mitigation options) is 853 Mt-CO_2e in 2050, representing a 55% reduction of emissions relative to the reference case WEM projection. The equivalent figures for 2020 and 2030 are 100 and 340 MtCO_2e (15% and 40% reduction relative to WEM), respectively.

For the energy sector, technical mitigation potential in 2020, 2030 and 2050 is 33, 173 and 467 MtCO_2e (accounting for 33%, 51% and 55% of available potential in those three snapshots). In calculating total technical mitigation potential for the energy sector, abatement estimates for the other energy industries and petroleum refining sectors have been adjusted to account for reductions in liquid fuels as a result of the implementation of abatement measures identified in the transport sector.

The industry sector accounts for 45, 104 and 258 MtCO_2e in 2020, 2030 and 2050. For the transport sector, the equivalent mitigation estimates (based on direct emission savings only) are 7, 23 and 62 MtCO_2e. Mitigation estimates in the waste and AFOLU sectors are smaller: 10, 22 and 40 MtCO_2e in the waste sector and 5, 10 and 5 MtCO_2e in the AFOLU sector.

Development of Marginal Abatement Cost Curves

Marginal abatement cost curves have been developed for a range of sectors and subsectors, with summaries provided for key sectors and on a national scale. This study represents the first comprehensive attempt to build MACCs for the South African economy as a whole.

Development of National Abatement Pathways

The assessment of technical mitigation potential discussed above is based on abatement estimates for individual measures. In developing national abatement pathways, the study has also focused on assessing options for implementing and prioritising groupings of mitigation measures. To achieve any particular abatement pathway, it is necessary to select a target level of abatement and to decide which measures to implement and which not to. Individual pathways, assuming different levels of ambition (targeted levels of available mitigation potential), have been illustrated.

A multi-criteria analysis (MCA) framework was developed expressly to incorporate additional factors into the decision-making process surrounding implementation of mitigation measures. The National Climate Change Response Policy (NCCRP) states clearly that the strategic response to mitigation must facilitate a "long-term transition to a climate-resilient, equitable and internationally competitive lower-carbon economy and society – a vision premised on Government's commitment to sustainable development and a better life for all" (DEA, 2011a p10) To this end, the MCA framework has been developed to allow consideration of factors other than mitigation and cost – including economic and social impact (including jobs), non-GHG environmental impacts and implementability. By weighting these factors differently when calculating a weighted average score for each measure, it has been possible to derive different abatement pathways – assuming differences in prioritising the order of implementation of those measures. The three pathways developed on this basis are the following.

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

These concepts were further developed to construct a marginal abatement net benefit curve (MANBC). 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.

Assessment of the Wider Impact of National Abatement Pathways

Lastly, the wider macroeconomic impact of implementing all mitigation measures under the balanced weighting pathway has been assessed. The impact on GDP indicates an increase of about R48 billion with all mitigation measures (100% ambition) applied over the programming period (the next 40 years). This constitutes approximately 1.5% of current GDP. In considering this 1.5% figure, the factors which influence the GDP change both positively and negatively need to be considered. While backward-linked impacts are mostly positive (driven by capital expenditure and increased operating expenditure associated with the mitigation measures) the forward linkages often give negative GDP changes, driven by increases in prices.

The net impact (the impact of the assessment, less the impact of the counterfactual) on employment of the various measures is 97,000 jobs based on the standard figures in the INFORUM model which uses the current structure of the economy in terms of labour intensity. Adjustments have been made to employment in the waste and AFOLU sectors to account for limitations of the modelling approach. As a consequence, the adjusted impact on employment is 195,000 jobs.

When all mitigation potential is implemented, the impact differs in terms of that for GDP, in that some of the sectors have a negative employment outcome, with the employment impact within the energy sector at 12,000 jobs lost. This job loss is primarily due to the fact that the proposed measures displace coal mining, which is a labour-intensive activity. Taking the results after adjustment into consideration, the biggest employment sectors are buildings, waste, mining, transport and AFOLU.

The final total of 195,000 jobs represents 1.2% of the average projected number of jobs in the South African economy over the period 2010 to 2050. The employment gains are, therefore, modest.

At average levels of impact on GDP of the order of 1.5% and employment of 1.2%, with all mitigation measures included, the mitigation measures considered in this analysis will not have a major impact on the economy. What gains there are from direct employment and backward linkages are counteracted by losses due to forward linked effects: prices typically increase with increasing costs associated with implementing most measures without a related gain in revenue.

In conclusion, the economic assessment conducted in this analysis aims to illustrate the possible economic impacts from implementation of the range of mitigation measures identified in this study. The complexity of the economy combined with the complex set of mitigation measures applied to many sectors of the economy means that the results are useful mainly to show the broad scale and trends with respect to economic impacts. Further, it needs to be emphasised that this analysis proceeds on the assumption that the required investments will indeed be made. As explained in the main body of the report, there are many factors which are beyond the scope of economic modelling which will influence whether this will happen.

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Additional Information

List of Mitigation Measures, Abatement Potential and Marginal Abatement Costs

A complete list of mitigation measures, abatement potential ($ktCO_2e$) and marginal abatement costs (R/tCO_2e abatement) for key sectors, sectors and subsectors covered in the Mitigation Potential Analysis is shown in Table 32. The list includes all 172 measures identified across the five key sectors considered.

Results are summarised for the three key time periods covered in the study: 2020, 2030 and 2050. Detailed descriptions of all the measures, as well as the procedures to develop, cost and estimate mitigation potential are provided in the relevant appendices for key sectors (Technical Appendices C–G).

Identifiers for each measure shown in Table 32 below are referenced consistently throughout the main report and in the technical appendices.

Results from the multi-criteria analysis, including quantitative data informing the scoring of options for all measures as well as score for each of the main criteria and overall weighted score for the balanced weighting pathway, are shown in Table 33.

Overall scores and rankings for all measures under the balanced weighting pathway; the pathway which emphasises costs and implementability; and the pathway which emphasises social and environmental factors are shown in Table 34.

Table 32: Abatement ($ktCO_2e$) and Marginal Abatement Cost (MAC, R/tCO_2e) for all measures in 2020, 2030 and 2050

ID	Key Sector	Sector	Subsector	Measure	2020		2030		2050	
					Abatement	MAC	Abatement	MAC	Abatement	MAC
1	Energy	Non-Power	Other Energy Industries	Increase onsite gas-fired power generation - using internal combustion engines	952	-536	937	-313	914	-16
2	Energy	Non-Power	Other Energy Industries	Waste heat recovery power generation	637	-334	1,754	-337	1,732	-341
3	Energy	Non-Power	Other Energy Industries	Waste gas recovery and utilisation	488	194	488	57	488	-118
4	Energy	Non-Power	Other Energy Industries	Carbon capture and storage (CCS) - process emissions from existing plants (storage onshore)	0	0	5,236	838	5,248	838
5	Energy	Non-Power	Other Energy Industries	Energy monitoring and management system	192	-331	385	-373	385	-437
6	Energy	Non-Power	Other Energy Industries	Improved process control	215	-216	215	-258	215	-322
7	Energy	Non-Power	Other Energy Industries	Improved electric motor system controls and variable speed drives (VSDs)	329	-652	653	-658	644	-666
8	Energy	Non-Power	Other Energy Industries	Energy efficient utility systems	141	-617	280	-623	276	-630
9	Energy	Non-Power	Other Energy Industries	Improved heat systems	574	-802	1,139	-808	1,125	-819
10	Energy	Non-Power	Other Energy Industries	CCS - process emissions from existing plants (storage offshore)	0	0	13,875	973	13,908	973
11	Energy	Non-Power	Other Energy Industries	CCS - process emissions from new plants	0	0	6,220	729	18,694	728
12	Energy	Non-Power	Petroleum Refining	Improve steam generating boiler efficiency	64	-365	63	-513	62	-702
13	Energy	Non-Power	Petroleum Refining	Improve process heater efficiency	30	-346	29	-494	29	-682
14	Energy	Non-Power	Petroleum Refining	Waste heat recovery and utilisation	85	165	168	21	164	-157
15	Energy	Non-Power	Petroleum Refining	Minimise flaring and utilise flare gas as fuel	42	319	42	319	42	319
16	Energy	Non-Power	Petroleum Refining	Efficient energy production combined cycle gas turbine and combined heat and power (CCGT and CHP)	0	0	276	289	267	401
17	Energy	Non-Power	Petroleum Refining	Waste heat boiler and expander applied to flue gas from the fluid catalytic cracking (FCC) regenerator	50	371	50	229	49	56
18	Energy	Non-Power	Petroleum Refining	CCS - existing refineries	0	0	998	1,745	1,007	1,848
19	Energy	Non-Power	Petroleum Refining	Energy monitoring and management system	87	-402	85	-519	84	-667
20	Energy	Non-Power	Petroleum Refining	Improved process control	87	-114	85	-227	84	-368
21	Energy	Non-Power	Petroleum Refining	Improved heat exchanger efficiencies	68	110	67	-34	66	-213
22	Energy	Non-Power	Petroleum Refining	Improved electric motor system controls and VSDs	28	142	55	154	53	178
23	Energy	Non-Power	Petroleum Refining	Energy-efficient utility systems	19	-124	37	-117	36	-102
24	Energy	Non-Power	Petroleum Refining	CCS - new refineries	0	0	994	1,392	1,949	1,465
25	Energy	Non-Power	Coal Mining	Coal mine methane recovery and utilisation for power and/or heat generation	0	0	144	30	483	30

ID	Key Sector	Sector	Subsector	Measure	2020		2030		2050	
					Abatement	MAC	Abatement	MAC	Abatement	MAC
26	Energy	Non-Power	Coal Mining	Coal mine methane recovery and destruction by flaring	0	0	147	83	494	83
27	Energy	Non-Power	Coal Mining	Use of 1st generation biodiesel (B5) for transport and handling equipment	13	305	15	329	0	0
28	Energy	Non-Power	Coal Mining	Improve energy efficiency of mine haul and transport operations	57	744	90	163	151	-1,057
29	Energy	Non-Power	Coal Mining	Use of 2nd generation biodiesel (B50) for transport and handling equipment	0	0	149	184	252	214
30	Energy	Non-Power	Coal Mining	Use of 2nd generation biodiesel (B100) for transport and handling equipment	0	0	0	0	503	193
31	Energy	Non-Power	Coal Mining	Process, demand & energy management system	30	-894	71	-901	118	-913
32	Energy	Non-Power	Coal Mining	Energy efficient lighting	6	-800	14	-807	24	-817
33	Energy	Non-Power	Coal Mining	Install energy-efficient electric motor systems	121	-564	284	-568	473	-575
34	Energy	Non-Power	Coal Mining	Optimise existing electric motor systems (controls and VSDs)	61	-869	142	-876	236	-887
35	Energy	Non-Power	Coal Mining	Onsite clean power generation	97	1,302	227	1,313	378	1,330
36	Energy	Power	Electricity and Heating	Nuclear pressurised water reactor (PWR)	0	126	52,973	126	132,433	126
37	Energy	Power	Electricity and Heating	Gas CCGT	2,913	721	6,797	992	24,016	1,224
38	Energy	Power	Electricity and Heating	Onshore wind	12,524	220	33,396	199	78,794	199
39	Energy	Power	Electricity and Heating	Concentrated solar power (CSP) (parabolic trough)	1,966	379	5,897	304	11,009	304
40	Energy	Power	Electricity and Heating	Solar photovoltaic (PV) (concentrated)	8,921	995	20,977	782	54,227	782
41	Energy	Power	Electricity and Heating	Import (hydro)	0	-95	1,695	-95	8,947	-95
42	Energy	Power	Electricity and Heating	Coal CCS	0	244	8,039	202	87,852	202
43	Energy	Power	Electricity and Heating	Biomass	900	429	2,699	420	11,471	420
44	Energy	Power	Electricity and Heating	Landfill gas (LFG)	619	346	964	346	3,166	346
45	Energy	Power	Electricity and Heating	Energy from waste	742	1,686	3,712	1,686	4,640	1,686
46	Industry	Metals	Primary Aluminium Production	Best process selection for primary aluminium smelting	481	-579	614	-564	1,315	-538
47	Industry	Metals	Primary Aluminium Production	Switch to secondary production and increase recycling	0	0	1,935	-311	9,000	-280
48	Industry	Metals	Primary Aluminium Production	Energy monitoring & management system	40	-452	55	-439	126	-408
49	Industry	Metals	Primary Aluminium Production	Improved process control	161	-529	220	-519	502	-496
50	Industry	Metals	Primary Aluminium Production	Improved electric motor system controls and variable speed drives	121	12	165	46	377	118
51	Industry	Metals	Primary Aluminium Production	Energy-efficient utility systems	40	322	55	369	126	468

ID	Key Sector	Sector	Subsector	Measure	2020		2030		2050	
					Abatement	MAC	Abatement	MAC	Abatement	MAC
52	Industry	Metals	Ferroalloys Production	Implementing best available production techniques	1,091	-338	2,871	-337	6,588	-302
53	Industry	Metals	Ferroalloys Production	Replace submerged arc furnace semi-closed with closed type	877	-840	2,325	-876	5,199	-898
54	Industry	Metals	Ferroalloys Production	Waste gas recovery and power generation - CO from closed furnace	1,112	-378	3,481	-332	7,591	-262
55	Industry	Metals	Ferroalloys Production	Waste heat recovery and power generation from semi-closed furnace - Rankine cycle	502	938	731	1,056	1,595	1,313
56	Industry	Metals	Ferroalloys Production	Waste heat recovery and power generation from semi-closed furnace - Organic Rankine cycle	502	1,062	731	1,188	1,595	1,463
57	Industry	Metals	Ferroalloys production	Use biocarbon reductants instead of coal/coke	838	278	2,388	289	5,911	299
58	Industry	Metals	Ferroalloys production	Energy monitoring and management system	263	-867	351	-874	766	-882
59	Industry	Metals	Ferroalloys production	Improved electric motor system controls and variable speed drives	132	103	176	164	383	301
60	Industry	Metals	Ferroalloys production	Energy-efficient utility systems	132	-190	176	-148	383	-54
61	Industry	Metals	Ferroalloys production	Improved heat exchanger efficiencies	132	-646	176	-642	383	-623
62	Industry	Metals	Iron and steel production	Basic oxygen furnace (BOF) waste heat and gas recovery	85	-973	138	-146	297	107
63	Industry	Metals	Iron and steel production	Top gas pressure recovery turbine	52	-858	84	-553	180	-460
64	Industry	Metals	Iron and steel production	Electric arc furnaces (EAF) and secondary production route	1,465	7	4,201	-4	9,779	-1
65	Industry	Metals	Iron and steel production	State-of-the-art power plant	1,576	618	2,205	877	4,848	1,016
66	Industry	Metals	Iron and steel production	Top gas-recycling blast furnace (with CCS)	0	0	2,148	600	4,956	599
67	Industry	Metals	Iron and steel production	CCS - blast furnace (post-combustion)	0	0	2,120	825	4,891	812
68	Industry	Metals	Iron and steel production	State-of-the-art power plant (with CCS)	0	0	3,341	1,421	7,465	1,556
69	Industry	Metals	Iron and steel production	Direct reduced iron (DRI) – Midrex process	893	444	1,308	505	3,140	516
70	Industry	Metals	Iron and steel production	DRI – HYL process	830	410	1,219	463	2,949	470
71	Industry	Metals	Iron and steel production	DRI – ULCORED process	0	0	1,474	438	3,499	454
72	Industry	Metals	Iron and steel production	Energy monitoring and management system	77	-126	106	-155	222	-174
73	Industry	Metals	Iron and steel production	Improved process control	385	118	530	104	1,109	130
74	Industry	Metals	Iron and steel production	Improved electric motor system controls and variable speed drives	92	-244	127	-155	266	145
75	Industry	Metals	Iron and steel production	Energy efficient boiler systems and kilns	154	281	212	277	443	333
76	Industry	Metals	Iron and steel production	Energy-efficient utility systems	62	-244	85	-155	177	145
77	Industry	Metals	Iron and steel production	Improved heat exchanger efficiencies	154	-45	212	-69	443	-73
78	Industry	Minerals	Cement production	Improved process control	196	140	215	168	420	310
79	Industry	Minerals	Cement production	Reduction of clinker content of cement products	754	-122	2,005	-134	4,570	-128

ID	Key Sector	Sector	Subsector	Measure	2020		2030		2050	
					Abatement	MAC	Abatement	MAC	Abatement	MAC
80	Industry	Minerals	Cement production	Waste heat recovery from kilns and coolers/cogeneration	0	0	187	172	357	454
81	Industry	Minerals	Cement production	Utilise waste material as fuel	196	71	918	40	1,777	50
82	Industry	Minerals	Cement production	Geopolymer cement production	0	0	109	434	522	340
83	Industry	Minerals	Cement production	CCS - back-end chemical absorption	0	0	0	0	4,641	910
84	Industry	Minerals	Cement production	CCS - oxyfuelling	0	0	0	0	2,321	820
85	Industry	Minerals	Cement production	Energy monitoring and management system	39	-237	43	-237	84	-185
86	Industry	Minerals	Cement production	Improved electric motor system controls and variable speed drives	47	-227	122	-146	236	51
87	Industry	Minerals	Cement production	Energy-efficient utility systems	26	79	68	199	131	488
88	Industry	Minerals	Lime production	Installation of shaft preheaters	148	-161	312	-222	469	-311
89	Industry	Minerals	Lime production	Replace rotary kilns with vertical kilns or parallel flow regenerative kilns (PFRK)	94	461	198	637	597	1,090
90	Industry	Minerals	Lime production	Use alternative fuels including waste and biomass	0		250	407	1,002	470
91	Industry	Minerals	Lime production	CCS for lime production	0		0		4,848	889
92	Industry	Minerals	Lime production	Energy monitoring and management system	10	-221	11	-289	18	-381
93	Industry	Minerals	Lime production	Improved process control	19	-72	20	-100	30	-111
94	Industry	Minerals	Lime production	Improved electric motor system controls and VSDs	6	-155	8	-75	16	117
95	Industry	Minerals	Lime production	Energy-efficient utility systems	5	-83	7	6	13	217
96	Industry	Minerals	Lime production	Improved heat exchanger efficiencies	13	-151	13	-210	20	-290
97	Industry	Chemicals production	Chemicals production	CCS for new ammonia production plants process emissions	0	0	110	585	945	585
98	Industry	Chemicals production	Chemicals production	Revamp: increase capacity and energy efficiency	316	-160	842	-111	1,699	34
99	Industry	Chemicals production	Chemicals production	N2O abatement for new production plants	76	48	185	29	686	20
100	Industry	Chemicals production	Chemicals production	Energy monitoring and management system	59	-571	157	-561	317	-513
101	Industry	Chemicals production	Chemicals production	Advanced process control	21	-208	56	-315	113	-388
102	Industry	Chemicals production	Chemicals production	Improved electric motor system controls and VSDs	152	-403	405	-347	815	-216
103	Industry	Chemicals production	Chemicals production	Energy efficient utility systems	51	-143	135	-55	272	147

ID	Key Sector	Sector	Subsector	Measure	2020		2030		2050	
					Abatement	MAC	Abatement	MAC	Abatement	MAC
104	Industry	Chemicals production	Chemicals production	Increase process integration and improved heat systems	42	-367	111	-492	227	-606
105	Industry	Chemicals production	Chemicals production	Combined heat and power (CHP)	221	292	581	659	1,152	1,310
106	Industry	Mining	Surface and underground mining	Use of 1st generation biodiesel (B5) for transport and handling equipment	41	179	58	203	0	0
107	Industry	Mining	Surface and underground mining	Improve energy efficiency of mine haul and transport operations	186	667	349	46	798	-1,175
108	Industry	Mining	Surface and underground mining	Use of 2nd generation biodiesel (B50) for transport and handling equipment	0		581	146	1,330	176
109	Industry	Mining	Surface and underground mining	Use of 2nd generation biodiesel (B100) for transport and handling equipment	0		0		2,659	168
110	Industry	Mining	Surface and underground mining	Process, demand & energy management system	518	-1,001	1,521	-955	3,948	-842
111	Industry	Mining	Surface and underground mining	Energy efficient lighting	104	-896	304	-855	790	-754
112	Industry	Mining	Surface and underground mining	Install energy-efficient electric motor systems	2,071	-631	6,084	-603	15,793	-531
113	Industry	Mining	Surface and underground mining	Optimise existing electric motor systems (controls and VSDs)	1,036	-973	3,042	-929	7,896	-819
114	Industry	Mining	SURFACE and underground mining	Onsite clean power generation	1,657	1,554	4,867	1,484	12,634	1,308
115	Industry	Other	Pulp and paper production	Convert fuel from coal to biomass/residual wood waste	1,225	-165	2,978	-219	6,470	-309
116	Industry	Other	Pulp and paper production	Application of co-generation of heat and power (CHP)	343	1,417	1,260	1,197	2,678	1,499
117	Industry	Other	Pulp and paper production	Energy recovery system	406	-139	403	-284	875	-406
118	Industry	Other	Pulp and paper production	Energy monitoring and management system	32	-352	71	-477	152	-545
119	Industry	Other	Pulp and paper production	Energy efficient electric motors, improved controls and variable speed drives	79	-175	212	-152	454	-102
120	Industry	Other	Pulp and paper production	Energy-efficient utility systems (e.g. lighting, refrigeration, compressed air)	34	178	91	215	195	295
121	Industry	Other	Pulp and paper production	Improved process control	102	32	201	-44	437	-151
122	Industry	Other	Pulp and paper production	Energy efficient boiler systems and kilns and Improved heat systems	203	-110	403	-244	875	-364
123	Industry	Buildings	Residential	Energy efficient appliances	973	-888	1,470	-898	2,772	-913
124	Industry	Buildings	Residential	Geyser blankets	542	-671	1,168	-728	2,553	-881

ID	Key Sector	Sector	Subsector	Measure	2020		2030		2050	
					Abatement	MAC	Abatement	MAC	Abatement	MAC
125	Industry	Buildings	Residential	Improved insulation - new buildings	1,160	-129	2,104	-151	4,660	-252
126	Industry	Buildings	Residential	Improved insulation - existing buildings	696	190	1,262	166	2,796	55
127	Industry	Buildings	Residential	Efficient lighting – fluorescent lamps (FLs)	7,019	-923	8,940	-930	10,660	-942
128	Industry	Buildings	Residential	Efficient Lighting - LEDs	241	-899	559	-908	1,333	-922
129	Industry	Buildings	Residential	Solar water heating	1,464	-701	3,216	-749	7,203	-867
130	Industry	Buildings	Residential	LPG for cooking	624	9	1,333	9	2,969	8
131	Industry	Buildings	Residential	Passive building/improved thermal design - new buildings	1,832	-633	3,322	-686	7,358	-822
132	Industry	Buildings	Commercial/ institutional	Efficient lighting	1,010	-923	2,015	-931	5,799	-943
133	Industry	Buildings	Commercial/ institutional	Heat pumps - existing buildings	293	-343	584	-299	1,681	-242
134	Industry	Buildings	Commercial/ institutional	Heat pumps - new buildings	340	-397	678	-353	1,952	-297
135	Industry	Buildings	Commercial/ institutional	Heating ventilation and air conditioning (HVAC) with heat recovery - new buildings	1,052	-1,061	2,107	-1,218	6,100	-1,425
136	Industry	Buildings	Commercial/ institutional	HVAC variable speed drives - existing buildings	668	-741	1,332	-747	3,834	-756
137	Industry	Buildings	Commercial/ institutional	HVAC variable speed drives - new buildings	811	-773	1,618	-779	4,655	-789
138	Industry	Buildings	Commercial/ institutional	HVAC central air conditioners - new buildings	242	-483	483	-487	1,390	-493
139	Industry	Buildings	Commercial/ institutional	Energy efficient appliances	218	-889	435	-896	1,252	-908
140	Industry	Buildings	Commercial/ institutional	Passive building/improved thermal design - new buildings	2,881	-1,068	5,770	-1,226	16,703	-1,432
141	Transport	Road	Road	Road - alternative fuels - CNG	20	-466	246	-790	1,579	-1,360
142	Transport	Road	Road	Road - alternative fuels - diesel PHEV	22	2,656	202	1,151	1,152	65
143	Transport	Road	Road	Road - improved efficiency – petrol internal combustion engine (ICE)	4,349	424	12,538	190	25,241	-335
144	Transport	Road	Road	Road - alternative fuels - petrol hybrid electric vehicle (HEV)	450	2,157	1,872	961	7,522	36
145	Transport	Road	Road	Road - improved efficiency - diesel ICE	1,875	1,667	8,122	634	28,448	6
146	Transport	Road	Road	Road - alternative fuels - petrol plug-in hybrid electric vehicle (PHEV)	64	1,930	467	660	1,951	-385
147	Transport	Road	Road	Road - alternative fuels – fuel cell electric vehicle (FCEV)	0	0	4	2,445	616	135
148	Transport	Road	Road	Road - alternative fuels - diesel hybrid electric vehicle (HEV)	176	3,048	933	1,658	5,041	625
149	Transport	Road	Road	Road - alternative fuels – electric vehicle (EV)	0	0	57	1,920	750	-348
150	Transport	Road	Road	Road - shifting passengers from cars to public transport	820	3,105	3,087	729	9,396	-1,128
151	Transport	Road	Road	Road - shifting freight from road to rail	1,840	1,375	2,729	2,085	2,997	1,497
152	Transport	Road	Road	Road - biofuels	1,959	1,808	8,286	1,108	30,374	232
153	Transport	Rail	Rail	Rail - improved efficiency – electric multiple unit (EMU) train sets	0	0	102	2,052	112	4,340

ID	Key Sector	Sector	Subsector	Measure	2020		2030		2050	
					Abatement	MAC	Abatement	MAC	Abatement	MAC
154	Transport	Rail	Rail	Rail - improved efficiency - diesel	47	-35	147	-187	372	-575
155	Transport	Rail	Rail	Rail - alternative fuels - hybrid diesel	0	0	39	322	128	-107
156	Transport	Rail	Rail	Rail - alternative fuels – compressed natural gas (CNG)	0	0	0	0	66	-36
157	Transport	Rail	Rail	Rail - biofuels	33	1,554	74	1,321	380	936
158	Transport	Aviation	Aviation	Aviation - biofuels	212	1,131	571	632	969	-17
159	Waste	Municipal solid waste	Municipal solid waste	LFG recovery and generation	4,843	68	11,325	68	28,020	68
160	Waste	Municipal solid waste	Municipal solid waste	LFG recovery and flaring	2,076	86	2,912	86	3,002	86
161	Waste	Municipal solid waste	Municipal solid waste	Paper recycling	1,506	359	2,802	359	3,223	628
162	Waste	Municipal solid waste	Municipal solid waste	Energy from waste	869	368	112	368	197	657
163	Waste	Municipal solid waste	Municipal solid waste	Home composting	83	371	2,935	371	2,913	892
164	Waste	Municipal solid waste	Municipal solid waste	Windrow composting	176	649	155	649	176	1,136
165	Waste	Municipal solid waste	Municipal Solid Waste	In-vessel composting	189	763	682	763	771	1,335
166	Waste	Municipal solid waste	Municipal solid waste	Anaerobic digestion	234	903	1,198	903	1,354	1,580
167	AFOLU	AFOLU	AFOLU	Expanding plantations	2,418	-91	5,240	-362	0	-554
168	AFOLU	AFOLU	AFOLU	Biochar addition to cropland	619	-35	473	-110	939	-221
169	AFOLU	AFOLU	AFOLU	Treatment of livestock waste	155	-33	1,485	-85	1,485	-85
170	AFOLU	AFOLU	AFOLU	Rural tree planting (thickets)	1,392	28	1,532	31	181	13
171	AFOLU	AFOLU	AFOLU	Urban tree planting	539	39	1,016	74	1,671	34
172	AFOLU	AFOLU	AFOLU	Restoration of mesic grasslands	192	482	461	1,158	499	1,254

Table 33: Quantitative data informing the scoring of options for the Industry sector scoring as well as score for main criteria and overall weighted score for the Balanced Weighting pathway (NPV – net present value, GPV – gross value added)

ID	Key Sector	Sector	Subsector	Measure	Score	Total emissions abated ($ktCO_2e$)	NPV of costs per $ktCO_2e$ mitigated	GVA impact per $ktCO_2e$ mitigated	Jobs created per $ktCO_2e$ mitigated	Ratio of unskilled to total	Cost	Economic impact	Social impact	Non-GHG environmental impact	Implementability
1	Energy	Non-power	Other energy industries	Increase onsite gas-fired power generation - using internal combustion engines	67.81	32,661	-63.41	11.07	0.08	0.34	80.63	71.12	34.01	75.00	85.00
2	Energy	Non-power	Other energy industries	Waste heat recovery power generation	53.24	52,908	-29.00	7.42	0.04	0.31	72.85	65.05	31.77	75.00	25.00
3	Energy	Non-power	Other energy industries	Waste gas recovery and utilisation	50.69	16,836	32.09	-0.80	-0.02	0.42	59.04	51.38	28.49	75.00	42.50
4	Energy	Non-power	Other energy industries	CCS - process emissions from existing plants (storage onshore)	31.50	120,930	77.15	-9.88	-0.08	0.35	48.85	36.28	24.40	30.00	17.50
5	Energy	Non-power	Other energy industries	Energy monitoring and management system	64.94	11,727	-34.20	5.66	0.04	0.34	74.02	62.13	31.82	70.00	92.50
6	Energy	Non-power	Other energy industries	Improved process control	64.90	7,639	-32.45	5.95	0.04	0.34	73.63	62.61	31.76	70.00	92.50
7	Energy	Non-power	Other Energy Industries	Improved electric motor system controls and VSDs	68.36	19,563	-64.98	11.18	0.08	0.34	80.98	71.32	34.06	70.00	92.50
8	Energy	Non-power	Other energy industries	Energy efficient utility systems	67.92	8,384	-60.31	10.63	0.07	0.34	79.93	70.39	33.76	70.00	92.50
9	Energy	Non-power	Other energy industries	Improved heat systems	70.26	34,139	-84.95	13.57	0.10	0.34	85.50	75.29	35.35	70.00	92.50
10	Energy	Non-power	Other energy industries	CCS - process emissions from existing plants (storage offshore)	25.32	292,698	141.09	-17.81	-0.15	0.35	34.39	23.10	20.22	30.00	17.50
11	Energy	Non-power	Other energy industries	CCS - process emissions from new plants	36.14	205,956	29.38	-3.86	-0.03	0.35	59.65	46.30	27.54	30.00	17.50
12	Energy	Non-power	Petroleum refining	Improve steam generating boiler efficiency	65.78	2,227	-65.15	0.00	0.08	0.34	81.02	52.72	34.12	70.00	92.50
13	Energy	Non-power	Petroleum refining	Improve process heater efficiency	68.24	1,039	-62.99	11.18	0.08	0.34	80.54	71.30	33.99	70.00	92.50

ID	Key Sector	Sector	Subsector	Measure	Score	Total emissions abated ($ktCO_2e$)	NPV of costs per $ktCO_2e$ mitigated	GVA impact per $ktCO_2e$ mitigated	Jobs created per $ktCO_2e$ mitigated	Ratio of unskilled to total	Cost	Economic impact	Social impact	Non-GHG environmental impact	Implementability
14	Energy	Non-power	Petroleum refining	Waste heat recovery and utilisation	51.53	5,092	2.58	2.70	0.01	0.14	65.71	57.20	28.38	70.00	40.00
15	Energy	Non-power	Petroleum refining	Minimise flaring and utilise flare gas as fuel	49.93	1,491	40.56	-4.67	-0.04	0.36	57.12	44.95	37.07	70.00	40.00
16	Energy	Non-power	Petroleum refining	Efficient energy production (CCGT and CHP)	47.23	6,843	17.05	-0.90	-0.01	0.40	62.44	51.21	28.97	70.00	25.00
17	Energy	Non-power	Petroleum refining	Waste heat boiler and expander applied to flue gas from the FCC regenerator	46.64	1,767	33.08	0.11	-0.02	0.46	58.81	52.91	28.99	70.00	25.00
18	Energy	Non-power	Petroleum refining	CCS - Existing Refineries	30.64	22,725	59.35	-8.34	-0.07	0.35	52.88	38.84	15.50	30.00	17.50
19	Energy	Non-power	Petroleum refining	Energy monitoring and management system	68.82	3,018	-68.89	11.96	0.08	0.34	81.87	72.60	34.37	70.00	92.50
20	Energy	Non-power	Petroleum refining	Improved process control	65.69	3,018	-35.49	8.15	0.05	0.32	74.32	66.28	32.27	70.00	92.50
21	Energy	Non-power	Petroleum refining	Improved heat exchanger efficiencies	63.22	2,376	-10.46	5.13	0.02	0.28	68.66	61.24	30.33	70.00	92.50
22	Energy	Non-power	Petroleum refining	Improved electric motor system controls and VSDs	62.40	1,648	-2.50	4.22	0.02	0.23	66.86	59.74	29.50	70.00	92.50
23	Energy	Non-power	Petroleum refining	Energy-efficient utility systems	64.85	1,099	-27.06	7.10	0.04	0.31	72.41	64.53	31.62	70.00	92.50
24	Energy	Non-power	Petroleum refining	CCS - New Refineries	35.17	21,654	38.50	-5.31	-0.04	0.35	57.59	43.89	26.90	30.00	17.50
25	Energy	Non-power	Coal mining	Coal mine methane recovery and utilisation for power and/or heat generation	47.58	7,505	0.37	0.63	0.00	0.16	66.21	53.76	28.12	50.00	42.50
26	Energy	Non-power	Coal mining	Coal mine methane recovery and destruction by flaring	53.74	7,704	3.95	-0.51	-0.00	0.35	65.40	51.86	19.24	70.00	67.50

ID	Key Sector	Sector	Subsector	Measure	Score	Total emissions abated ($ktCO_2e$)	NPV of costs per $ktCO_2e$ mitigated	GVA impact per $ktCO_2e$ mitigated	Jobs created per $ktCO_2e$ mitigated	Ratio of unskilled to total	Cost	Economic impact	Social impact	Non-GHG environmental impact	Implementability
27	Energy	Non-power	Coal mining	Use of 1st generation biodiesel (B5) for transport and handling equipment	48.81	276	62.14	-8.24	-0.07	0.35	52.24	39.02	35.45	50.00	67.50
28	Energy	Non-power	Coal mining	Improve energy efficiency of mine haul and transport operations	63.75	3,433	26.15	10.51	-0.00	3.89	60.38	70.19	29.32	70.00	100.00
29	Energy	Non-power	Coal mining	Use of 2nd generation biodiesel (B50) for transport and handling equipment	47.11	4,679	11.08	-1.64	-0.01	0.35	63.79	49.99	48.69	45.00	25.00
30	Energy	Non-power	Coal mining	Use of 2nd generation biodiesel (B100) for transport and handling equipment	47.03	6,347	5.85	-0.89	-0.01	0.35	64.97	51.24	59.03	30.00	25.00
31	Energy	Non-power	Coal mining	Process, demand & energy management system	71.95	2,478	-87.96	13.82	0.10	0.34	86.18	75.70	35.53	70.00	100.00
32	Energy	Non-power	Coal mining	Energy efficient lighting	71.23	496	-80.58	12.89	0.09	0.34	84.51	74.16	35.05	70.00	100.00
33	Energy	Non-power	Coal mining	Install energy-efficient electric motor systems	69.28	9,911	-60.54	10.34	0.07	0.34	79.98	69.91	33.72	70.00	100.00
34	Energy	Non-power	Coal mining	Optimise existing electric motor systems (controls and VSDs)	71.75	4,956	-85.90	13.56	0.10	0.34	85.71	75.28	35.39	70.00	100.00
35	Energy	Non-power	Coal mining	Onsite clean power generation	67.12	7,929	-24.86	10.34	0.05	0.29	71.91	69.92	31.86	85.00	85.00
36	Energy	Power	Electricity and heating	Nuclear (PWR)	51.85	2,052,714	8.47	-1.17	-0.01	0.36	64.38	50.77	29.01	65.00	52.50
37	Energy	Power	Electricity and heating	Gas CCGT	56.18	359,763	141.73	-16.76	-0.15	0.36	34.25	24.85	40.32	95.00	85.00
38	Energy	Power	Electricity and heating	Onshore wind	58.42	1,485,869	22.46	-2.72	-0.02	0.36	61.22	48.19	28.19	90.00	67.50
39	Energy	Power	Electricity and heating	Solar CSP (Parabolic trough)	56.73	228,033	45.63	-5.37	-0.05	0.36	55.98	43.78	46.78	85.00	50.00
40	Energy	Power	Electricity and heating	Solar PV (Concentrated)	60.22	1,018,444	75.36	-9.00	-0.08	0.36	49.26	37.75	44.93	100.00	67.50

ID	Key Sector	Sector	Subsector	Measure	Score	Total emissions abated ($ktCO_2e$)	NPV of costs per $ktCO_2e$ mitigated	GVA impact per $ktCO_2e$ mitigated	Jobs created per $ktCO_2e$ mitigated	Ratio of unskilled to total	Cost	Economic impact	Social impact	Non-GHG environmental impact	Implementability
41	Energy	Power	Electricity and heating	Import (Hydro)	58.34	202,632	23.52	-2.83	-0.02	0.37	60.97	48.01	28.20	90.00	67.50
42	Energy	Power	Electricity and heating	Coal CCS	38.74	1,092,115	9.17	-1.17	-0.01	0.36	64.22	50.78	18.91	45.00	17.50
43	Energy	Power	Electricity and heating	Biomass	63.18	204,122	36.74	-4.41	-0.04	0.36	57.99	45.39	47.22	80.00	85.00
44	Energy	Power	Electricity and heating	LFG	45.48	53,202	26.43	-3.15	-0.03	0.36	60.32	47.48	27.86	70.00	22.50
45	Energy	Power	Electricity and heating	Energy from waste	37.13	108,951	114.04	-13.90	-0.12	0.36	40.51	29.60	22.46	70.00	22.50
46	Industry	Metals	Primary aluminium production	Best process selection for primary aluminium smelting	64.47	25,859	-56.58	9.27	0.07	0.34	79.09	68.13	33.40	70.00	77.50
47	Industry	Metals	Primary aluminium production	Switch to secondary production and increase recycling	62.26	121,585	-26.90	4.28	0.03	0.34	72.37	59.83	31.29	75.00	77.50
48	Industry	Metals	Primary aluminium production	Energy monitoring & management system	66.65	2,378	-47.84	8.83	0.06	0.33	77.11	67.41	32.92	70.00	92.50
49	Industry	Metals	Primary aluminium production	Improved process control	67.26	9,510	-54.19	9.60	0.07	0.34	78.55	68.68	33.33	70.00	92.50
50	Industry	Metals	Primary aluminium production	Improved electric motor system controls and variable speed drives	62.93	7,133	-9.72	4.23	0.02	0.28	68.49	59.76	30.17	70.00	92.50
51	Industry	Metals	Primary aluminium production	Energy-efficient utility systems	61.03	2,378	15.69	1.17	-0.01	0.58	62.75	54.66	30.71	70.00	92.50
52	Industry	Metals	Ferroalloys production	Implementing best available production techniques	58.37	115,087	-26.10	4.92	0.03	0.33	72.19	60.90	31.31	55.00	77.50
53	Industry	Metals	Ferroalloys production	Replace submerged arc furnace semi-closed with closed type	53.90	91,739	-11.13	4.41	0.02	0.29	68.81	60.05	30.27	55.00	60.00
54	Industry	Metals	Ferroalloys production	Waste gas recovery and power generation - CO from closed furnace	58.18	132,764	-25.89	5.49	0.03	0.33	72.15	61.84	31.35	70.00	60.00

ID	Key Sector	Sector	Subsector	Measure	Score	Total emissions abated ($ktCO_2e$)	NPV of costs per $ktCO_2e$ mitigated	GVA impact per $ktCO_2e$ mitigated	Jobs created per $ktCO_2e$ mitigated	Ratio of unskilled to total	Cost	Economic impact	Social impact	Non-GHG environmental impact	Implementability
55	Industry	Metals	Ferroalloys production	Waste heat recovery and power generation from semi-closed furnace - Rankine cycle	28.58	31,408	256.52	-27.91	-0.26	0.37	8.30	6.30	14.11	55.00	60.00
56	Industry	Metals	Ferroalloys production	Waste heat recovery and power generation from semi-closed furnace - organic Rankine cycle	25.05	31,408	279.64	-30.71	-0.28	0.37	3.07	1.64	12.66	65.00	42.50
57	Industry	Metals	Ferroalloys production	Use biocarbon reductants instead of coal/coke	35.85	99,174	20.32	-3.13	-0.02	0.26	61.70	47.52	27.42	35.00	7.50
58	Industry	Metals	Ferroalloys production	Energy monitoring and management system	70.39	14,947	-85.73	13.84	0.10	0.34	85.68	75.73	35.43	70.00	92.50
59	Industry	Metals	Ferroalloys production	Improved electric motor system controls and variable speed drives	62.05	7,473	-1.35	3.29	0.01	0.22	66.60	58.19	29.21	70.00	92.50
60	Industry	Metals	Ferroalloys production	Energy-efficient utility systems	64.59	7,473	-26.31	6.31	0.04	0.32	72.24	63.22	31.47	70.00	92.50
61	Industry	Metals	Ferroalloys production	Improved heat exchanger efficiencies	66.39	7,473	-68.33	12.00	0.08	0.34	81.74	72.67	24.35	70.00	92.50
62	Industry	Metals	Iron and steel production	BOF waste heat and gas recovery	63.03	5,902	-130.35	22.48	0.16	0.34	95.76	90.10	38.80	55.00	42.50
63	Industry	Metals	Iron and steel production	Top gas pressure recovery turbine	61.94	3,584	-94.93	15.61	0.11	0.34	87.76	78.68	36.12	70.00	42.50
64	Industry	Metals	Iron and steel Production	Electric arc furnaces (EAF) and secondary production route	54.72	169,738	-11.75	2.15	0.01	0.34	68.95	56.29	30.22	45.00	77.50
65	Industry	Metals	Iron and steel production	State-of-the-art power plant	42.35	94,670	65.31	-6.33	-0.06	0.37	51.53	42.19	25.80	35.00	60.00
66	Industry	Metals	Iron and steel production	Top gas-recycling blast furnace (with CCS)	35.75	75,109	14.21	-1.80	-0.02	0.35	63.08	49.72	28.56	30.00	7.50
67	Industry	Metals	Iron and steel production	CCS - blast furnace (post-combustion)	35.91	74,121	22.15	-3.04	-0.02	0.35	61.29	47.66	27.98	35.00	7.50
68	Industry	Metals	Iron and steel production	State-of-the-art power plant (with CCS)	31.82	113,702	64.70	-8.32	-0.07	0.35	51.67	38.88	25.30	35.00	7.50

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69	Industry	Metals	Iron and steel production	DRI - Midrex	43.03	57,962	43.97	-4.98	-0.05	0.36	56.35	44.43	26.85	30.00	60.00
70	Industry	Metals	Iron and steel production	DRI - HYL	40.02	54,181	40.28	-4.64	-0.04	0.36	57.19	45.00	27.06	30.00	42.50
71	Industry	Metals	Iron and steel production	DRI - ULCORED	41.02	54,969	22.42	-2.66	-0.02	0.36	61.22	48.29	28.13	60.00	7.50
72	Industry	Metals	Iron and steel production	Energy monitoring and management system	63.71	4,469	-20.52	4.39	0.03	0.33	70.93	60.02	30.92	70.00	92.50
73	Industry	Metals	Iron and steel production	Improved process control	61.53	22,343	0.06	1.88	0.01	0.20	66.28	55.84	28.72	70.00	92.50
74	Industry	Metals	Iron and steel production	Improved electric motor system controls and variable speed drives	67.69	5,362	-46.31	13.14	0.07	0.31	76.76	74.58	33.43	70.00	92.50
75	Industry	Metals	Iron and steel production	Energy efficient boiler systems and kilns	63.66	8,937	13.79	0.21	-0.01	0.46	63.18	53.06	29.70	85.00	92.50
76	Industry	Metals	Iron and steel production	Energy-efficient utility systems	67.69	3,575	-46.31	13.14	0.07	0.31	76.76	74.58	33.43	70.00	92.50
77	Industry	Metals	Iron and steel production	Improved heat exchanger efficiencies	63.04	8,937	-13.66	3.55	0.02	0.32	69.38	58.63	30.40	70.00	92.50
78	Industry	Minerals	Cement production	Improved process control	59.26	9,242	29.42	-1.08	-0.02	0.41	59.64	50.92	28.51	70.00	92.50
79	Industry	Minerals	Cement production	Reduction of clinker content of cement products	61.16	80,694	-0.08	0.43	0.00	0.21	66.31	53.44	28.54	70.00	92.50
80	Industry	Minerals	Cement production	Waste heat recovery from kilns and coolers/cogeneration	47.41	6,155	50.17	-4.70	-0.05	0.37	54.95	44.90	26.73	70.00	42.50
81	Industry	Minerals	Cement production	Utilise waste material as fuel	51.85	32,373	5.36	-0.64	-0.01	0.36	65.08	51.65	29.18	80.00	35.00
82	Industry	Minerals	Cement production	Geopolymer cement production	41.25	7,146	26.00	-3.11	-0.03	0.36	60.41	47.54	27.90	70.00	0.00
83	Industry	Minerals	Cement production	CCS - back-end chemical absorption	35.03	56,864	57.06	-7.44	-0.06	0.35	53.39	40.35	15.73	50.00	17.50
84	Industry	Minerals	Cement production	CCS - oxyfuelling	35.65	28,432	50.75	-6.61	-0.06	0.35	54.82	41.73	16.14	50.00	17.50

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85	Industry	Minerals	Cement production	Energy monitoring and management system	63.67	1,848	-18.71	4.68	0.03	0.32	70.52	60.50	30.84	70.00	92.50
86	Industry	Minerals	Cement production	Improved electric motor system controls and variable speed drives	61.53	4,524	-0.98	2.65	0.01	0.04	66.51	57.13	27.76	70.00	92.50
87	Industry	Minerals	Cement production	Energy-efficient utility systems	59.09	2,513	31.22	-1.28	-0.03	0.41	59.23	50.58	28.36	70.00	92.50
88	Industry	Minerals	Lime production	Installation of shaft preheaters	55.71	10,348	-21.76	4.34	0.03	0.33	71.21	59.94	31.01	70.00	50.00
89	Industry	Minerals	Lime production	Replace rotary kilns with vertical kilns or PFRK	53.18	9,173	49.66	-4.77	-0.05	0.37	55.07	44.79	26.74	75.00	67.50
90	Industry	Minerals	Lime production	Use alternative fuels including waste and biomass	50.29	14,645	17.22	-2.68	-0.02	0.35	62.40	48.27	28.23	55.00	60.00
91	Industry	Minerals	Lime production	CCS for lime production	34.74	37,106	19.93	-2.63	-0.02	0.35	61.79	48.34	28.15	35.00	0.00
92	Industry	Minerals	Lime production	Energy monitoring and management system	65.40	431	-36.98	6.75	0.05	0.33	74.65	63.95	32.11	70.00	92.50
93	Industry	Minerals	Lime production	Improved process control	63.73	760	-20.24	4.52	0.03	0.32	70.87	60.23	30.93	70.00	92.50
94	Industry	Minerals	Lime production	Improved electric motor system controls and VSDs	64.60	341	-25.79	6.45	0.04	0.31	72.12	63.44	31.48	70.00	92.50
95	Industry	Minerals	Lime production	Energy-efficient utility systems	63.99	273	-19.57	5.70	0.03	0.30	70.72	62.20	31.02	70.00	92.50
96	Industry	Minerals	Lime production	Improved heat exchanger efficiencies	64.63	506	-29.55	5.64	0.04	0.33	72.97	62.09	31.58	70.00	92.50
97	Industry	Chemicals production	Chemicals production	CCS for new ammonia production plants process emissions	55.99	9,979	12.48	-1.57	-0.01	0.35	63.47	50.11	28.66	90.00	50.00
98	Industry	Chemicals production	Chemicals production	Revamp: increase capacity and energy efficiency	44.29	31,782	-12.00	1.88	0.02	0.30	69.01	55.84	30.32	50.00	17.50
99	Industry	Chemicals production	Chemicals production	N2O abatement for new production plants	61.04	9,836	2.72	-0.32	-0.00	0.36	65.68	52.19	29.38	70.00	92.50

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100	Industry	Chemicals production	Chemicals production	Energy monitoring and management system	58.47	5,930	-48.13	8.40	0.06	0.34	77.17	66.68	32.87	70.00	50.00
101	Industry	Chemicals production	Chemicals production	Advanced process control	64.85	2,134	-30.24	6.31	0.04	0.33	73.13	63.22	31.69	70.00	92.50
102	Industry	Chemicals production	Chemicals production	Improved electric motor system controls and VSDs	65.22	15,228	-34.39	6.71	0.04	0.33	74.07	63.88	31.96	70.00	92.50
103	Industry	Chemicals production	Chemicals production	Energy efficient utility systems	63.34	5,076	-15.11	4.37	0.02	0.31	69.71	59.98	30.58	70.00	92.50
104	Industry	Chemicals production	Chemicals production	Increase process integration and improved heat systems	64.53	4,268	-41.70	7.71	0.05	0.33	75.72	65.54	32.46	70.00	85.00
105	Industry	Chemicals production	Chemicals production	Combined heat and power (CHP)	53.19	21,334	42.76	-2.81	-0.04	0.39	56.63	48.05	27.54	70.00	67.50
106	Industry	Mining	Surface and underground mining	Use of 1st generation biodiesel (B5) for transport and handling equipment	51.26	1,004	36.32	-5.15	-0.04	0.35	58.08	44.16	37.04	50.00	67.50
107	Industry	Mining	Surface and underground mining	Improve energy efficiency of mine haul and transport operations	64.86	14,773	6.40	11.22	0.02	0.14	64.85	71.37	28.96	70.00	100.00
108	Industry	Mining	Surface and underground mining	Use of 2nd generation biodiesel (B50) for transport and handling equipment	47.38	21,180	8.32	-1.27	-0.01	0.35	64.41	50.61	48.86	45.00	25.00
109	Industry	Mining	Surface and underground mining	Use of 2nd generation biodiesel (B100) for transport and handling equipment	47.13	30,555	4.90	-0.76	-0.01	0.35	65.19	51.46	59.09	30.00	25.00
110	Industry	Mining	Surface and underground mining	Process, demand & energy management system	68.65	83,759	-56.65	8.90	0.07	0.34	79.10	67.52	33.35	70.00	100.00
111	Industry	Mining	Surface and underground mining	Energy efficient lighting	68.18	16,752	-51.83	8.28	0.06	0.34	78.01	66.49	33.04	70.00	100.00
112	Industry	Mining	Surface and underground mining	Install energy-efficient electric motor systems	66.91	335,037	-38.82	6.61	0.05	0.34	75.07	63.71	32.16	70.00	100.00

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113	Industry	Mining	Surface and underground mining	Optimise existing electric motor systems (controls and VSDs)	68.52	167,519	-55.31	8.73	0.06	0.34	78.80	67.24	33.26	70.00	100.00
114	Industry	Mining	Surface and underground mining	Onsite clean power generation	56.49	268,030	81.18	-8.52	-0.08	0.37	47.94	38.55	24.66	90.00	85.00
115	Industry	Other	Pulp and paper production	Convert fuel from coal to biomass/ residual wood waste	65.60	118,367	-16.42	2.72	0.02	0.34	70.01	57.24	30.56	90.00	85.00
116	Industry	Other	Pulp and paper production	Application of co-generation of heat and power (CHP)	52.29	46,120	87.62	-7.98	-0.08	0.38	46.48	39.45	24.69	70.00	85.00
117	Industry	Other	Pulp and paper production	Energy recovery system	67.05	18,588	-25.42	6.06	0.04	0.32	72.04	62.79	31.40	90.00	85.00
118	Industry	Other	Pulp and paper production	Energy monitoring and management system	65.70	2,824	-39.79	7.19	0.05	0.34	75.29	64.67	32.30	70.00	92.50
119	Industry	Other	Pulp and paper production	Energy efficient electric motors, improved controls and variable speed drives	63.83	8,169	-20.42	4.87	0.03	0.32	70.91	60.81	30.98	70.00	92.50
120	Industry	Other	Pulp and paper production	Energy-efficient utility systems (e.g. lighting, refrigeration, compressed air)	60.68	3,501	6.51	1.53	0.00	-14.88	64.82	55.26	26.91	70.00	92.50
121	Industry	Other	Pulp and paper production	Improved process control	62.66	8,287	-8.97	3.33	0.02	0.30	68.32	58.25	30.05	70.00	92.50
122	Industry	Other	Pulp and paper production	Energy efficient boiler systems and kilns and Improved heat systems	64.33	16,574	-25.51	5.50	0.03	0.32	72.06	61.87	31.35	70.00	92.50
123	Industry	Buildings	Residential	Energy efficient appliances	77.94	47,676	-135.84	21.27	0.16	0.34	97.01	88.09	48.84	70.00	92.50
124	Industry	Buildings	Residential	Geyser blankets	70.86	27,104	-91.36	14.28	0.11	0.34	86.95	76.47	35.75	70.00	92.50
125	Industry	Buildings	Residential	Improved Insulation - new buildings	71.20	56,592	-43.41	8.81	0.06	0.32	76.11	67.37	52.86	70.00	92.50

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126	Industry	Buildings	Residential	Improved insulation - existing buildings	68.41	33,955	-13.75	5.53	0.03	0.28	69.40	61.91	50.86	70.00	92.50
127	Industry	Buildings	Residential	Efficient lighting - FLs	77.16	328,381	-147.31	23.02	0.17	0.34	99.60	91.00	39.63	65.00	100.00
128	Industry	Buildings	Residential	Efficient lighting - LEDs	73.34	13,155	-110.84	17.35	0.13	0.34	91.35	81.57	37.11	65.00	100.00
129	Industry	Buildings	Residential	Solar water heating	76.10	74,941	-95.51	14.96	0.11	0.34	87.89	77.60	56.05	70.00	92.50
130	Industry	Buildings	Residential	LPG for cooking	62.22	32,001	0.39	-0.05	-0.00	0.36	66.21	52.63	39.48	70.00	85.00
131	Industry	Buildings	Residential	Passive building/improved thermal design - new buildings	70.75	89,355	-98.53	15.62	0.12	0.34	88.57	78.69	46.30	70.00	75.00
132	Industry	Buildings	Commercial/ institutional	Efficient lighting	73.71	57,750	-114.46	17.89	0.13	0.34	92.17	82.46	37.35	65.00	100.00
133	Industry	Buildings	Commercial/ institutional	Heat pumps - existing buildings	66.99	16,739	-62.06	10.46	0.07	0.34	80.33	70.12	33.85	65.00	92.50
134	Industry	Buildings	Commercial/ institutional	Heat pumps - new buildings	68.33	19,443	-65.54	10.90	0.08	0.34	81.11	70.84	34.07	70.00	92.50
135	Industry	Buildings	Commercial/ institutional	HVAC: with heat recovery - new buildings	76.98	60,808	-149.08	23.52	0.17	0.34	100.00	91.84	39.79	70.00	92.50
136	Industry	Buildings	Commercial/ institutional	HVAC: variable speed drives - existing buildings	72.15	38,181	-102.72	16.41	0.12	0.34	89.52	80.01	36.60	70.00	92.50
137	Industry	Buildings	Commercial/ institutional	HVAC: variable speed drives - new buildings	72.35	46,362	-104.79	16.67	0.12	0.34	89.98	80.44	36.74	70.00	92.50
138	Industry	Buildings	Commercial/ institutional	HVAC: Central air conditioners - new buildings	70.55	13,840	-86.17	14.33	0.10	0.34	85.78	76.55	35.54	70.00	92.50
139	Industry	Buildings	Commercial/ institutional	Energy efficient appliances	73.04	12,466	-111.93	17.56	0.13	0.34	91.60	81.92	37.19	70.00	92.50
140	Industry	Buildings	Commercial/ institutional	Passive building/improved thermal design - new buildings	76.04	166,497	-148.60	23.55	0.17	0.34	99.89	91.88	49.78	70.00	75.00
141	Transport	Road	Road	Road - alternative fuels - CNG	62.36	92,297	-10.81	1.29	0.01	0.35	68.74	54.86	50.18	70.00	67.50

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142	Transport	Road	Road	Road - alternative fuels - diesel PHEV	50.38	14,164	9.11	-1.74	-0.01	0.41	64.23	49.83	39.42	65.00	32.50
143	Transport	Road	Road	Road - improved efficiency - petrol ICE	68.05	504,410	-69.07	8.84	0.08	0.35	81.91	67.42	34.15	70.00	92.50
144	Transport	Road	Road	Road - alternative fuels - petrol HEV	60.20	104,746	26.58	-3.27	-0.03	0.37	60.28	47.28	38.07	65.00	92.50
145	Transport	Road	Road	Road - improved efficiency - diesel ICE	63.65	432,845	-24.27	3.05	0.03	0.34	71.78	57.80	31.14	70.00	92.50
146	Transport	Road	Road	Road - alternative fuels - petrol PHEV	51.99	26,422	-8.59	0.67	0.01	0.31	68.24	53.82	39.95	65.00	32.50
147	Transport	Road	Road	Road - alternative fuels - FCEV	42.46	6,118	37.81	-5.50	-0.04	0.36	57.74	43.56	37.09	40.00	32.50
148	Transport	Road	Road	Road - alternative fuels - Diesel HEV	58.15	63,581	47.09	-6.01	-0.05	0.36	55.65	42.72	36.64	65.00	92.50
149	Transport	Road	Road	Road - alternative fuels - EV	54.80	8,886	-21.88	1.34	0.02	0.35	71.24	54.95	50.92	45.00	50.00
150	Transport	Road	Road	Road - shifting passengers from cars to public transport	65.86	153,850	65.20	-6.81	-0.06	0.38	51.55	41.39	56.18	100.00	77.50
151	Transport	Road	Road	Road - shifting freight from road to rail	72.14	87,159	-23.51	1.88	0.01	0.48	71.61	55.84	61.25	85.00	85.00
152	Transport	Road	Road	Road - biofuels	50.65	396,964	33.36	-4.08	-0.04	0.36	58.75	45.93	37.43	35.00	77.50
153	Transport	Rail	Rail	Rail - improved efficiency - EMUs	77.19	2,435	-163.99	28.43	0.29	0.35	88.90	100.00	46.53	70.00	92.50
154	Transport	Rail	Rail	Rail - improved efficiency - diesel	62.96	6,349	-16.76	2.32	0.02	0.33	70.08	56.57	30.61	70.00	92.50
155	Transport	Rail	Rail	Rail - alternative fuels - hybrid diesel	65.43	1,886	34.64	-4.79	-0.03	0.40	58.46	44.75	38.09	95.00	92.50
156	Transport	Rail	Rail	Rail - alternative fuels - CNG	54.51	366	33.23	-5.84	-0.04	0.34	58.78	43.00	37.08	90.00	42.50

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157	Transport	Rail	Rail	Rail - biofuels	51.83	4,626	39.54	-6.43	-0.01	1.33	57.35	42.03	45.94	35.00	77.50
158	Transport	Aviation	Aviation	Aviation - biofuels	48.84	20,733	52.89	-6.28	-0.06	0.36	54.34	42.27	36.25	35.00	77.50
159	Waste	Municipal solid waste	Municipal solid waste	LFG recovery and generation	60.63	292,263	-0.98	0.21	0.02	-0.51	66.52	53.07	38.23	70.00	77.50
160	Waste	Municipal solid waste	Municipal solid waste	LFG recovery and flaring	63.45	56,446	5.36	-0.72	0.06	-0.45	65.08	51.53	40.39	70.00	92.50
161	Waste	Municipal solid waste	Municipal solid waste	Paper recycling	69.01	164,273	37.34	-3.91	0.38	0.80	57.85	46.21	65.26	80.00	92.50
162	Waste	Municipal solid waste	Municipal solid waste	Energy from waste	38.66	83,312	164.70	-16.69	0.07	-1.40	29.06	24.96	30.87	65.00	42.50
163	Waste	Municipal solid waste	Municipal solid waste	Home composting	69.04	4,579	-55.41	8.69	-0.06	1.06	78.82	67.12	24.74	90.00	92.50
164	Waste	Municipal solid waste	Municipal solid waste	Windrow composting	54.34	11,932	120.35	-13.74	2.35	0.77	39.08	29.86	63.95	65.00	67.50
165	Waste	Municipal solid waste	Municipal solid waste	In-vessel composting	61.09	36,163	105.61	-12.21	1.21	0.79	42.42	32.42	72.08	100.00	50.00
166	Waste	Municipal solid waste	Municipal solid waste	Anaerobic digestion	49.15	45,867	157.42	-18.19	0.47	0.91	30.70	22.47	71.64	85.00	25.00
167	AFOLU	AFOLU	AFOLU	Expanding plantations	46.12	81,011	-1.84	3.09	0.02	0.34	66.71	57.86	20.64	15.00	77.50
168	AFOLU	AFOLU	AFOLU	Biochar addition to cropland	59.28	44,727	12.46	-0.29	0.00	1.37	63.48	52.23	36.94	95.00	50.00
169	AFOLU	AFOLU	AFOLU	Treatment of livestock waste	61.24	19,359	45.16	-2.11	1.12	0.71	56.08	49.21	61.35	60.00	77.50
170	AFOLU	AFOLU	AFOLU	Rural tree planting (thickets)	71.16	57,050	3.03	-0.33	0.24	0.73	65.61	52.17	56.72	95.00	85.00
171	AFOLU	AFOLU	AFOLU	Urban tree planting	75.77	20,229	11.56	-1.25	0.35	0.76	63.68	50.63	83.46	75.00	100.00
172	AFOLU	AFOLU	AFOLU	Restoration of mesic grasslands	53.27	14,694	293.22	-31.70	3.32	0.76	0.00	0.00	75.51	95.00	85.00

Table 34: Overall weighted score and ranking of all measures for the balanced weighting, cost and implementability, and social and environmental pathways

Item	Key sector	Sector	Subsector	Measure	Balanced weighting		Cost and implementability		Social and environmental	
					Score	Rank	Score	Rank	Score	Rank
1	Energy	Non-power	Other energy industries	Increase onsite gas-fired power generation - using internal combustion engines	67.81	37	75.77	40	61.83	38
2	Energy	Non-power	Other energy industries	Waste heat recovery power generation	53.24	121	53.82	128	53.66	116
3	Energy	Non-power	Other energy industries	Waste gas recovery and utilisation	50.69	131	51.85	135	51.51	122
4	Energy	Non-power	Other energy industries	CCS - process emissions from existing plants (storage onshore)	31.50	168	33.86	168	29.30	170
5	Energy	Non-power	Other energy industries	Energy monitoring and management system	64.94	55	73.75	48	58.50	73
6	Energy	Non-power	Other energy industries	Improved process control	64.90	56	73.64	49	58.49	74
7	Energy	Non-power	Other energy industries	Improved electric motor system controls and VSDs	68.36	31	77.68	25	60.90	45
8	Energy	Non-power	Other energy industries	Energy efficient utility systems	67.92	36	77.14	32	60.60	52
9	Energy	Non-power	Other energy industries	Improved heat systems	70.26	23	80.01	18	62.20	37
10	Energy	Non-power	Other energy industries	CCS - process emissions from existing plants (storage offshore)	25.32	171	26.34	171	25.08	172
11	Energy	Non-power	Other energy industries	CCS - process emissions from new plants	36.14	159	39.49	155	32.48	165
12	Energy	Non-power	Petroleum refining	Improve steam generating boiler efficiency	65.78	48	75.84	39	59.07	61
13	Energy	Non-power	Petroleum refining	Improve process heater efficiency	68.24	33	77.49	27	60.83	48
14	Energy	Non-power	Petroleum refining	Waste heat recovery and utilization	51.53	129	53.84	127	50.72	127
15	Energy	Non-power	Petroleum refining	Minimise flaring and utilise flare gas as fuel	49.93	135	50.05	139	51.68	121
16	Energy	Non-power	Petroleum refining	Efficient energy production (CCGT and CHP)	47.23	142	47.49	145	48.51	132
17	Energy	Non-power	Petroleum refining	Waste heat boiler and expander applied to flue gas from the FCC regenerator	46.64	146	46.22	148	48.32	133
18	Energy	Non-power	Petroleum refining	CCS - Existing Refineries	30.64	169	34.83	167	26.85	171
19	Energy	Non-power	Petroleum refining	Energy monitoring and management system	68.82	27	78.19	22	61.23	41
20	Energy	Non-power	Petroleum refining	Improved process control	65.69	50	74.33	44	59.10	60
21	Energy	Non-power	Petroleum refining	Improved heat exchanger efficiencies	63.22	76	71.37	71	57.35	95
22	Energy	Non-power	Petroleum refining	Improved electric motor system controls and VSDs	62.40	83	70.42	76	56.74	101
23	Energy	Non-power	Petroleum refining	Energy-efficient utility systems	64.85	58	73.33	51	58.51	72
24	Energy	Non-power	Petroleum refining	CCS - New Refineries	35.17	164	38.36	157	31.81	167
25	Energy	Non-power	Coal mining	Coal mine methane recovery and utilisation for power and/or heat generation	47.58	139	52.42	133	43.59	146
26	Energy	Non-power	Coal mining	Coal mine methane recovery and destruction by flaring	53.74	119	60.52	107	49.71	129
27	Energy	Non-power	Coal mining	Use of 1st generation biodiesel (B5) for transport and handling equipment	48.81	138	53.59	129	45.78	142

Item	Key sector	Sector	Subsector	Measure	Balanced weighting		Cost and implementability		Social and environmental	
					Score	Rank	Score	Rank	Score	Rank
28	Energy	Non-power	Coal mining	Improve energy efficiency of mine haul and transport operations	63.75	68	71.10	74	57.82	86
29	Energy	Non-power	Coal mining	Use of 2nd generation biodiesel (B50) for transport and handling equipment	47.11	144	47.38	146	46.67	138
30	Energy	Non-power	Coal mining	Use of 2nd generation biodiesel (B100) for transport and handling equipment	47.03	145	47.52	144	45.28	144
31	Energy	Non-power	Coal mining	Process, demand & energy management system	71.95	14	82.59	10	63.12	28
32	Energy	Non-power	Coal mining	Energy efficient lighting	71.23	16	81.73	14	62.63	33
33	Energy	Non-power	Coal mining	Install energy-efficient electric motor systems	69.28	24	79.36	19	61.29	40
34	Energy	Non-power	Coal mining	Optimise existing electric motor systems (controls and VSDs)	71.75	15	82.35	12	62.99	30
35	Energy	Non-power	Coal mining	Onsite clean power generation	67.12	41	72.94	56	63.58	23
36	Energy	Power	Electricity and heating	Nuclear (PWR)	51.85	127	55.98	124	49.67	130
37	Energy	Power	Electricity and heating	Gas CCGT	56.18	111	55.22	125	61.77	39
38	Energy	Power	Electricity and heating	Onshore wind	58.42	104	61.38	105	59.06	62
39	Energy	Power	Electricity and heating	Solar CSP (Parabolic trough)	56.73	109	54.95	126	61.10	43
40	Energy	Power	Electricity and heating	Solar PV (Concentrated)	60.22	98	58.22	116	66.17	14
41	Energy	Power	Electricity and heating	Import (Hydro)	58.34	106	61.26	106	59.02	64
42	Energy	Power	Electricity and heating	Coal CCS	38.74	156	42.41	153	35.62	156
43	Energy	Power	Electricity and heating	Biomass	63.18	77	65.96	97	63.37	26
44	Energy	Power	Electricity and heating	LFG	45.48	148	45.41	150	47.28	136
45	Energy	Power	Electricity and heating	Energy from Waste	37.13	158	35.16	166	41.62	152
46	Industry	Metals	Primary aluminium production	Best process selection for primary aluminium smelting	64.47	64	72.04	67	58.66	71
47	Industry	Metals	Primary aluminium production	Switch to secondary production and increase recycling	62.26	85	68.81	88	58.17	81
48	Industry	Metals	Primary aluminium production	Energy monitoring & management system	66.65	45	75.63	41	59.72	57
49	Industry	Metals	Primary aluminium production	Improved process control	67.26	40	76.37	36	60.14	56
50	Industry	Metals	Primary aluminium production	Improved electric motor system controls and variable speed drives	62.93	81	71.14	73	57.13	98
51	Industry	Metals	Primary aluminium production	Energy-efficient utility systems	61.03	95	68.39	89	56.24	103
52	Industry	Metals	Ferroalloys production	Implementing best available production techniques	58.37	105	66.85	92	51.27	124
53	Industry	Metals	Ferroalloys production	Replace submerged arc furnace semi-closed with closed type	53.90	118	60.06	108	48.73	131
54	Industry	Metals	Ferroalloys production	Waste gas recovery and power generation - CO from closed furnace	58.18	107	63.18	102	54.87	112

Item	Key sector	Sector	Subsector	Measure	Balanced weighting		Cost and implementability		Social and environmental	
					Score	Rank	Score	Rank	Score	Rank
55	Industry	Metals	Ferroalloys production	Waste heat recovery and power generation from semi-closed furnace - Rankine Cycle	28.58	170	28.86	170	31.65	168
56	Industry	Metals	Ferroalloys production	Waste heat recovery and power generation from semi-closed furnace - Organic Rankine Cycle	25.05	172	21.91	172	31.90	166
57	Industry	Metals	Ferroalloys production	Use biocarbon reductants instead of coal/coke	35.85	161	37.92	160	33.52	161
58	Industry	Metals	Ferroalloys production	Energy monitoring and management system	70.39	22	80.14	17	62.29	36
59	Industry	Metals	Ferroalloys production	Improved electric motor system controls and variable speed drives	62.05	87	70.13	77	56.45	102
60	Industry	Metals	Ferroalloys production	Energy-efficient utility systems	64.59	62	73.12	53	58.31	78
61	Industry	Metals	Ferroalloys production	Improved heat exchanger efficiencies	66.39	46	77.15	31	57.72	88
62	Industry	Metals	Iron and steel production	BOF waste heat and gas recovery	63.03	79	69.45	84	55.67	109
63	Industry	Metals	Iron and steel production	Top gas pressure recovery turbine	61.94	88	66.33	95	58.04	83
64	Industry	Metals	Iron and steel production	Electric Arc Furnaces (EAF) and secondary production route	54.72	115	63.98	100	46.60	139
65	Industry	Metals	Iron and steel production	State-of-the-Art Power Plant	42.35	152	48.91	140	36.65	154
66	Industry	Metals	Iron and steel production	Top gas-recycling blast furnace (with CCS)	35.75	162	38.31	158	32.52	164
67	Industry	Metals	Iron and steel production	CCS - blast furnace (post-combustion)	35.91	160	37.83	161	33.69	160
68	Industry	Metals	Iron and steel production	State-of-the-art power plant (with CCS)	31.82	167	32.84	169	30.91	169
69	Industry	Metals	Iron and steel production	DRI – Midrex process	43.03	150	50.67	138	35.98	155
70	Industry	Metals	Iron and steel production	DRI – HYL process	40.02	155	45.83	149	34.44	158
71	Industry	Metals	Iron and steel production	DRI – ULCORED process	41.02	154	40.38	154	42.55	149
72	Industry	Metals	Iron and steel production	Energy monitoring and management system	63.71	70	72.22	63	57.67	90
73	Industry	Metals	Iron and steel production	Improved process control	61.53	90	69.72	82	56.01	105
74	Industry	Metals	Iron and steel production	Improved electric motor system controls and variable speed drives	67.69	39	76.26	37	60.58	54
75	Industry	Metals	Iron and steel production	Energy efficient boiler systems and kilns	63.66	72	69.80	81	61.02	44
76	Industry	Metals	Iron and steel production	Energy-efficient utility systems	67.69	38	76.26	37	60.58	53
77	Industry	Metals	Iron and steel production	Improved heat exchanger efficiencies	63.04	78	71.41	70	57.19	97
78	Industry	Minerals	Cement production	Improved process control	59.26	101	66.55	93	54.79	113
79	Industry	Minerals	Cement production	Reduction of clinker content of cement products	61.16	92	69.47	83	55.72	108
80	Industry	Minerals	Cement production	Waste heat recovery from kilns and coolers/cogeneration	47.41	140	48.89	141	48.09	134
81	Industry	Minerals	Cement production	Utilise waste material as fuel	51.85	126	52.62	132	53.39	118

Item	Key sector	Sector	Subsector	Measure	Balanced weighting		Cost and implementability		Social and environmental	
					Score	Rank	Score	Rank	Score	Rank
82	Industry	Minerals	Cement production	Geopolymer cement production	41.25	153	38.71	156	45.06	145
83	Industry	Minerals	Cement production	CCS - back-end chemical absorption	35.03	165	37.21	163	34.13	159
84	Industry	Minerals	Cement production	CCS - oxyfuelling	35.65	163	37.96	159	34.55	157
85	Industry	Minerals	Cement production	Energy monitoring and management system	63.67	71	72.09	66	57.65	91
86	Industry	Minerals	Cement production	Improved electric motor system controls and variable speed drives	61.53	89	69.84	80	55.83	106
87	Industry	Minerals	Cement production	Energy-efficient utility systems	59.09	102	66.34	94	54.66	114
88	Industry	Minerals	Lime production	Installation of shaft preheaters	55.71	113	59.58	110	53.47	117
89	Industry	Minerals	Lime production	Replace rotary kilns with vertical kilns or PFRK	53.18	123	56.93	120	52.34	119
90	Industry	Minerals	Lime production	Use alternative fuels including waste and biomass	50.29	134	56.11	123	46.20	140
91	Industry	Minerals	Lime production	CCS for lime production	34.74	166	35.86	165	33.12	162
92	Industry	Minerals	Lime production	Energy monitoring and management system	65.40	53	74.22	45	58.85	67
93	Industry	Minerals	Lime production	Improved process control	63.73	69	72.21	64	57.69	89
94	Industry	Minerals	Lime production	Improved electric motor system controls and VSDs	64.60	61	73.09	54	58.32	77
95	Industry	Minerals	Lime production	Energy-efficient utility systems	63.99	66	72.36	60	57.90	84
96	Industry	Minerals	Lime production	Improved heat exchanger efficiencies	64.63	60	73.31	52	58.31	79
97	Industry	Chemicals production	Chemicals production	CCS for new ammonia production plants process emissions	55.99	112	57.27	119	57.89	85
98	Industry	Chemicals production	Chemicals production	Revamp: increase capacity and energy efficiency	44.29	149	46.47	147	42.35	150
99	Industry	Chemicals production	Chemicals production	N2O abatement for new production plants	61.04	94	69.18	85	55.82	107
100	Industry	Chemicals production	Chemicals production	Energy monitoring and management system	58.47	103	62.82	103	55.39	110
101	Industry	Chemicals production	Chemicals production	Advanced process control	64.85	59	73.49	50	58.48	76
102	Industry	Chemicals production	Chemicals production	Improved electric motor system controls and VSDs	65.22	54	73.96	46	58.73	69
103	Industry	Chemicals production	Chemicals production	Energy efficient utility systems	63.34	75	71.69	68	57.42	94

Item	Key sector	Sector	Subsector	Measure	Balanced weighting		Cost and implementability		Social and environmental	
					Score	Rank	Score	Rank	Score	Rank
104	Industry	Chemicals production	Chemicals production	Increase process integration and improved heat systems	64.53	63	72.59	59	58.49	75
105	Industry	Chemicals production	Chemicals production	Combined heat and power (CHP)	53.19	122	57.46	118	51.36	123
106	Industry	Mining	Surface and underground mining	Use of 1st generation biodiesel (B5) for transport and handling equipment	51.26	130	56.60	121	47.44	135
107	Industry	Mining	Surface and underground mining	Improve energy efficiency of mine haul and transport operations	64.86	57	72.97	55	58.26	80
108	Industry	Mining	Surface and underground mining	Use of 2nd generation biodiesel (B50) for transport and handling equipment	47.38	141	47.71	142	46.85	137
109	Industry	Mining	Surface and underground mining	Use of 2nd generation biodiesel (B100) for transport and handling equipment	47.13	143	47.63	143	45.35	143
110	Industry	Mining	Surface and underground mining	Process, demand & energy management system	68.65	28	78.73	20	60.84	47
111	Industry	Mining	Surface and underground mining	Energy efficient lighting	68.18	34	78.16	23	60.51	55
112	Industry	Mining	Surface and underground mining	Install energy-efficient electric motor systems	66.91	44	76.62	34	59.64	58
113	Industry	Mining	Surface and underground mining	Optimise existing electric motor systems (controls and VSDs)	68.52	29	78.57	21	60.75	50
114	Industry	Mining	Surface and underground mining	Onsite clean power generation	56.49	110	60.00	109	57.28	96
115	Industry	Other	Pulp and paper production	Convert fuel from coal to biomass/residual wood waste	65.60	51	71.28	72	63.42	25
116	Industry	Other	Pulp and paper production	Application of co-generation of heat and power (CHP)	52.29	124	57.51	117	50.23	128
117	Industry	Other	Pulp and paper production	Energy recovery system	67.05	42	72.74	58	64.47	19
118	Industry	Other	Pulp and paper production	Energy monitoring and management system	65.70	49	74.56	42	59.05	63
119	Industry	Other	Pulp and paper production	Energy efficient electric motors, improved controls and variable speed drives	63.83	67	72.29	62	57.76	87
120	Industry	Other	Pulp and paper production	Energy-efficient utility systems (e.g. lighting, refrigeration, compressed air)	60.68	96	68.90	87	55.18	111
121	Industry	Other	Pulp and paper production	Improved process control	62.66	82	70.91	75	56.93	100
122	Industry	Other	Pulp and paper production	Energy efficient boiler systems and kilns and Improved heat systems	64.33	65	72.90	57	58.12	82
123	Industry	Buildings	Residential	Energy efficient appliances	77.94	1	87.25	3	69.35	8
124	Industry	Buildings	Residential	Geyser Blankets	70.86	19	80.75	15	62.60	34
125	Industry	Buildings	Residential	Improved Insulation - New Buildings	71.20	17	77.22	30	66.60	13
126	Industry	Buildings	Residential	Improved Insulation - Existing Buildings	68.41	30	73.79	47	64.68	18
127	Industry	Buildings	Residential	Efficient Lighting - FLs	77.16	3	89.40	1	65.68	16
128	Industry	Buildings	Residential	Efficient Lighting - LEDs	73.34	9	84.91	6	63.03	29
129	Industry	Buildings	Residential	Solar water heating	76.10	5	83.27	9	69.91	7

Item	Key sector	Sector	Subsector	Measure	Balanced weighting		Cost and implementability		Social and environmental	
					Score	Rank	Score	Rank	Score	Rank
130	Industry	Buildings	Residential	LPG for cooking	62.22	86	68.19	90	58.70	70
131	Industry	Buildings	Residential	Passive building/improved thermal design - new buildings	70.75	20	77.43	29	64.93	17
132	Industry	Buildings	Commercial/ institutional	Efficient Lighting	73.71	8	85.35	4	63.29	27
133	Industry	Buildings	Commercial/ institutional	Heat pumps - existing buildings	66.99	43	76.78	33	58.89	66
134	Industry	Buildings	Commercial/ institutional	Heat pumps - new buildings	68.33	32	77.69	24	60.87	46
135	Industry	Buildings	Commercial/ institutional	HVAC: with heat recovery - new buildings	76.98	4	87.91	2	66.86	12
136	Industry	Buildings	Commercial/ institutional	HVAC: variable speed drives - existing buildings	72.15	12	82.22	13	63.51	24
137	Industry	Buildings	Commercial/ institutional	HVAC: variable speed drives - new buildings	72.35	11	82.46	11	63.65	22
138	Industry	Buildings	Commercial/ institutional	HVAC: central air conditioners - new buildings	70.55	21	80.27	16	62.42	35
139	Industry	Buildings	Commercial/ institutional	Energy efficient appliances	73.04	10	83.30	8	64.12	20
140	Industry	Buildings	Commercial/ institutional	Passive building/improved thermal design - new buildings	76.04	6	83.62	7	68.60	10
141	Transport	Road	Road	Road - alternative fuels - CNG	62.36	84	65.25	98	61.17	42
142	Transport	Road	Road	Road - alternative fuels - diesel PHEV	50.38	133	50.87	137	51.20	125
143	Transport	Road	Road	Road - improved efficiency - petrol ICE	68.05	35	77.67	26	60.64	51
144	Transport	Road	Road	Road - alternative fuels - petrol HEV	60.20	99	66.90	91	56.08	104
145	Transport	Road	Road	Road - improved efficiency - diesel ICE	63.65	73	72.36	61	57.61	92
146	Transport	Road	Road	Road - alternative fuels - petrol PHEV	51.99	125	52.92	131	52.19	120
147	Transport	Road	Road	Road - alternative fuels - FCEV	42.46	151	44.91	151	40.36	153
148	Transport	Road	Road	Road - alternative fuels - Diesel HEV	58.15	108	64.44	99	54.66	115
149	Transport	Road	Road	Road - alternative fuels - EV	54.80	114	58.58	114	51.19	126
150	Transport	Road	Road	Road - shifting passengers from cars to public transport	65.86	47	63.63	101	71.71	5
151	Transport	Road	Road	Road - shifting freight from road to rail	72.14	13	74.35	43	72.43	4
152	Transport	Road	Road	Road - biofuels	50.65	132	58.59	113	43.57	147
153	Transport	Rail	Rail	Rail - improved efficiency - EMUs	77.19	2	84.96	5	68.92	9
154	Transport	Rail	Rail	Rail - improved efficiency - Diesel	62.96	80	71.50	69	57.13	99
155	Transport	Rail	Rail	Rail - alternative fuels - Hybrid diesel	65.43	52	68.92	86	66.15	15
156	Transport	Rail	Rail	Rail - alternative fuels - CNG	54.51	116	53.27	130	58.91	65
157	Transport	Rail	Rail	Rail - biofuels	51.83	128	58.49	115	46.02	141

Item	Key sector	Sector	Subsector	Measure	Balanced weighting		Cost and implementability		Social and environmental	
					Score	Rank	Score	Rank	Score	Rank
158	Transport	Aviation	Aviation	Aviation - biofuels	48.84	137	56.34	122	42.35	151
159	Waste	Municipal Solid Waste	Municipal solid waste	LFG recovery and generation	60.63	97	65.99	96	57.59	93
160	Waste	Municipal Solid Waste	Municipal solid waste	LFG recovery and flaring	63.45	74	69.98	79	59.55	59
161	Waste	Municipal Solid Waste	Municipal solid waste	Paper recycling	69.01	26	70.04	78	70.50	6
162	Waste	Municipal Solid Waste	Municipal solid waste	Energy from waste	38.66	157	36.46	164	43.21	148
163	Waste	Municipal Solid Waste	Municipal solid waste	Home composting	69.04	25	77.46	28	64.00	21
164	Waste	Municipal Solid Waste	Municipal solid waste	Windrow composting	54.34	117	51.76	136	58.78	68
165	Waste	Municipal Solid Waste	Municipal solid waste	In-vessel composting	61.09	93	52.42	134	72.71	3
166	Waste	Municipal Solid Waste	Municipal solid waste	Anaerobic digestion	49.15	136	37.69	162	62.64	32
167	AFOLU	AFOLU	AFOLU	Expanding plantations	46.12	147	59.28	111	32.68	163
168	AFOLU	AFOLU	AFOLU	Biochar addition to cropland	59.28	100	58.81	112	62.75	31
169	AFOLU	AFOLU	AFOLU	Treatment of livestock waste	61.24	91	62.74	104	60.75	49
170	AFOLU	AFOLU	AFOLU	Rural tree planting (thickets)	71.16	18	72.13	65	73.38	2
171	AFOLU	AFOLU	AFOLU	Urban tree planting	75.77	7	76.38	35	76.89	1
172	AFOLU	AFOLU	AFOLU	Restoration of mesic grasslands	53.27	120	42.55	152	68.18	11

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First publication in 2014

S-1566 • www.studio112.co.za