mitigation REPORT

SOUTH AFRICA'S GREENHOUSE GAS MITIGATION POTENTIAL ANALYSIS

TECHNICAL APPENDIX E – TRANSPORT SECTOR

environmental affairs

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

Technical Summary

Main Report

Technical Appendices:

Appendix A: Approach and Methodology

Appendix B: Macroeconomic Modelling

Appendix C: Energy Sector

Appendix D: Industry Sector

Appendix E: Transport Sector

Appendix F: Waste Sector

Appendix G: Agriculture, Forestry and Other Land Use Sector

List of Abbreviations

Acronym	Definition
AD	anaerobic digestion
AFOLU	agriculture, forestry and other land use
BFAP	Bureau for Food and Agricultural Policy
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DEA	Department of Environmental Affairs
DoE	Department of Energy
EMU	electric multiple unit (train set)
ERC	Energy Research Centre
EV	electric vehicle
FCEV	fuel cell electric vehicle
GDP	gross domestic product
Gg/yr	gigagrams per year
GHG	greenhouse gas
GHGI	Greenhouse Gas Inventory for South Africa
GJ	gigajoules
GVA	gross value added
GW	gigawatt
GWh	gigawatt hour
ICAO	International Civil Aviation Organisation
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
JRC	Joint Research Centre
kW	kilowatt
kWh	kilowatt hour
$ktCO_2e$	kilotonnes of carbon dioxide equivalent
LCV	light commercial vehicles
MAC	marginal abatement cost
MACC	marginal abatement cost curve
MBT	minibus taxi
MCA	multi-criteria (decision) analysis
MJ	megajoules

Acronym	Definition
Mt	million tonnes
$MtCO_2e$	million tonnes of carbon dioxide equivalent
NAC	net annualised cost
NPV	net present value
PHEV	plug-in hybrid electric vehicle
PJ	petajoule
PRASA	Passenger Rail Association of South Africa
SATIM	South African TIMES model
SULTAN	Sustainable Transport Illustrative Scenario Accounting Tool
TWG-M	Technical Working Group on Mitigation
UNFCCC	United Nations Framework Convention on Climate Change
Vkm	vehicle kilometres
WAM	'with additional measures' scenario
WEM	'with existing measures' scenario
WOM	'without measures' scenario
WTW	well to wheel (life-cycle) emissions
WTT	well to tank (indirect) emissions
ZAR/R	South African rand

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Chapter 1: Introduction

1. Introduction

This appendix provides an overview of the emissions trends, existing policies and potential future abatement opportunities for the transport sector. Specifically, this includes emissions associated with the following Intergovernmental Panel on Climate Change (IPCC) emissions categories:

- 1A3a civil aviation
- 1A3b road transport
- 1A3c railway
- 1A3d water-borne navigation

Emissions are restricted to those arising within South African national territory, in accordance with IPCC reporting. Therefore, emissions associated with international aviation and international maritime transportation are excluded from the analysis.

In analysing the abatement opportunities, 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). Likewise emission factors associated with the use of biofuel take into account upstream emissions from biofuel production. The emission factors that have been applied in the calculation of the life-cycle impacts are described further in Box 1.

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.

Box 1: Direct and indirect emission factors

The following emissions factors have been applied in the assessment of direct emissions in the transport sector. All factors are assumed to hold constant over the full assessment period.

Direct	$kgCO_2e/GJ$	Source
Diesel	74	GHGI and IPCC guidelines (2006)
Petrol	69	GHGI and IPCC guidelines (2006)
Natural gas (CNG)	56	GHGI and IPCC guidelines (2006)

The following emissions factors have been applied in the assessment of indirect emissions in the transport sector. All factors are assumed to hold constant over the full assessment period. In practice, certain factors will be expected to change due to structural changes in the energy sector including, for example decarbonisation of power generation. It is also important to note that not all indirect emissions will arise in South Africa; certain indirect emissions, for example those associated with fuel production, will be produced in other territories.

Box 1: Direct and indirect emission factors - continued

Indirect (well to tank)	$kgCO_2e/GJ$	Source
Diesel	50	Coal to liquid (CTL) weighted average based on EC JRC WTW Study on CTL process (EC, 2007c) and Defra GHG reporting guidelines (2012).[1]
Biodiesel (FAME)	53	Based on average of values for canola and soy in South Africa, as calculated using UK carbon calculator for biofuels.
2G FT biodiesel*	7	Based on farmed wood.
Petrol (CTL process)	50	CTL weighted average based on EC JRC WTW Study on CTL process (EC, 2007c) and Defra GHG reporting guidelines (2012).
Bioethanol	30	Based on average for sugar cane production (in SA) and corn (based on EU) as modelling of SA in tool not possible.
Aviation	15	Defra GHG reporting guidelines (2012)
Natural gas (CNG)	9	Defra GHG reporting guidelines (2012)
Electricity	285[2]	Calculated from the power sector tool, based upon fuel use and power generation data provided by Eskom and using calorific values for fuels and emissions factors that are consistent with the GHGI.

Second generation biodiesel from syngas using the Fischer-Tropsch process.

It is also important to recognise that mitigation actions taken within the transport sector will have important feedbacks in other sectors of the economy. For example, abatement measures that influence the level of fuel demand will affect the amount of liquid fuel that needs to be produced in South Africa to meet the transport demand, and therefore the associated emissions from the sector. Likewise, the large scale take up of biofuels, if supplied from indigenous sources, will have an influence on future land use scenarios, and the associated direct emissions from this sector.

The bottom-up approach that has been used in the current study does not assess each of these sectoral interactions automatically, and to do so fully would require additional modelling effort which is beyond the scope of the current study. However, the use of emission factors, which include an estimate of the impacts of measures on indirect emissions such as those associated with fuel production, allows the scale of some of these interactions to be understood. Some further discussion of this issue is provided in Section 9.

1. Conventional diesel well to tank (WTT) emission factor is taken to be 16 $kgCO_2e/GJ$ while the CTL specific factor is 130 $kgCO_2e/GJ$. A weighted average is taken to arrive at the figure quoted above which assumes that 30% of all diesel production in South Africa is CTL (http:/www.worldcoal.org/coal/uses-of-coal/coal-to-liquids/).

2. The emission factor for electricity is the only factor not to be fixed along the time series. Please refer to the Power Sector chapter for details of the projection up to 2050.

Chapter II: Reference Case Projection

2. Introduction

A reference case 'without measures' (WOM) emissions projection has been developed for the three main transport modes (aviation, road transport and railways). The data for the maritime subsector was insufficient for the development of scenarios. The WOM represents a projection of the emissions trajectory without any mitigation policies and measures factored in. In addition, a 'with existing measures' (WEM) emissions scenario has been developed to take into account the influence of existing policies, although for most transport modes this influence is limited.

Emissions from the transport sector arise directly from the combustion of fuels, and indirectly from the production of electricity or other energy carriers. The level of energy consumption is a factor of the activity levels (for example passenger or tonne km), the energy intensity of the transport activity (for example MJ per tonne km) and the carbon intensity of the energy (for example gCO_2 per MJ). Transport activity levels are strongly related to socio-economic drivers, in particular the assumed growth in population and GDP. These drivers will, in turn, influence other important social factors such as levels of vehicle ownership and the nature and frequency of journeys made.

In developing the reference case projections, the assumed growth in activity levels for road and rail transport have been taken from a study by the Energy Research Centre (ERC, 2012). These are broadly comparable with demand projections published elsewhere.[3] Furthermore, the overall economic growth assumptions used in the ERC study (3.9% GDP growth p.a.) are comparable to those from the Conningarth modelling that have been used to inform the projections for the other sectors.

The ERC study developed a detailed bottom up model of the energy needs of the transport sector in South Africa, and included macroeconomic modelling of key socio-economic drivers on activity levels. Given the level of detail in the previous work, and the fact that the analysis is still very recent, the results in terms of the projected activity levels have been applied directly. The impact of these changes on emissions from the sector has been calculated using Ricardo-AEA's SULTAN tool (Ricardo-AEA et al., 2012, see Box 2). For aviation, a more simplified approach has been taken, based on the emissions reported for the sector in the Greenhouse Gas Inventory (GHGI) for South Africa (DEA, 2013).[4]

Box 2: The Ricardo-AEA SULTAN Tool

The SULTAN (SUstainabLe TrANsport) Illustrative Scenarios Tool has been developed by Ricardo-AEA as a scenario tool to help provide indicative estimates of the possible impacts of policy on transport.[5] SULTAN is a calculation tool developed as part of a project for the European Commission. It is designed to help with long-term planning for reducing the environmental impacts of the transport system through exploring scenarios. The tool allows users to quantify the current and projected future impacts of transport, understand the drivers behind these impacts and develop policies and measures to mitigate them. SULTAN assesses a number of impacts, including:

- energy consumption and energy security
- greenhouse gas emissions (direct and indirect)
- local air quality pollutants
- costs (vehicle capital costs, operating costs, fuel costs) and cost-effectiveness.

3. For example, ERC (2012) assumes a growth in freight demand, measured in terms of billion tonne kilometres, of 157% over the period 2010 to 2040. In comparison, from personal communication with Transnet, a growth in surface freight transport, measured in terms of tonne kilometres, of 150% between 2011 and 2040 is projected. Similarly, rail freight demand is projected to grow 170% from 2011–2040 by Transnet while ERC (2012) quotes a growth rate of 141%.
4. The ERC (2012) study also included aviation. However, due to a discrepancy between the reported level of transport activities and the associated emissions, as reported in the GHGI, an alternative approach was adopted.
5. http://www.eutransportghg2050.eu/cms/illustrative-scenarios-tool/

Box 2: The Ricardo-AEA SULTAN Tool - continued

SULTAN allows different transport scenarios to be created and compared. Scenarios are run from 2010 to 2050, and consider a single region (for example a country, continent or city). Each scenario is divided into transport modes, and then subdivided into different vehicle technologies and fuels. By comparing different scenarios (for example, a business-as-usual scenario and a scenario where policy measures are implemented to reduce the impact of transport), the advantages and disadvantages of different options can be assessed. SULTAN also includes a dedicated results viewer that automatically generates a range of results tables and charts for comparing scenarios quickly and easily.

Past services include developing and analysing emission reduction options for different transport modes, technologies, fuels and behavioural measures transport activity and emissions scenarios policy packages from combinations of individual policies and measures and analysing their economic and environmental impacts.

The projections allow for a certain underlying (autonomous) level of energy efficiency improvements, which would be expected even in the absence of any new policies. This reflects the fact that over time the oldest vehicles in the stock will be replaced by new, more energy-efficient vehicles, improving the average energy efficiency of the stock. At the same time, vehicle manufacturers will strive to improve the energy efficiency of new vehicles, as this may offer them a competitive advantage. This means that the overall energy efficiency of the new vehicles entering the market will continue to improve over time.

3. Assumptions

3.1 Aviation

As for all transport modes, historical emissions from domestic aviation over the period 2000 to 2010 are based on the GHGI and the underlying energy consumption statistics.

Emissions to 2050 have been projected assuming that emissions follow the trend in passenger demand growth, but allowing for some underlying improvements in energy efficiency. Due to a lack of detailed information on aircraft activity levels, the sector has been characterised as one homogenous unit with no differentiation by aircraft type or route. This simplification is sufficient for the purposes of developing an emissions projection, but provides a more limited basis for assessing the potential from abatement measures.

In projecting emissions forward, an annual growth rate in passenger km of 6% has been assumed between 2010 and 2020,[6] declining to 5% between 2020 and 2030 and 4% from 2030 onwards. This is broadly consistent with the latest Global Market Forecast from Airbus of 7.2% annual growth rate to 2021 and 5.2% from 2021 to 2031 (Airbus, 2012), and slightly less optimistic than the growth assumed in the National Transport Master Plan of 6.9% to 2020 and 5.9% to 2030 (Department of Transport, 2010).The rate of growth is assumed to apply equally to both passenger and freight transport.

An underlying level of autonomous energy efficiency improvement of 1.5% per year has been assumed in the WOM projection. This reflects improving fuel efficiency of aircraft and improved aircraft operations in response to the strong existing economic drivers for fuel efficiency in the sector. The assumed efficiency is at the upper range applied in other studies (for example, UK Committee on Climate Change, 2009).

3.2 Road Transport

Emissions from road transport have been projected using Ricardo-AEA's SULTAN tool, based on previous detailed modelling by ERC (2012). The projected growth in overall passenger and freight demand was taken directly from ERC (2012). The mix of vehicle types and the average vehicle kilometres (Vkm) is assumed to remain fixed over time, in accordance with base year data from the ERC report, but some further dieselisation of the stock over time is assumed following recent trends.

6. In practice, passenger demand has actually declined in the past two years.

Estimates of load factors for passenger road transport in South Africa were taken from ERC (2012), as was information on the fuel economy per mode in the base year.

One important factor which influences future emissions is stock replacement. In the analysis, a vintage profile derived from realistic scrapping curves was used, and an assessment made of annual vehicle mileage per mode and how this decays as the vehicle ages. The assumed survival rates were taken from ERC (2012) for surface passenger transport. The Richard's Survival function from Schmoyer et al. (2001) was then used to obtain parameters for the survival rate datasets which are then input into SULTAN to obtain year on year sales using the stock model.[7]

In the WOM scenario, existing vehicles are assumed to be replaced by equivalent (but more efficient) vehicles of the same type. An assumed level of autonomous efficiency improvement of 0.5% per year has been applied.

The data inputs were integrated into the SULTAN tool and the fuel use in petajoules (PJ) and direct emissions ($MtCO_2e$) from the stock in 2010 were calculated and compared with the GHGI. Following this, some small modifications were made to the model inputs to ensure closer calibration as follows:

- Matching of the fuel use share in 2010 to align with the latest inventory data.
- Increasing load factors of cars from 1.4 to 2.0 – The ERC (2012) study used an average load factor from Johannesburg. This was adjusted to reflect an average across all regions which brought the factor up to 2.0.[8]
- Decreasing load factors of minibus taxis (MBTs).

Following these changes the SULTAN model outputs for 2010 were within 1% of the emissions reported in the GHGI.

3.3 Rail Transport

Historical emissions associated with rail transportation have been taken from the GHGI. This includes the direct emissions from fuel combustion in diesel engines, but not indirect emissions associated with the electricity consumed by the electrified stock which is accounted for as part of the electricity generation sector.[9]

Information on activity levels associated with passenger rail in 2010/2011 has been obtained from the Passenger Rail Association of South Africa (PRASA). [10] This includes the number of engines used for mainline and metro services, and the total annual distance travelled. An estimate was also provided of the total energy consumption, allowing a calculation of the overall energy intensity of the current MetroRail service. Almost all passenger rail is electrified, with diesel representing around 2% of total activity.

Emissions to 2050 were projected forward based on the growth in activity levels modelled in ERC (2012) for consistency with the road transport projections. Improvements in the energy efficiency of the stock over time were estimated based on planned investments in new passenger rail infrastructure by PRASA (2011), and Transnet's investment plans for freight (Transnet, 2012). However, it was not possible to fully reconcile the assumed growth in rail transport by PRASA and Transnet with the growth in activity levels from the ERC report. The former tend to show a stronger level of growth, and therefore the use of the ERC growth assumptions may underestimate slightly the total emissions from the sector. Table 1 below shows the assumed rail demand used for this analysis.

7. The Richard's curve is a generalised logistic curve widely-used for growth modelling, extending the well-known logistic function. It is decaying in nature and imitates the expected survival rates (and inversely the retirement rates) of different road vehicles.
8. The justification behind this stems from the assumption that load factor largely increases with lower incomes and salaries in Johannesburg are on average higher than the national average.
9. These indirect emissions are significant in the case of rail transport, with emissions from electricity consumption representing over 85% of the total emissions.
10. Personal communication, Mosili Ntene, PRASA, 6th March 2013.

Table 1: Rail Demand

		2010	2020	2030	2040	2050
Billion pkm						
Passenger electric	Metrorail electric multiple unit (EMU)	14.1	16.5	17.5	18.2	18.7
Passenger diesel	Electric locomotives	0.3	0.3	0.3	0.3	0.3
Billion tkm						
Freight diesel	Diesel locomotives	19.9	24.9	34.3	48.0	65.8
Freight electric	Electric locomotives	109.1	136.1	187.7	263.0	360.2

3.4 Water-Borne Navigation

Insufficient information is available on the emissions associated with inland navigation. In the GHGI, energy use associated with inland navigation is assumed to be captured in other use categories. Overall, the emissions associated with this activity are considered small in comparison to other subsectors. For example, Aurecon (2012) estimate that coastal and short-sea shipping represents less than 1% of total freight transport in South Africa. On this basis the omission of this subsector is not considered to represent a material impact on the overall results.

3.5 Pipeline Transportation

The starting point for the sector definitions in the study is the GHGI. In the GHGI the transport sector is defined in terms of road transport, railways, civil aviation and water borne navigation categories (explained above). However, transportation of certain products (for example primary fuels) can also be made using pipelines. Within the GHGI the emissions associated with energy used in pipeline transportation and fugitive releases are allocated to other sectors, and are not discussed here.

4. Reference Case Projection

4.1 'Without Measures' (WOM) Projection

Overall, emissions from the transport sector in South Africa have been rising since 2000. By 2025, emissions are forecast to be 100% higher than in 2000 under the 'without measures' reference scenario. By 2050, the increase in emissions is projected to be almost 300%.

Figure 1 highlights the dominance of the road transport sector, accounting for around 94% of transport GHG emissions in South Africa in 2000. The reference projections indicate that there will be little change in this share over the period to 2050, with that figure never dropping below 84%. Cars (27%) and light commercial vehicles (around 23%) make up the majority share of road transport emissions in 2000 and this is the case throughout the time series. Emissions from domestic aviation have more than doubled (up about 140%) since 2000, reflecting the large growth in passenger demand over this period, and are forecast to increase further. However, as of 2010 this emissions source represents less than 8% of the transport total. In the rail sector, total direct emissions are less than 1% of all transport emissions, but this does not include emissions from electricity consumption.

Inclusion of indirect emissions associated with the production of fuels and electricity increases the emissions total by 69% in 2010 and 67% in 2050, on the basis of the WOM assumptions. These emissions are associated with the production of fuels for use in road transport, although indirect emissions from electricity consumed in the rail sector are also important. Some of these indirect emissions will arise in South Africa from the indigenous production of electricity and other energy carriers, and some will arise in other countries, for example from fuel imports.

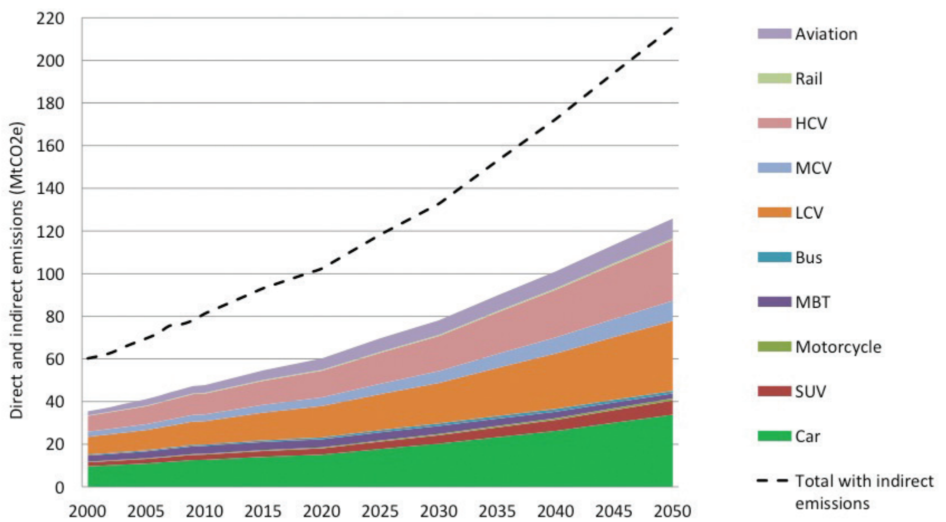

Figure 1: GHG emissions from the transport sector under the 'without measures' scenario, 2000–2050

4.2 'With Existing Measures' (WEM) projection

The 'With Existing Measures' (WEM) projection takes into account existing and planned policies that will influence future emissions from the sector. These policy impacts are not taken into account as part of the WOM reference projections presented above.

Table 2 summarises the main policies that have been identified that are expected to influence emissions from the transport sectors in South Africa to 2050. In addition to these policies, there will also be initiatives that have been implemented at municipal level or policies that will indirectly affect emissions from transport (for example planning and local development). These initiatives have not been considered explicitly, and are assumed to feature equally in all projection scenarios.

By calculating the projected impact of these existing policies it is possible to provide an updated emissions projection which is more representative of the current policy landscape. The WEM projection for the transport sector is provided in Figure 2 below, which also shows the total indirect emissions from the transport sector.

On the basis of the above estimates and assumptions, emissions from the transport sector in South Africa would be 8% lower in 2050, in the WEM projection scenario, relative to the WOM scenario. This reduction in emissions between the WOM and WEM scenario is entirely a result of the assumed impacts of the voluntary sectoral agreement in the aviation sector. A summary of all emissions split by mode can be viewed in Table 3.

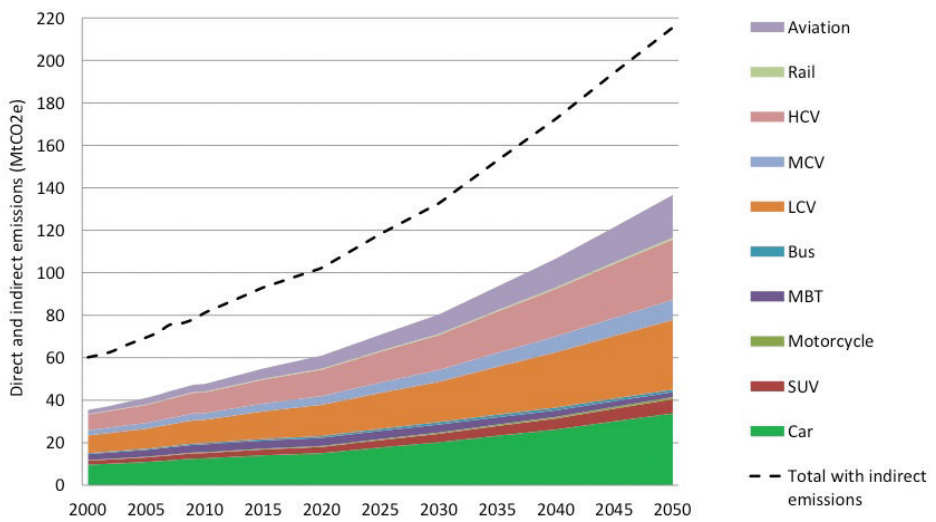

Figure 2: GHG emissions from the transport sector under the 'with existing measures' scenario, 2000–2050

Table 2: Current and planned policies that target the South African transport sector

Sector	Policy	Description	Inclusion or exclusion
Aviation	Voluntary sectoral agreement to reduce net CO_2 emissions from the aviation sector	Collective commitments have been made by the Airports Council International (ACI), the Civil Air Navigation Services Organisation (CANSO), the International Air Transport Association (IATA), and the International Coordinating Council of Aerospace Industries Associations (ICCAIA) on behalf of the international air transport industry to continuously improve CO_2 efficiency by an average of 1.5% per annum from 2009 until 2020, to achieve carbon neutral growth from 2020 and to reduce its carbon emissions by 50% by 2050 compared to 2005 levels. The International Civil Aviation Organization (ICAO) recently agreed to have the tools in place by 2016 that will be needed to develop a global market-based measure to reduce greenhouse gases from aviation.	Policy is included, but only partial achievement is assumed. WEM assumes a 1.5% efficiency improvement to 2020 and then an additional 1% efficiency improvement (that is 2.5% in total), from 2030 onwards. These changes result in an increase in carbon emissions of 198% by 2050 compared to 2005 levels. The increase in demand over this period is assumed to be offset to some extent by improved efficiency, but not totally, and not to the extent that emissions are reduced relative to the 2005 level. The use of biofuels is likely to make an important contribution towards achieving the target. However, in the WEM scenario, penetration of biofuels is assumed to be zero, and the use of biofuels has been included as an abatement measure. In practice, the take up of biofuels is likely to be necessary in any case, in order to meet the voluntary agreement target. Moreover, the existence of this long-term global agreement is expected to drive the take up of a large proportion of abatement measures available within the sector (the target was based on the total technical potential in the sector), even in the absence of any additional policy stimulus in South Africa.
Road Transport	Carbon tax on new vehicles	Tax placed on light vehicles from to encourage consumers to buy vehicles with lower carbon emissions.	Policy has not been included explicitly in the projection. The impacts of this measure could not be easily accounted for in the modelling, and the scale of the impacts is expected to be small in comparison to the underlying uncertainty in the vehicle stock model.
Road Transport	Regulations regarding the mandatory blending of biofuels with petrol and diesel (GN 671, August 2012)	The adopted mandatory blending regulations stipulate that the minimum concentration of biodiesel blending in diesel is to be 5% volume per volume (v/v), with the permitted range for bioethanol blending in petrol ranging between 2% v/v and 10% v/v.	Impact of current regulation is uncertain so policy has not been included in the projection.

Table 3: WEM projection for the transport sector: total of all GHGs

CO_2 (Gg/yr) equivalents	2000	2010	2020	2030	2040	2050
Road transport	33	44	54	71	92	116
Rail	0	0	0	1	1	1
Aviation*	2	4	5	7	8	9
Total	35	48	60	78	101	126
Total indirect emissions (all modes)	25	33	42	55	71	90

** as described in Table 3 the emissions projection for the aviation sector under the WEM scenario assumes only the partial implementation of the target implied by the voluntary sectoral agreement to reduce net CO_2 emissions from the aviation sector. This scenario does assume an ambitious level of efficiency improvement in the sector, but may nevertheless overestimate the emissions from the sector if the full delivery of the target is assumed. In particular, the WEM projection does not assume the take up of any biofuels. The full delivery of the target, which is likely to require the significant use of biofuels, would imply an emission level from the aviation sector in 2050 of around 1.6MtCO_2.*

Chapter III: Identification and Analysis of Mitigation Potential

5. Identification of Mitigation Opportunities

A range of potential mitigation measures was 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 can be categorised into the following types:

- modal shifts
- demand reduction measures
- more efficient vehicle technologies
- more efficient operations
- alternative low carbon fuels

The list of measures includes those that act on the level of transport activity, those that influence the energy efficiency of a given level of activity, and those that influence the carbon intensity of the energy consumed.

Table 4 below shows the full list of the initial mitigation opportunities identified by the Transport Task Team and includes a brief description of the measure with some justification for why the options were either included or excluded from the analysis.

Table 4: List of mitigation opportunities identified by the Transport Task Team

Subsector	Abatement measure/ mitigation opportunity	Description and motivation for inclusion or exclusion	Included?
1A3a Civil aviation	Shifting demand from aviation to other modes	Certain trips can be made using alternative transport modes such as high speed rail, potentially reducing carbon emissions. Whilst high speed rail has been discussed for certain routes in South Africa, the initial indication from a scoping study of the Johannesburg – Durban route is that the modal shift from aviation will be limited.	No
1A3a Civil aviation	Demand reduction	Certain measures can directly limit demand for aviation. One measure that has been proposed is the use of videoconferencing, which has merits as a low cost option and could form part of a wider mitigation package. However, there is considerable uncertainty about the overall potential mitigation that could be delivered.	No
1A3a Civil aviation	More fuel-efficient aircraft	Technologies to improve fuel efficiency through aerodynamic measures or through engine design can be applied in new aircraft, and retrofitted to existing aircraft. Manufacturers determine the development and application of measures in new aircraft and national government can exert limited influence on this. Greater opportunity exists to influence the retrofitting of measures.	No (for new aircraft) Yes (for retrofitting of existing aircraft)
1A3a Civil aviation	More efficient operations	Operational measures such as improvements to air traffic management and flight routing can play a role in reducing fuel burn by aircraft. International voluntary agreements cover these measures, so the potential for national government to intervene and deliver additional savings is limited.	No

Subsector	Abatement measure/ mitigation opportunity	Description and motivation for inclusion or exclusion	Included?
1A3a Civil aviation	Fleet management	Certain fleet management measures with potential to influence emissions are open to airlines. These include, for example, aircraft retirement.	Yes
1A3b Road transport	Passenger/freight demand reduction	Certain spatial planning actions can influence demand for passenger or freight transport. The potential for these measures is extremely site specific and it is difficult to generalise savings from these measures nationally.	No
1A3b Road transport	Improved operational efficiency for passenger/ freight transport	A range of operational and behavioural measures can reduce emissions. These range from intelligent routing to reduce speed (e.g. speed enforcement) and smoother driving (e.g. driver training). The potential for these measures to deliver long term savings is uncertain. For some measures (e.g. smoother driving) potential savings may overlap with those claimed for technology measures.	No
1A3b Road transport	Shifting passenger transport from passenger cars to public transport	These measures would involve increased use of public transport. Their cost and effectiveness is 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.	Yes
1A3b Road transport	Shifting freight from road to rail	This measures would involve an increased use of rail to transport freight. The cost and effectiveness of these measures is also extremely site specific, so therefore more uncertain in a national context. It was nevertheless considered important to capture these measures, albeit on a more illustrative basis.	Yes
1A3b Road transport	More fuel efficient vehicles	Improving the fuel efficiency of gasoline/diesel vehicles through engine efficiency improvements, hybridisation, lightweighting, reducing rolling resistance, reducing aerodynamic drag.	Yes
1A3b Road transport	Alternative fuel vehicles	Switching to vehicles recharged by electricity, powered by gas (e.g. compressed natural gas (CNG)) or hydrogen fuel cells.	Yes
1A3b Road transport	Biofuels	Blending biofuels into road transport fuels to reduce their carbon intensity.	Yes
1A3c Railway	More energy efficiency trains	Technology applications have the potential to improve the energy efficiency of new trains.	Yes
1A3c Railway	Alternative fuel vehicles	This measure involves the application of alternative engine technologies and/or fuels including natural gas and biofuels.	Yes
1A3c Railway	Voltage upgrade	This measure would involve switching from 3000V AC to 25kV DC to reduce efficiency losses on the Metrorail system.	Yes
1A3d Water-borne navigation	More energy efficient ships	Overall emissions from this sector are small, and the overall level of abatement potential is more limited.	No

6. Costing and Mitigation Potential of Mitigation Measures

For each type of measure, 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 making it more difficult to define generic benchmarks for their cost or effectiveness. The assumptions used for making mitigation projections and costing the intervention in each case are given in Table 5.

Table 5: Assumptions regarding costing and mitigation potential of mitigation measures for the Transport Sector

Mitigation Option	Basis for estimating quantum of emission mitigation	Key data elements and data sources	Notes
Aviation			
Retrofitting efficiency measures to aircraft	Emissions potential determined by relative improvements in fuel burn from the application of measures, the total number of aircraft the measures can be applied to, and the operation of those aircraft. Cost includes capital cost of measures, cost of retrofit, and the cost savings from fuel savings.	Fuel savings and retrofitting cost based upon data from Morris et al. (2009) and Holland et al. (2011). Illustrative abatement potential based on the retrofitting of winglets, and an engine upgrade for a single Boeing A737-300 aircraft. Retrofitting measures only applicable as abatement option in 2020, as measures likely to be integrated in new aircraft by 2030 and 2050.	Both cost and emissions data are based on international benchmarks.
Early retirement of aircraft	Emissions quantified on the basis of an assumed improvement in fuel efficiency of replacement aircraft. Cost estimate includes revenue from resale of existing aircraft, additional cost of new aircraft, and associated fuel savings.	Fuel savings, carbon savings and cost parameters based on data from Morris et al. (2009) and Holland et al. (2011) for A320/B737 family of aircraft. Illustrative abatement potential based on single application in South Africa. Measures assumed to be applicable in later time periods as current South African fleet still relatively young.	Both cost and emissions data are based on international benchmarks.
Road transport			
More efficient vehicles, and alternative vehicle technologies	Total emissions reduction potential determined by the relative penetration of the measure in the stock, the relative energy intensity compared to the counter-factual technology, the fuel source and the associated emission factor. Costs reflect the relative additional cost of the measures, accounting for any additional maintenance costs, and cost differential for alternative power trains. Innovation and learning assumed to reduce cost of technologies in future.	Capital and operation costs data and changes in fuel efficiency over time based on the review of technology measures in AEA (2012). Relative share of measures in new vehicle sales based on expert judgement, taking into account technical constraints, and relative cost-effectiveness of measures.	It should be noted that measures such as electric vehicles, CNG and hydrogen will require additional infrastructure investment. Fuel costs are based on single scenario.

Mitigation Option	Basis for estimating quantum of emission mitigation	Key data elements and data sources	Notes
Modal shift	Emissions determined by shift in passenger and freight from cars and freight vehicles to buses and passenger rail, and to freight rail services. Assumption of emissions of existing travel modes, and new modes. Costs assume alternative investment from road infrastructure to passenger transport infrastructure.	Level of modal shift from cars to public transport, and from road to rail freight based on analysis of potential in Western Cape region by PDG (2013). Total potential at national level assumes savings can be scaled by a factor of four from regional results. Emissions from road and rail transport calculated from factors in road transport, and rail projections. For shifting road freight to rail, nationwide modal shift assumptions have been used along with equivalent investment cost data to achieve this shift. Both of these were taken from recent Transnet estimates and applied to an in-house model which aligned with the passenger modal shift methodology.	Estimated cost and effectiveness of measure highly site specific. Total potential based on simple scaling of potential from single region to national level.
Rail transport			
More efficient vehicles, and alternative vehicle technologies	Emissions and costs of measures assessed relative to counterfactual technologies, which is new vehicles without the measures. Emissions account for direct and indirect emissions (e.g. electricity). Scale of emissions savings determined by the level of stock turnover and the rate of implementation of measures.	Planned investment in stock based on PRASA (2011) and Transnet (2012), which determines the penetration rate of the technologies. Capital cost and energy savings assumption for more efficient diesel freight locomotives based on Ricardo & TRL (2012). Technical parameters for energy savings from more efficient EMUs for passenger rail based on published literature, with capital cost based on expert judgement. Cost for voltage upgrade based on international case studies.	International benchmarks provide reasonable basis for certain measures but not all.
All modes			
Biofuels	Biofuels supplied from conventional bioethanol and biodiesel in early years, with second generation biofuels coming onstream later in period. For road transport maximum potential of road transport fuels of 27% by 2050 assumed, with conventional fuels providing maximum of 10%. For rail biofuel potential is capped at 27%, and for aviation biokerosene is assumed to contribute 5% of fuel requirements in 2050.	Biofuel supply sources based on previous analysis of Biofuels Industrial Strategy (BFAP, 2008). Emissions factors and production costs for different biofuel feedstocks taken from literature (IEA, 2011). Penetration of biofuels based on expert judgement, and international research (IEA, 2011). First generation biofuels (e.g. conventional bioethanol from maize or sorghum, biodiesel from soybeans) could be introduced in South Africa from 2017, which allows sufficient time for biofuel production plant to be built. Competition for second generation biofuels may limit uptake.	The role that biofuels can play in the mitigation from different sectors was not determined.

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.

The main cost assumptions are summarised for each of the modes below in Sections 6.1, 6.2 and 6.3. In each case, a consistent set of assumptions have been applied with respect to the energy prices over the assessment period. These are summarised in Box 3 below.

Box 3: Energy Price Assumptions

The following energy prices have been applied when assessing the measures in the transport sector.

Cost (R/MJ)	2010	2020	2030	2040	2050	Source
Petrol	0.124	0.153	0.188	0.211	0.234	ERC, 2013
Diesel	0.117	0.145	0.180	0.203	0.226	ERC, 2013
Electricity	0.117	0.264	0.264	0.264	0.264	ERC, 2013
Hydrogen	0.338	0.338	0.338	0.338	0.338	Based on Euro data from EURELECTRIC[11]
Natural Gas	0.034	0.053	0.058	0.06	0.062	ERC, 2013
Bio-ethanol	0.23	0.24	0.24	0.24	0.24	BFAP (2008), IEA (2011)
Cellulosic bioethanol	0.31	0.27	0.24	0.24	0.23	IEA (2011)
Biodiesel - conventional	0.32	0.33	0.34	0.34	0.34	BFAP (2008), IEA (2011)
Biodiesel - advanced	0.31	0.27	0.25	0.23	0.22	IEA (2011)

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 based upon the supply costs of various locally produced sources of primary fossil and renewable energy and imports prices from 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/MJ. This source was considered to be the most comprehensive and consistent data source for South African fuel prices on which to base the fuel price assumptions.

In reality, the fuel prices paid by different businesses and industry subsectors might 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 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 on 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 this source also provides the foundations for the projections developed for the power sector.

Current prices for indigenous first generation biofuels (e.g. conventional bioethanol from maize or sorghum, biodiesel from soybeans) are based upon previous analysis of production costs in South Africa (BFAP, 2008). Future prices were projected following the trend from the report by the International Energy Agency Biofuels for Transport Roadmap (IEA, 2011). Production costs for second generation biofuels were also taken from this source.

11. http://www.eurelectric.org/

The following subsections provide further information on the assumptions used for generating the marginal abatement cost curves (MACCs) for the road transport, rail and aviation sectors.

6.1 Road Transport

In addition to fuel prices, the marginal cost calculations rely on three main metrics: the capital cost of new cars,[12] their fuel efficiency and maintenance costs. The capital costs and fuel efficiency used in the modelling are shown in Table 6 and Table 7 respectively. Maintenance costs are typically between 0.5% and 2% of the capital costs.

In the WOM scenario, conventional petrol and diesel engine vehicles are the default option for new vehicles. These are shown ***in italics*** in the tables below. The rest represent the costs for alternative vehicles, with the relative difference between the cost of these alternatives and conventional petrol/diesel engine vehicles representing the marginal cost.

Table 6: Capital cost for new cars (ZAR)

Capex (R)	2010	2030	2050
Petrol conventional engine	*195,521*	*201,620*	*204,795*
Diesel conventional engine	*203,783*	*210,388*	*211,243*
More efficient petrol conventional engine	195,521	218,619	222,899
More efficient diesel conventional engine	203,783	228,596	230,000
Petrol hybrid electric vehicle (EV)	236,952	227,259	227,273
Diesel hybrid EV	242,757	235,346	232,781
Petrol plug in hybrid EV	325,499	250,952	241,407
Diesel plug in hybrid EV	331,304	255,393	244,472
Battery only EV	426,371	264,141	245,133
Fuel cell EV	1,332,315	270,257	243,122
Natural gas conventional engine	215,298	226,044	227,340

For more efficient petrol and diesel conventional engine vehicles the capital costs increase over time, as it is assumed that the improvements in vehicle efficiency come at a cost which is in excess of any learning effects. These are associated with much more aggressive improvements in fuel efficiency, though. For conventional engine vehicles, the autonomous level of fuel efficiency assumed is equivalent to 0.5% per annum, while for more efficient conventional engine vehicles, the assumed improvement in fuel efficiency is between 1% and 2%.

12. Similar data is available for the other vehicle types analysed (buses, motorbikes, light goods vehicles, heavy good vehicles and so on), and follows similar trends for each type of measure (for example uptake of BEVs, uptake of FCEVs and so on) in terms of the change in capital cost and vehicle efficiency over time.

Table 7: Fuel efficiencies for new cars

MJ/km	2010	2030	2050
Petrol conventional engine	*3.11*	*2.81*	*2.54*
Diesel conventional engine	*2.84*	*2.57*	*2.32*
More efficient petrol conventional engine	3.11	1.90	1.55
More efficient diesel conventional engine	2.84	1.86	1.52
Petrol hybrid EV	2.33	1.59	1.33
Diesel hybrid EV	2.13	1.57	1.31
Petrol plug in hybrid EV	1.53	1.03	0.91
Diesel plug in hybrid EV	1.43	1.04	0.93
Battery only EV	0.82	0.68	0.61
Fuel cell EV	1.06	0.82	0.70
Natural gas conventional engine	2.57	1.57	1.28

For the alternative fuel vehicles, it is assumed that costs will decline over time as a result of learning effects. This leads to significant reductions in the assumed capital costs for certain technologies by 2050. Improvements in fuel efficiency are also expected for these technologies which further increases their attractiveness over time.

As with any cost estimates extending over a long time frame, the further into the future costs are estimated the more uncertain they become. However, the broad trends in costs are in agreement with analysis carried out elsewhere.

6.2 Rail Transport

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 therefore the cost associated with each measure. Assumptions and sources are shown below in Table 8.

Table 8: Assumed cost of rail sector measures

Scenario	Measure	Saving over current average value	Additional Capex unit value in R million	Source
Measure 1	EMU with even lower energy consumption	50%	5,100 (for 50% of fleet)	UIC - International Union of Railways (2003)
Measure 2	New diesel locomotives with start-stop-device	40%	1.4	Ricardo and TRL(2012)
Measure 3	New hybrid diesel locomotive	50%	2.7	GE Transportation (2005)
Measure 4	Cost of switching from 3000 V DC to 25kV AC		5,100	Janicki and Horst (2008)
Measure 5	Use of CNG in non- electric systems		4.5	Wall Street Journal (2013)

6.3 Aviation

Two separate measures have been quantified for the aviation sector. In both cases, the key technical data, including cost assumptions, have drawn on 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. The key cost parameters are summarised in Table 9 below.

Table 9: Assumed cost of aviation sector measures

Scenario	Measure	Capex unit value in R million	Opex unit value in R million	Source
Retrofitting efficiency measures*	Retrofitting of winglets	11.3	-0.8 per year	Morris et al. (2009), Holland et al. (2011)
	Retrofitting of engine	10.6	-0.7 per year	
Early retirement of aircraft**	Early replacement of existing aircraft with new more efficient aircraft	668	-253 over lifetime	

* *Measure assumes aircraft are A737-300*

** *Measures assume aircraft are A320/B737 family*

7. Marginal Abatement Cost Curves

Marginal abatement cost curves (MACCs) provide insight into the marginal costs and associated mitigation potential for a given snapshot in time, and have been calculated for 2020, 2030 and 2050. These are shown in figures 3, 4 and 5. The abatement potential and cost-effectiveness of measures in the transport sector have been assessed for each of the respective vehicle types and are shown below on separate MACCs.

7.1 Key assumptions for building MACCs

The following key assumptions drive the construction of MACCs for the transport sector.

7.1.1 Penetration of measures

For any given mode, the potential abatement measures interact. This is particularly the case for the technological measures where the options are substitutes. Therefore, in defining the technical potential for abatement it is necessary to define a scenario of the potential penetration (that is new sales) of the measures which allows for this interaction. A judgement has to be made about which measures will be implemented in preference to other competing measures. The MACC itself provides one basis for making this decision, by indicating the overall marginal abatement cost of the measures. However, other barriers (such as lack of supporting infrastructure, up-front capital cost or lack of familiarity with new technology) will also influence the level of uptake. Therefore, in this analysis the assumed penetration of the measures is based on an 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.

In practice, the penetration of certain measures (and therefore the total abatement they can deliver) may deviate from the levels assumed in this analysis, but the total mitigation across all measures would still be limited by the total sales of new vehicles. For example, electric vehicles can technically provide an increasing proportion of the vehicle stock over time. However, sales of electric vehicles will compete with other powertrains which, in the short term, may provide lower marginal abatement costs and face fewer technical barriers. Therefore, in estimating the mitigation potential from electric vehicles, we have assumed that battery only electric vehicles would represent 5% of the stock of passenger cars by 2050, while all electric vehicles (including plug-ins and hybrids) would make up 40% of this market.[13]

The mix of powertrains that has been assumed when calculating the technical potential of measures in the road transport MACC is summarised below in Table 10. The mix represents a stock weighted average across all vehicle types, including buses, cars, commercial vehicles, taxis and motorbikes.

Table 10: Assumed sales uptake (stock weighted average) for different vehicle powertrains

	2010	2020	2030	2050
More efficient petrol conventional engine	88.3%	72.1%	45.3%	23.4%
More efficient diesel conventional engine	11.7%	18.7%	32.4%	35.6%
Petrol hybrid EV	0.0%	4.7%	9.3%	12.8%
Diesel hybrid EV	0.0%	2.3%	5.9%	11.1%
Petrol plug in hybrid EV	0.0%	1.2%	2.7%	4.2%
Diesel plug in hybrid EV	0.0%	0.5%	1.6%	3.7%
Battery only EV	0.0%	0.0%	0.9%	4.0%
Fuel cell EV	0.0%	0.0%	0.1%	1.6%
Natural gas conventional engine	0.0%	0.4%	1.8%	3.6%

13. The battery only vehicle uptake may be considered to be a conservative estimate. However, as a comparator, the IEA's Annual Energy Outlook quotes that 15% of sales in the USA will be 'alternative fuels' in 2040 (International Energy Agency, 2013).

For the rail sector, like the road scenarios, we have assumed the following fleet make up when calculating the technical potential of measures (Table 11).

Table 11: Rail measures fleet mix

	2020	2030	2040	2050
EMUs				
Existing EMU for Metrorail	50%	0%	0%	0%
Planned new EMU for Metrorail	50%	60%	50%	50%
New EMU with even lower energy consumption	0%	40%	50%	50%
Electric Locomotives				
Existing electric locomotive	25%	0%	0%	0%
Planned new electric locomotive	75%	100%	100%	100%
Diesel Locomotives				
Existing standard diesel locomotive	25%	0%	0%	0%
Planned new diesel locomotive	50%	44%	32%	25%
New diesel locomotives with start-stop-device	25%	19%	14%	11%
New hybrid diesel locomotive	0%	38%	55%	64%

For EMUs, electric and diesel locomotives the model calculates emissions from existing stock and planned new investments. Additional (new) abatement measures have been assessed for EMUs and diesel locomotives and two other scenarios are looked at:

- Voltage upgrade
  - Assumes a voltage change from 3kV DC to 25kV AC on Metrorail network is undertaken post 2020-2050.
- Alternative fuels – CNG
  - Assumes a 10% uptake of CNG among non-electric locomotives post 2040.

For aviation it has not been possible to distinguish between different aircraft in the modelling, so the assessment is much more simplistic assuming two mitigations options are implemented:

- Retrofitting measures
  - Assumes that retrofitting is applied to one aircraft by 2020.
  - Assumes that retrofitting includes both engine upgrades and winglets.
  - Assumes the costs defined above are representative of the aircraft that the measures are applied to.
- Early retirement
  - With recent fleet renewal, further opportunities for retirement are assumed to occur post 2040. In this case, the analysis assumes that the measure is applied to five aircraft by 2040.

7.1.2 Measures interaction

One area where interactions are important is biofuels. As biofuels are blended with fossil fuels, or used as direct replacements, they will reduce the net emissions from fuel combustion and therefore reduce the apparent effectiveness of measures that reduce fuel consumption. For rail and aviation, the penetration of biofuels has been limited to a relatively low level (27% and 5%, respectively). This reflects an assumption that available resources of sustainable biofuels[14] will be constrained, and therefore decisions will be required on where they will be used. To assess this properly requires a detailed assessment of the biofuels resources available, and the potential demand elasticities of the different sectors. This level of analysis was not possible within the scope of the current study, so a more simplified approach was adopted.

Given the large uncertainty in the availability of sustainable biofuel resources, both locally and globally, we have applied

14. Sustainable biofuels are defined here to mean biofuels that meet certain sustainability criteria, which may include environmental (for example greenhouse gas savings, impact on water and biodiversity), economic and social considerations. However, there are currently no internationally recognised criteria for defining sustainable biofuels, which makes estimates of available resources very challenging.

a conservative assumption in the current study. Therefore, while it is technically possible for second generation biofuels to provide 100% of the fuel for both rail and aviation,[15] we assume that take up will be constrained at a much lower level. This assumption has a large impact on the abatement potential of the measure shown in the MACCs.[16] For road transport the technical potential of biofuels is assumed to be equivalent to 27% of fuel requirements by 2050. This assumes that a larger proportion of available resources will be diverted to road transport. At the same time, as measures are introduced to reduce fuel requirements they will reduce the total savings from biofuels. The interaction of biofuels with abatement measures has been accounted for in the impact of biofuels on direct combustion emissions, with indirect emissions assumed to remain unchanged.[17] To ensure biofuel savings were not overstated, the savings are based on the energy requirements allowing for a reduction in fuel requirements as efficiency measures are implemented.

7.1.3 Counterfactual technology

For the vehicle technologies, the 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. However, changes in costs over time and differences in energy sources mean that the relative marginal abatement cost of different technology measures varies over time. Furthermore, the rate at which costs evolve varies between technologies and this in turn changes the relative priority of measures over time. However, for all measures the general trend is a reduction in cost over time. Different assumptions on energy prices from those used in the current study may alter this trend.

For the modal shift measures, the assessment is based on a Western Cape illustrative case study (PDG, 2013). The savings represent the relative difference in emissions between different modes, and can be considered relatively robust in isolation. However, since the assumed growth in demand has been developed separately to the growth assumption used for vehicle technologies, this may lead to a degree of double-counting. Likewise, the total savings are based on the fuel efficiency of vehicles in the WEM scenario, so they do not account for changes in these efficiencies over time. The costs for the modal shift measures are overall much more uncertain, particularly where the projects include significant capital expenditure as in the case study example. These costs are very project specific and cannot be generalised for other circumstances.

7.1.4 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 also 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.

7.2 Road Transport

As shown in Figure 3–Figure 5, a number of measures have a negative marginal abatement cost. In particular, the uptake of 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.

15. Currently the airlines have approval for a maximum of a 50% blend of aviation biofuel with the standard Jet A1.

16. As an illustration, based on current assumptions the abatement potential from replacing diesel with biofuels in rail freight is estimated to be 88 $kgCO_2e$ in 2050, based on lifecycle emissions. However, if the assumption was made that second generation biofuels could replace 100% of the diesel used, then the total emissions reductions would be about 879 $kgCO_2e$ in 2050.

17. Further indirect emission reductions may also arise as less refined product will be required. However the scale of the emissions reductions is uncertain, and will depend upon the scale of the indirect emissions from the conventional diesel/kerosene relative to the biofuel equivalent.

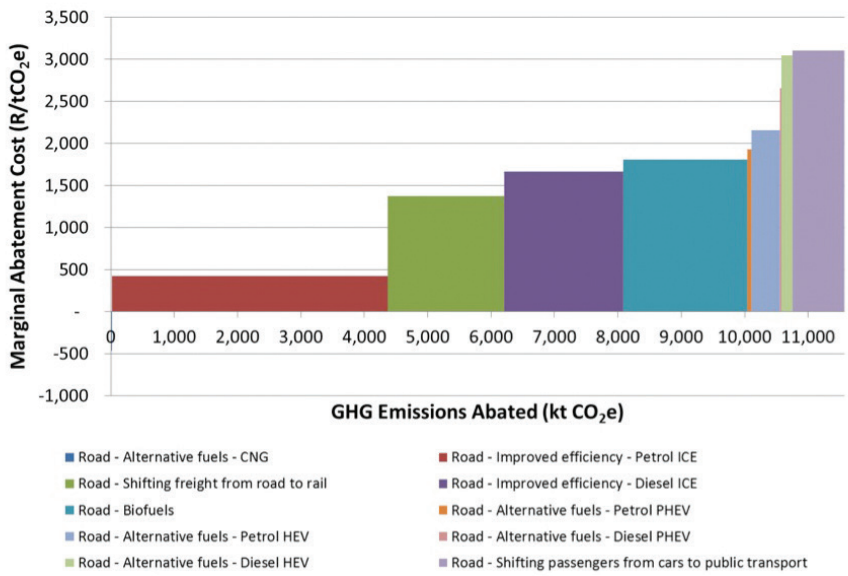

Figure 3: MACC in 2020 for the road transport sector

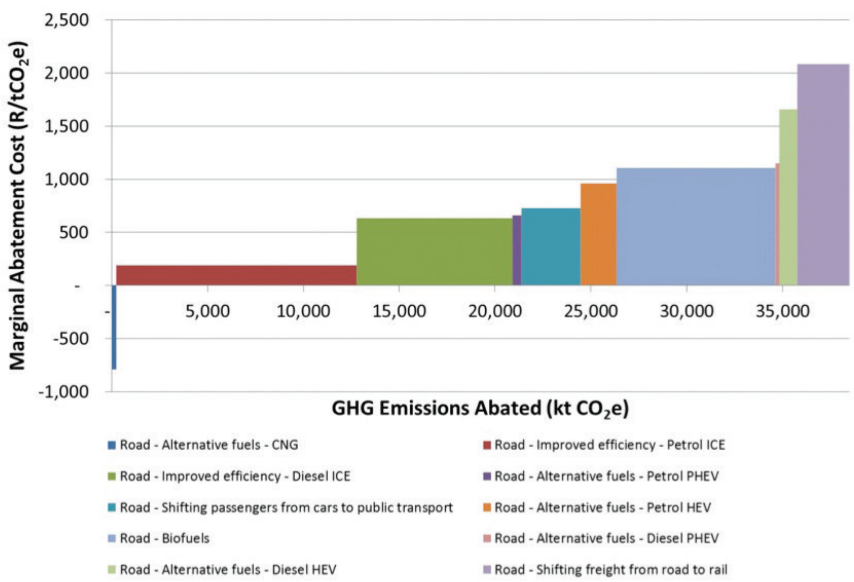

Figure 4: MACC in 2030 for the road transport sector

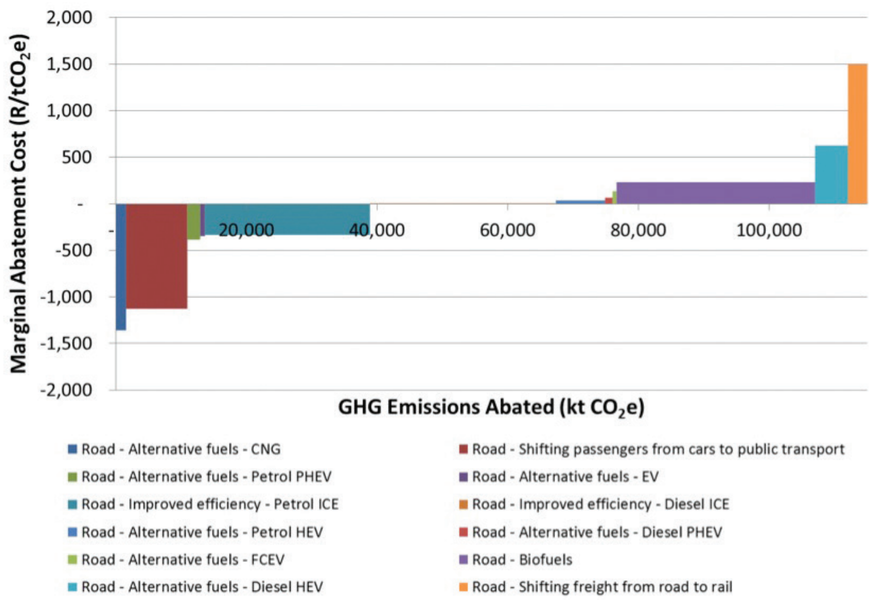

Figure 5: MACC in 2050 for the road transport sector

Note that two measures which make only a small contribution to abatement have been omitted from Figure 4 for reasons of readability. These are petrol hybrid electric vehicles (EV) (Road – Alternative fuels – EV; accounting for abatement of 57 ktCO_2e with a marginal abatement cost of R 1,920/ ktCO_2e) and fuel cells EVs (Road – Alternative fuels – FCEV; accounting for abatement of 4 ktCO_2e with a marginal abatement cost of R 2,445/ ktCO_2e).

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 cost of abatement of hybrid electric vehicles also improves over time, although not to the extent where it becomes negative.

7.3 Rail Transport

In the rail sector, improved efficiency of diesel freight and diesel hybrid engines, and switching to CNG appear as promising options, first appearing on the MACCs in 2020, 2030 and 2050 respectively at relatively low (or slightly negative) marginal abatement costs. Meanwhile improvements to passenger rail either through more efficient EMUs, or a voltage upgrade to the network appear to be much more expensive. However, the cost estimates for these measures are also far more uncertain.

For 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.

The relevant MACC for 2020 is also shown here, despite only containing two measures at that time, as the MACCs will show how these measures evolve over time. All the relevant figures from this and other transport sectors can be found in Table 13.

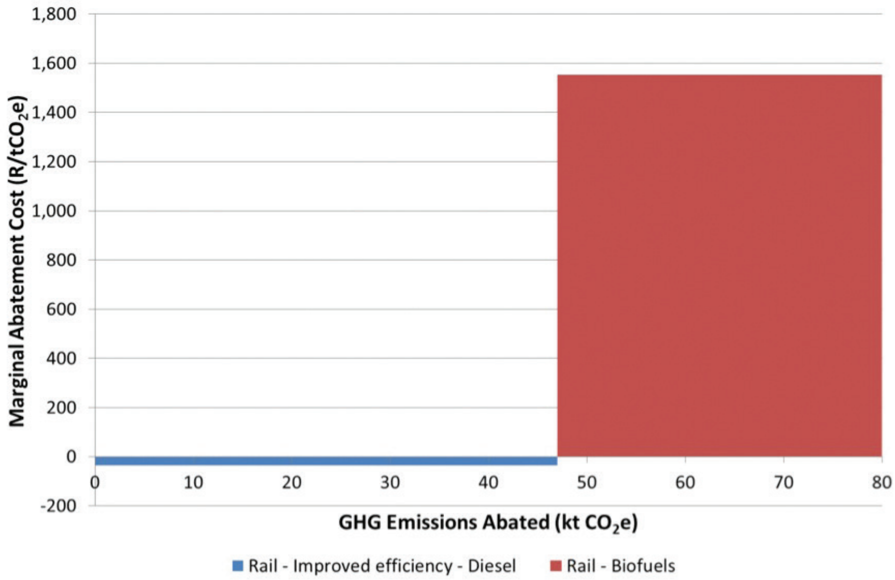

Figure 6: MACC in 2020 for the rail transport sector

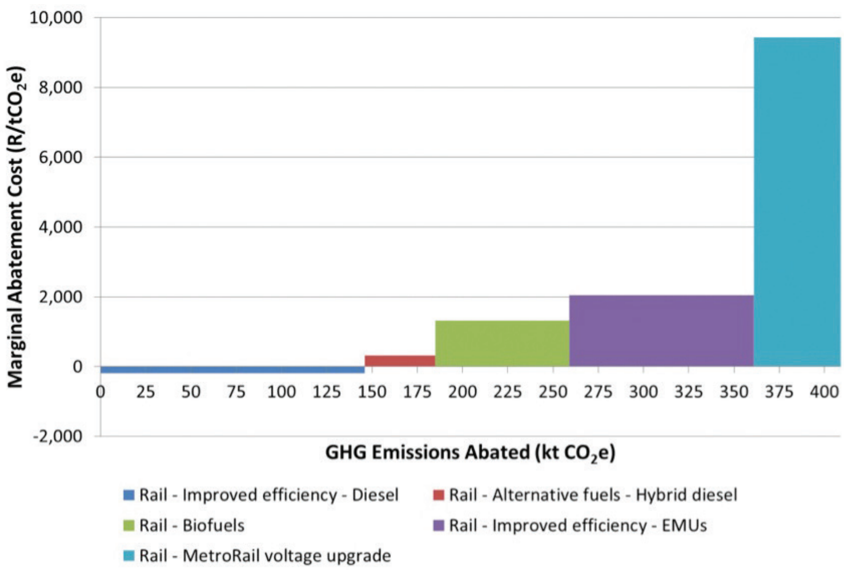

Figure 7: MACC in 2030 for the rail transport sector

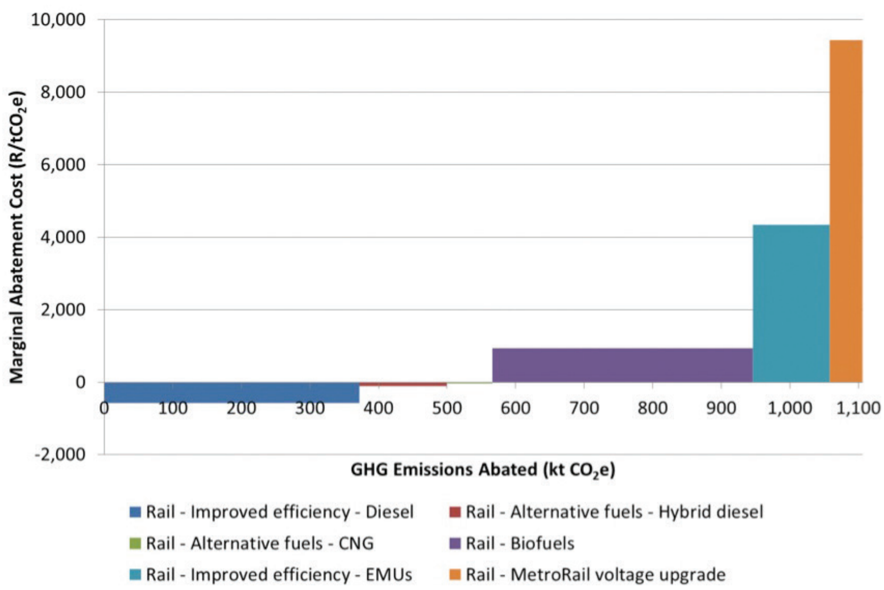

Figure 8: MACC in 2050 for the rail transport sector

7.4 Modal Shifts

The MACCs including the modal shift measures are shown in Figure 3 to Figure 5 above. The modal shift scenarios were the most complex to analyse. The cost-effectiveness of modal shift programmes is extremely site dependant, making it difficult to derive an estimate applicable at 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.

As described above, the analysis of passenger modal shift has been based on a single case study. In the short term (to 2020) the measure does not have a negative marginal abatement cost but costs decrease 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 quotes a GHG reduction potential of 25% through passenger modal shift that can be achieved at a cost of US$30/t$CO_2$e.[18]

For freight modal shift, the analysis is based on data provided by Transnet. This has the advantage of being based upon a national estimate of the potential, so is considered more robust than the estimate for passenger transport. The abatement potential has been estimated by overlaying the data from Transnet on the modal shift potential in the rail sector using the demand data from the ERC study (2012). Infrastructure (capital) cost data is again sourced from a Transnet annual report[19] and from this a cost of R1 billion per 1 billion tonne km shifted was assumed. Details of the analysis can be seen in Table 12.

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

19. http://www.transnet.co.za/BusinessWithUs/LTPF%202012/8.%20Capital%20investment%20summary.pdf

Table 12: Modal Shift Mitigation Potential

Modal shift	2020 ktCO$_2$	2020 R/tCO$_2$	2030 ktCO$_2$	2030 R/tCO$_2$	2050 ktCO$_2$	2050 R/tCO$_2$
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

7.5 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 Section 8.

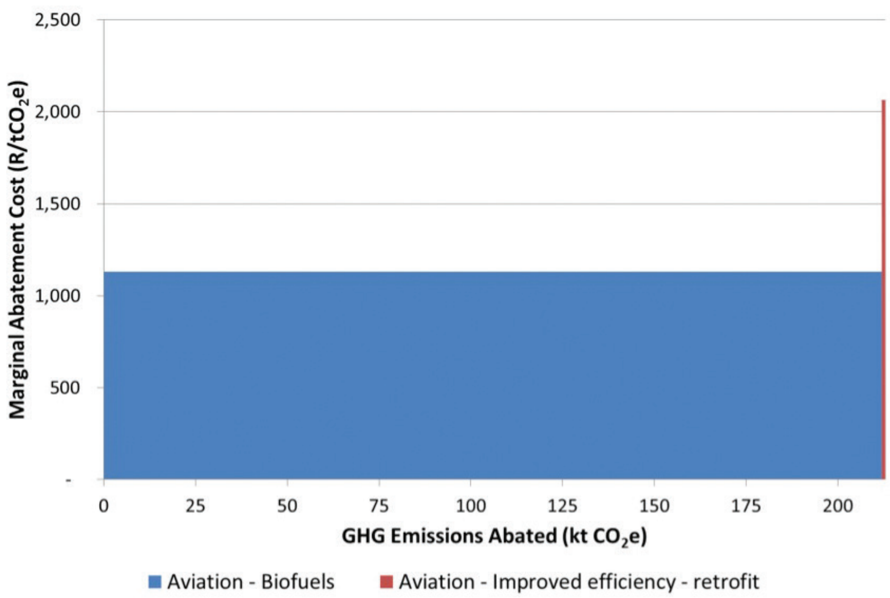

Figure 9: MACC in 2020 for the aviation transport sector

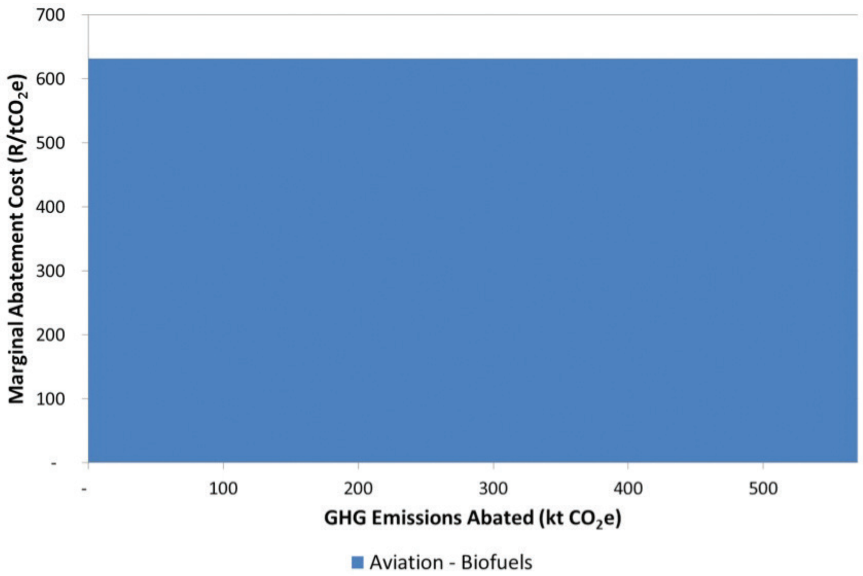

Figure 10: MACC in 2030 for the aviation transport sector

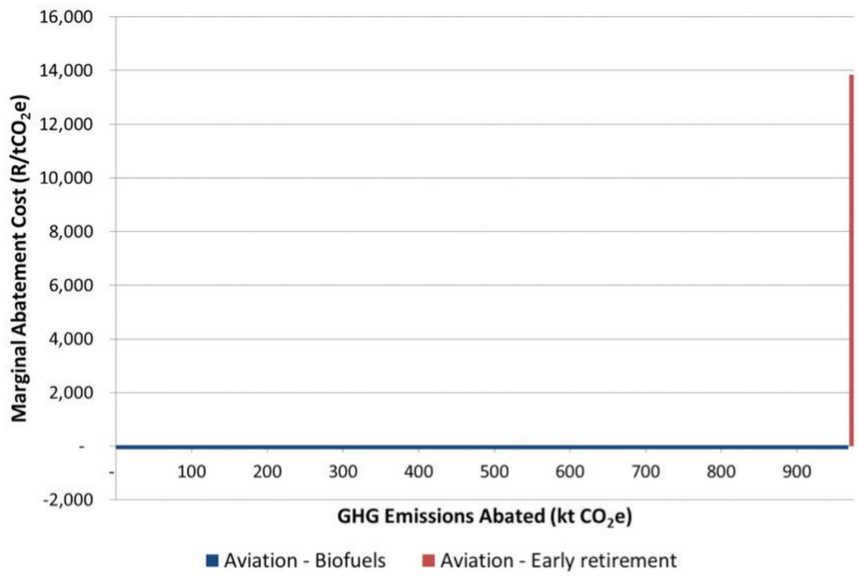

Figure 11: MACC in 2050 for the aviation transport sector

Note that in 2050 (Figure 11), the aviation biofuels measure has a technical abatement potential of 969 $ktCO_2e$, at a marginal abatement cost of R -17/ $ktCO_2e$ while the early retirement options achieves a mitigation potential of 6 $ktCO_2e$, at a marginal abatement cost of R 13,845/ $ktCO_2e$.

Chapter IV: Summary

8. Technical Mitigation Potential

The analysis shows that, if all technically available mitigation potential in the transport sector was implemented, GHG emissions could be reduced by 11,869 ktCO$_2$e by 2020, 39,525 ktCO$_2$e by 2030 and 117,151 ktCO$_2$e by 2050 (Table 13). These emission reductions are associated with both direct fuel combustion in the transport sector and indirect emissions from the production of electricity and other energy carriers in South Africa and other territories.

The estimate of mitigation potential for measures which result in a reduction in demand for liquid fuels may overestimate indirect savings as the impact of these changes on mitigation measures in the other energy industries and petroleum refining sectors (see Appendix C) have not been taken into account. An estimate of the impact of these changes is provided in the calculation of national mitigation potential in Section 18 of the Main Report.

Table 13: Total mitigation potential for the transport sector, assuming all measures are implemented (in ktCO$_2$e)

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 – EMUs	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 – 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 PHEV	22	202	1,152
	Road – improved efficiency – petrol ICE	4,349	12,538	25,241
	Road – alternative fuels – petrol 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 – 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%

The total cost of mitigation potential for the transport sector, assuming all measures are implemented is shown in Table 14.

Table 14: Total cost of mitigation potential for the transport sector, assuming all measures are implemented (in R/ktCO_2e)

Subsector	Measure	2020	2030	2050
Aviation	Aviation – improved efficiency – retrofit	2,065	N/A	N/A
	Aviation – early retirement	N/A	N/A	13,845
	Aviation – biofuels	1,131	632	-17
Rail	Rail – improved efficiency - EMUs	N/A	2,052	4,340
	Rail – improved efficiency – diesel	-35	-187	-575
	Rail – alternative fuels – hybrid diesel	N/A	322	-107
	Rail – Metrorail voltage upgrade	N/A	9,436	9,436
	Rail – alternative fuels – CNG	N/A	N/A	-36
	Rail – biofuels	1,554	1,321	936
Road	Road – alternative fuels – CNG	-466	-790	-1,360
	Road – alternative fuels – diesel PHEV	2,656	1,151	65
	Road – improved efficiency – petrol ICE	424	190	-335
	Road – alternative fuels – petrol HEV	2,157	961	36
	Road – improved efficiency – diesel ICE	1,667	634	6
	Road – alternative fuels – petrol PHEV	1,930	660	-385
	Road – alternative fuels – FCEV	N/A	2,445	135
	Road – alternative fuels – diesel HEV	3,048	1,658	625
	Road – alternative fuels – EV	N/A	1,920	-348
	Road – shifting passengers from cars to public transport	3,105	729	-1,128
	Road – shifting freight from road to rail	1,375	2,085	1,497
	Road – biofuels	1,808	1,108	232

9. Projections 'With Additional Measures'

Applying all the measures identified above, in the order in which they are ranked using the MACCs gives an emissions projection curve as shown in Figure 12. The diagram illustrates clearly the dominance of measures from the road sector (which includes modal shifts from passenger vehicles to public transport and for freight from road to rail). Note that in Figure 12, the reference case WEM projection has been adjusted to include indirect emissions from all transport subsectors.

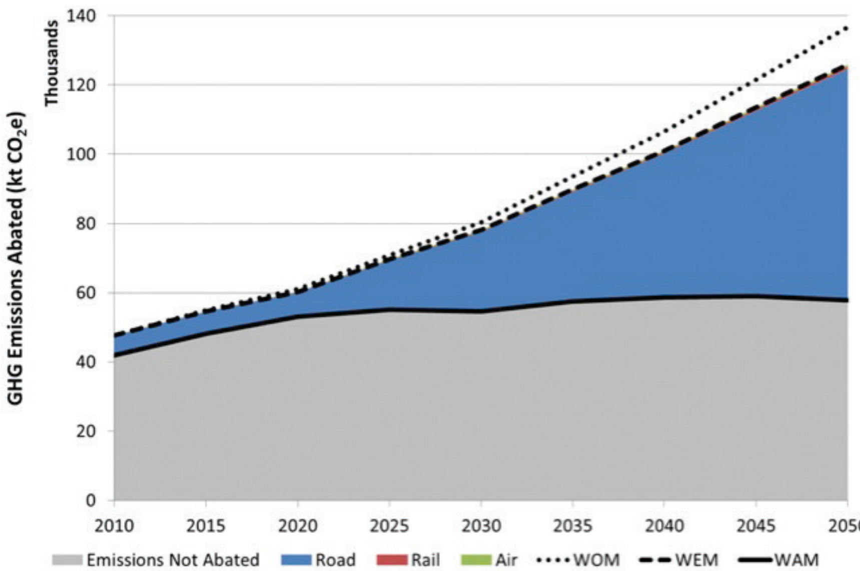

Figure 12: Emissions projection with all additional measures (WAM) for the transport sector.

As described above, action taken in the transport sector will have indirect impacts on emissions from other sectors. Specifically, measures that reduce the demand for fuels will reduce the level of fuel production capacity required in future scenarios, and the emissions associated with liquid fuel production. It has not been possible to explore this interaction fully. However, as an illustration, if the abatement measures relating to more efficient and alternative fuelled vehicles were implemented 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.

10 Impact Assessment of Individual Mitigation Measures

The impact assessment is undertaken using the multi-criteria analysis (MCA) approach described in the main body of the report.

10.1 Scoring Each Measure in Relation to Agreed Criteria

The criteria for assessing each measure are applied consistently across all sectors with the scoring and weighting options described in the main body of the report. Two methods have been applied for scoring:

- A quantitative assessment using the costs estimated for each measure and the economic models which provide figures for gross value added (the economic criterion) and jobs (part of the social criterion).
- A qualitative assessment based on scoring by the Sector Task Team.

In the case of the quantitative analysis which informs the cost, economic and social criteria, the data associated with each criterion is summarised in Table 15 below.

Three measures (rail – Metrorail voltage upgrade; aviation – improved efficiency/retrofit; and aviation – early retirement) all indicate relatively small mitigation potential combined with large marginal abatement costs (see Table 13 and Table 14). In assigning value functions to the quantitative and qualitative scores under the MCA analysis, these measures appear as outliers and hence skew the allocation of final scores for all other measures. Consequently, they have been excluded from the MCA analysis.

Table 15: Quantitative data informing the scoring of options for the transport sector

Option descriptions	NPV* of costs per ktCO_2e mitigated	GVA** impact per ktCO_2e mitigated	Jobs created per ktCO_2e mitigated	Ratio of unskilled to total jobs
	R/ktCO_2e	R/ktCO_2e	Jobs/ktCO_2e	
Road – alternative fuels – CNG	-10.81	1.29	0.01	0.35
Road – alternative fuels – diesel PHEV	9.11	-1.74	-0.01	0.41
Road – improved efficiency – petrol ICE	-69.07	8.84	0.08	0.35
Road – alternative fuels – petrol HEV	26.58	-3.27	-0.03	0.37
Road – improved efficiency – diesel ICE	-24.27	3.05	0.03	0.34
Road – alternative fuels – petrol PHEV	-8.59	0.67	0.01	0.31
Road – alternative fuels – FCEV	37.81	-5.50	-0.04	0.36
Road – alternative fuels – diesel HEV	47.09	-6.01	-0.05	0.36
Road – alternative fuels – EV	-21.88	1.34	0.02	0.35
Road – shifting passengers from cars to public transport	65.20	-6.81	-0.06	0.38
Road – shifting freight from road to rail	-23.51	1.88	0.01	0.48
Road – biofuels	33.36	-4.08	-0.04	0.36
Rail – improved efficiency – EMUs	-163.99	28.43	0.29	0.35
Rail – improved efficiency – diesel	-16.76	2.32	0.02	0.33
Rail – alternative fuels – hybrid diesel	34.64	-4.79	-0.03	0.40
Rail – alternative fuels – CNG	33.23	-5.84	-0.04	0.34
Rail – biofuels	39.54	-6.43	-0.01	1.33
Aviation – biofuels	52.89	-6.28	-0.06	0.36

** Net present value*

*** Gross value added*

Taking both quantitative and qualitative scores into consideration for each criterion, points are allocated to each measure with the results for the 'base scenario' shown in Table 16 below (zero is the worst result and 100 the best).

Table 16: Distribution of points assigned to each option for the transport sector

Option descriptions	Overall score	Cost	Economic impact	Social impact	Non-GHG environ-mental impact	Implement-ability
Road – alternative fuels – CNG	62.4	68.7	54.9	50.2	70.0	67.5
Road – alternative fuels – diesel PHEV	50.4	64.2	49.8	39.4	65.0	32.5
Road – improved efficiency – petrol ICE	68.0	81.9	67.4	34.2	70.0	92.5
Road – alternative fuels – petrol HEV	60.2	60.3	47.3	38.1	65.0	92.5
Road – improved efficiency – diesel ICE	63.6	71.8	57.8	31.1	70.0	92.5
Road – alternative fuels – petrol PHEV	52.0	68.2	53.8	39.9	65.0	32.5
Road – alternative fuels -–FCEV	42.5	57.7	43.6	37.1	40.0	32.5
Road – alternative fuels – diesel HEV	58.1	55.6	42.7	36.6	65.0	92.5
Road – alternative fuels – EV	54.8	71.2	55.0	50.9	45.0	50.0
Road – shifting passengers from cars to public transport	65.9	51.6	41.4	56.2	100.0	77.5
Road – shifting freight from road to rail	72.1	71.6	55.8	61.3	85.0	85.0
Road – biofuels	50.7	58.8	45.9	37.4	35.0	77.5
Rail – improved efficiency – EMUs	77.2	88.9	100.0	46.5	70.0	92.5
Rail -– improved efficiency – diesel	63.0	70.1	56.6	30.6	70.0	92.5
Rail – alternative fuels – hybrid diesel	65.4	58.5	44.8	38.1	95.0	92.5
Rail – alternative fuels – CNG	54.5	58.8	43.0	37.1	90.0	42.5
Rail – biofuels	51.8	57.4	42.0	45.9	35.0	77.5
Aviation – biofuels	48.8	54.3	42.3	36.2	35.0	77.5

The 'Road – improved efficiency – petrol ICE' measure scores highly overall because it is a relatively low-cost measure which is also relatively easy to implement. The 'Rail – improved efficiency – EMUs' measure is also a relatively low-cost and easy-to-implement measure, although it has limited mitigation potential. The impact analysis for this measure also shows that its overall economic impact (measured as gross value added per unit of CO_2e mitigated) is positive. The fuel switch measure in the rail sector 'Rail – alternative fuels – hybrid diesel' scores highly because its non-GHG environmental impact is low and the measure is considered relatively easy to implement.

The modal shift options score highly overall, not only in comparison to other transport sector measures, but in comparison to all other measures identified in this study. As a general comment, this is because the estimated costs of these measures (calculated per unit of emissions abatement) is relatively low, while their impact on the economy is positive as is their non-greenhouse gas impact. The positive impact of a modal shift in the transport sector is thus recognised.

10.2 Net Benefit Curve

The concept of net benefit is described in the main body of the report. In the case of the 'balanced weighting' scenario the net benefit curve is shown in Figure 13.

The amount of CO_2e which can be mitigated for each measure, for the full period from 2010 to 2050, is shown on the horizontal axis. In order to maximise the net benefit (as determined by the MCA analysis), the measures should be implemented in order from left to right as they appear in Figure 13.

According to the graph, a significant amount of abatement is available for measures which also achieve a high marginal net benefit score. At least 1,350 $MtCO_2$e of abatement over the 40-year lifetime of the assessment is available for measures whose marginal net benefit score exceeds 60.

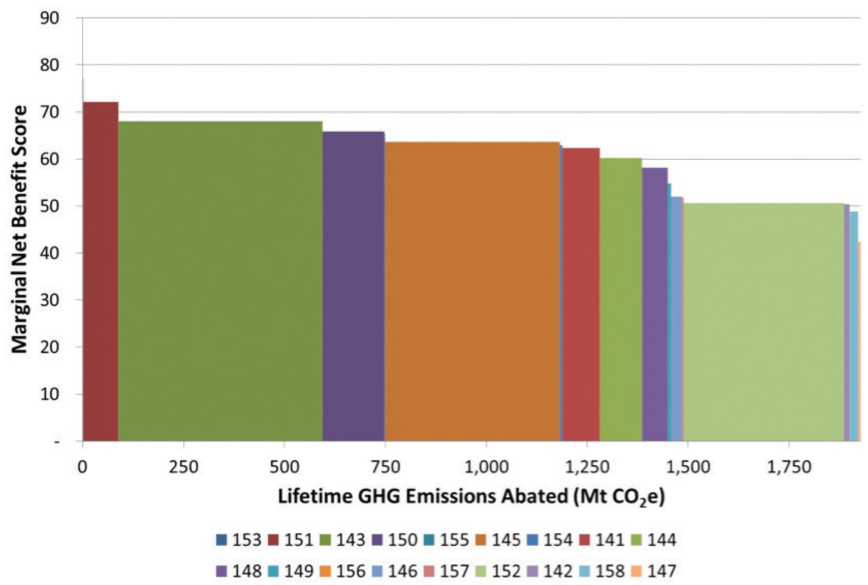

Figure 13: Net benefit curve for the 'balanced weighting' scenario for the transport sector

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