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Modelling of Transport Emissions

Version 1

9 February 2011

Australian Transport Emissions Projections to 2050

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9 February 2011

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Executive Summary

SKM MMA have been commissioned by the Department of Climate Change and Energy Efficiency (DCCEE) to develop two projections of transport emissions to 2030, with accompanying sensitivity analysis on the baseline projection to consider high and low changes in GDP, oil price, population, congestion parameters and a combination of all four. The two projections required include a baseline and a business-as-usual projection, where the baseline projection includes the effect of all known government policies, while the business as usual projection excludes these impacts.

Transport sector emissions encompass emissions from the following transport modes:

- Road, including private and commercial vehicles, buses, motorcycles, rigid and articulated trucks;
- Air, including domestic scheduled and general aviation, and emissions arising from fuel uplifted for international travel (normally included under the category of international bunker fuels);
- Rail (passenger and freight), including electrified sources (though the emissions from electric powered rail are included in the stationary energy sector);
- Sea, including emissions arising from fuel uplifted for international travel (normally included under the category of international bunker fuels);
- Non-recreational off-road vehicle emissions.

Australian transport emissions include emissions from road and rail use, as well as emissions from domestic air and sea transport. The modelling is to also include emissions from international bunker fuels, which are defined as emissions from international air and sea travel. Road transport emissions may be categorised by vehicle type, including passenger vehicles, light commercial vehicles, rigid trucks, articulated trucks, buses and motorcycles. Rail transport emissions may also be divided into passenger and freight task, with passenger rail travel divided further into heavy urban, non-urban, and light rail travel, and freight task divided further into government bulk, government non-bulk, and private freight task. Air transport emissions are divided into domestic and international components, with the domestic component split into general air travel (charter services, helicopters, ballooning, emergency air travel, etc) and domestic air travel. Sea transport emissions are also divided into domestic and international categories.

Historical overview

Historically, the majority of emissions from the transport sector are produced by road transport, making up 87% of emissions in 2007/08. The next largest sector is air transport with 7% of emissions in 2007/08, and this is also the fastest growing, with emissions expected to increase to 17% by 2050.

Within the road transport sector, the largest contribution to emissions is made by passenger vehicles, accounting for 60% of road sector emissions in 2007/08. Growth in emissions from this sector averaged around 1.2% p.a. since 1990, in comparison to around 2.4% on average from commercial vehicles, indicating that the fastest growth has been in the commercial fleet. Energy intensity of passenger vehicles has also dropped sharply over this time, from around 4.16 MJ/kilometre in 1990, to around 3.7 MJ/kilometre in 2008, implying that the growth in emissions has come from growth in kilometres travelled rather than from reduced fuel efficiency. Changes in fuel efficiency are likely to have occurred as a result of improving vehicle technology, trends towards purchases of smaller vehicles, and trends towards diesel technology in preference to petrol technology in vehicles. This has been counteracted to some extent by increasing congestion, which has been estimated to have an impact of around 0.3% p.a., and growth in kilometres travelled, to which future increases are expected to arise from changes in population levels, since kilometres travelled per person has stabilised and in some cases dropped since 2004.

Trends in fuel intensity in the passenger vehicle sector do not appear to have flowed through to commercial road travel in terms of fuel use per kilometre travelled. However the heavy freight sector has shown improvement to operational efficiency which has reduced the fuel use per tonne-kilometre.

The air transport sector has also seen change in the last 18 years. Load factors on commercial aircraft have increased by around 10% for both domestic and international aircraft since 1990, implying that less fuel will be required to move each passenger assuming the trend is to continue. At the same time, fuel use per seat-kilometre has dropped, yet it is expected that these two trends alone will be insufficient to counter expected increases in passenger air travel over the forecast period.

Assumptions

Travel activity was modelled using population, GDP and oil prices as key drivers. A summary is provided in Table Exec 1.

Fuel intensity was determined from the use of a technology model developed by SKM MMA, drawing from results of a technology review undertaken by SKM. This model assessed various forms of vehicle technology by examining the economic costs of take-up of any new technology against traditional forms. The assessment was also done in conjunction with a practical overview in terms of availability of infrastructure, rate of take-up, and so forth, and the modelling results were independently reviewed for adequacy.

Table Exec 1 Summary of key assumptions

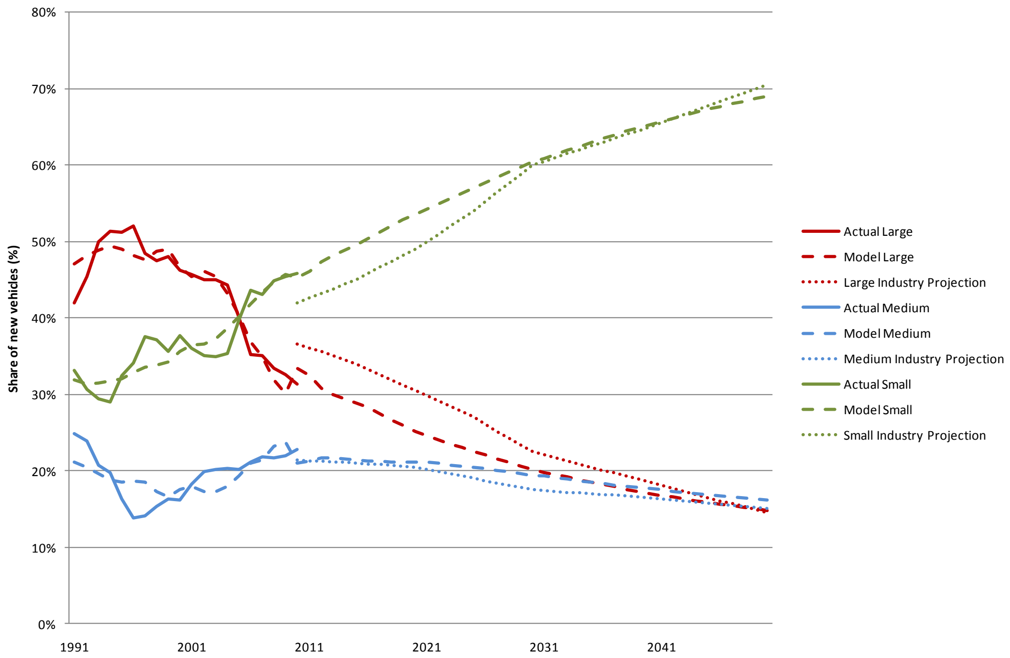
	Annual % change (1990-2000)	Annual % change (2000-2008)	Annual % change (2008-2020)	Annual % change (2020-2030)
GDP	*3.4%*	*3.3%*	*3.2%*	*2.2%*
Population	*1.2%*	*1.5%*	*1.5%*	*1.0%*
GDP/person	*2.2%*	*1.8%*	*1.7%*	*1.1%*
Oil Price	*-1.1%*	*14.1%*	*0.2%*	*1.2%*

Source: SKM MMA analysis of oil prices consistent with the 2009 International Energy Agency (IEA) World Energy Outlook and GDP and population from the Treasury consistent with the Pre-Election Economic and Fiscal Outlook (PEFO) 2010 and Intergenerational Report (IGR) 2010.

Technologies considered included petrol, diesel, LPG, LNG, CNG, petrol hybrids and diesel hybrids. A key assumption was that capital costs of alternative technologies will drop to match the capital cost of conventional petrol vehicles by 2025 in most cases. The main exceptions to this rule are for LPG, LNG, CNG and electric vehicles where the capital costs are assumed to remain substantially higher than the cost of conventional vehicles. Efficiency of most vehicle types was expected to improve by around 1% p.a., although some technologies gained higher efficiency gains such as diesel and hybrid technologies. Hybrid vehicles were expected to take some power from the grid after 2017, generally improving the emissions intensity of these vehicles relative to standard technologies. Off-take from the grid was expected to reduce between 20 and 50% of petrol or diesel energy requirement by 2050.

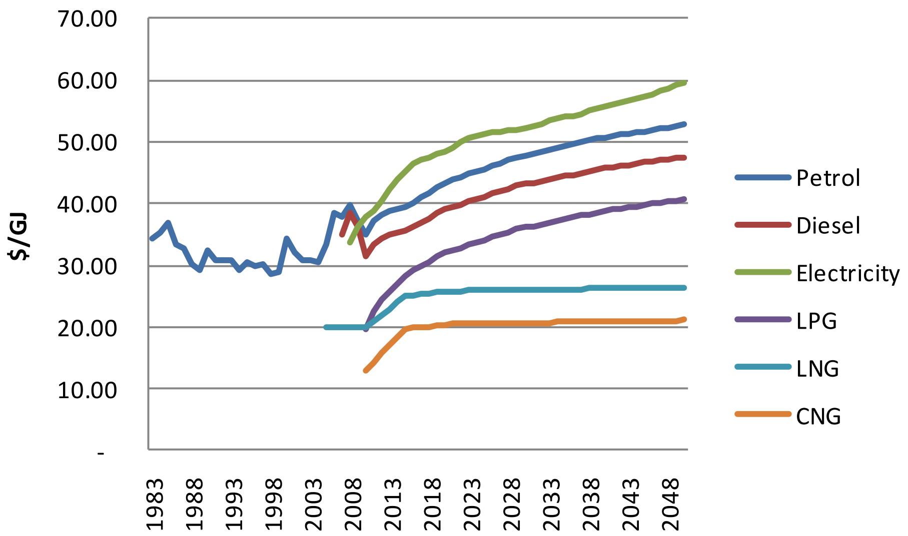
The model also took vehicle size into consideration, with passenger vehicles segregated into small, medium and large vehicle categories. SKM MMA considered that, through both modelling and independent review, the trend towards smaller vehicles would continue into the future, replicating trends overseas. See Figure Exec 1.

■ **Figure Exec 1 Projected shares of small, medium and large passenger vehicles**



The combination of electric grid off-take and smaller sized vehicles implied significant reductions to emission intensity in the fleet. Take-up of electric based technology and, in the case of articulated trucks, LNG technology, was enhanced by improving relative cost differences between these fuels and fossil based petrol and diesel fuels. See Figure Exec 2.

■ **Figure Exec 2 Fuel price projections**



Results

Domestic Transport Emissions are projected to peak at 99.3 Mt CO_2e by 2030, growing by 1.1% p.a.to 2020, and then slowing down to 0.4% p.a. to 2030. Growth is expected to decline post 2030 to provide an emissions estimate of 94.4 Mt CO_2e by 2050, with average emissions decline of -0.5% p.a.

Of these emissions, perhaps the largest and potentially most changeable sector is the private vehicle road emissions sector. The private vehicle road emissions sector created 43.5 Mt CO_2e in 2008, having grown by 0.6% p.a. since the year 2000. This has been a significant improvement to the previous decade where growth in emissions had increased by 1.6% p.a., and the drop has been attributed to reduced car travel per person, trends to reduced vehicle size and trends to diesel technology, particularly in the large vehicle market. Assuming these trends continue, growth in emissions is expected to continue to slow, growing at 0.4% p.a. to 2020, flattening off between 2020 and 2030 and eventually dropping at 2.3% p.a. after 2030 when the full impact of hybrid vehicle technology and electrification of the fleet might be expected to emerge.

The commercial road emissions sector is also expected to undergo change, and growth in travel is expected to be relatively strong in line with change to GDP and recent trends toward just-in-time inventory control. This strong growth is mitigated by continuing productivity improvement in this sector, although the rate of improvement may slow in time as the sector reaches practical limits to productivity improvement. Strong growth in travel is also countered by expectations of commercial fleet slowly moving toward LNG / CNG / hybrid technology from around 2020, and this change is expected to reduce growth in emissions in this sector. Growth in emissions to 2020 is expected to be 1.1-2.6% p.a., followed by growth to 2030 at 0.1-0.8% p.a. and growth beyond this time to be -1.9 to 0.1% p.a. Emissions for articulated fleet peak in 2050 at 13.9 Mt CO_2e, while emissions for rigid trucks peak in 2030 at 7.4 Mt CO_2e. Emissions for light commercial vehicles are expected to peak in 2020 at 14.4 Mt CO_2e, because there is greater scope to reduce emissions in this sector from a technological perspective.

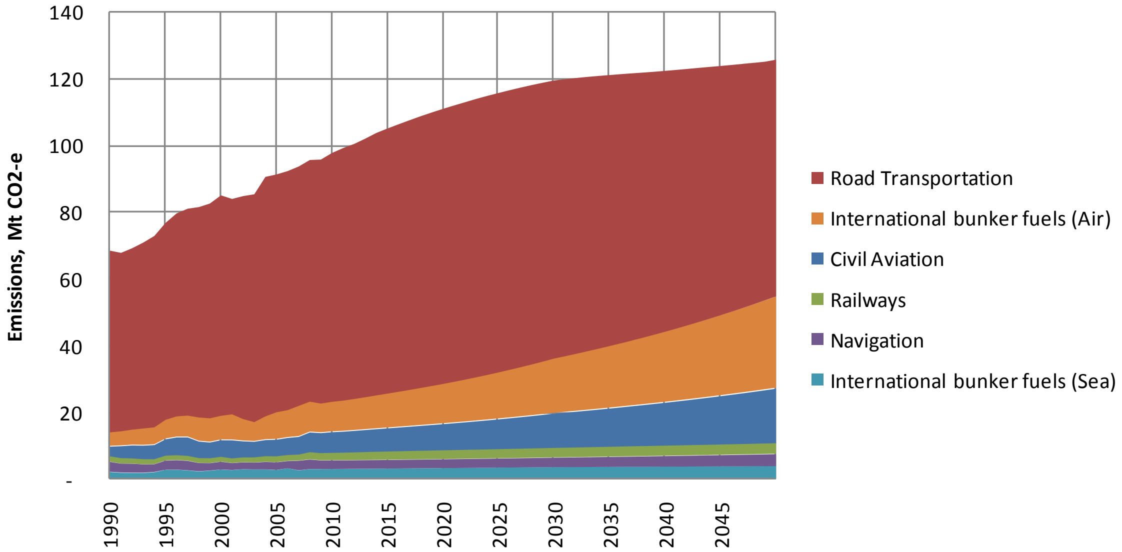
Air travel emissions are expected to maintain strong growth in the absence of a great range of counter measures in this industry. Emissions are expected to peak in 2050 at 16.1 Mt CO_2e, and growth is generally sustained at 2.2% p.a. until 2030 when growth in emissions is expected to increase as productivity improvements become harder to sustain.

Rail emissions are expected to peak in 2050 at 3.3 Mt CO_2e. Growth in emissions slows as a result of some expected electrification in this sector. Sea emissions also peak in 2050 at 3.6 Mt CO_2e.

International bunker fuel emissions are expected to maintain strong growth during the forecast period to 2050, with average growth of 1.7-2.2% p.a. to 2030 followed by stronger growth post 2030 of 4.7% p.a. The dominant sector here is international air transport which exhibits strong growth over the forecast period as a result of projected increases in international passenger kilometres travelled.

Baseline emissions projections are summarised in Figure Exec 3.

▪ Figure Exec 3 Emissions by transport sector



Source: SKM MMA Analysis

The dominant sector for domestic transport emissions and fuel use is the road transport sector, which currently makes up around 87% of total domestic transport emissions. However, by 2020 this share is expected to drop to 86% of total domestic transport emissions and by 2030 drop further to 84% of total domestic transport emissions. By 2050, the road transport sector is expected to contribute only 76% of all domestic transport emissions. This drop in share is expected to occur as a result of improved vehicle emission and/or fuel intensity, softening of travel demand projections, and great expectations with regard to growth in the aviation industry combined with limited technical potential to reduce emissions in that industry[1]. It is also expected that congestion impacts will be limited by improvements to infrastructure and the presence of stop-start technology and hybridisation.

The technology take-up modelled in the study in terms of new vehicle market share is described further in the body of the report. Modelling was conservative in the sense that historical take-up of new technology has generally been slow and this trend is expected into the future. Passenger

[1] Bio-fuel is one recognised means of reducing air emissions, yet is still unproven for air transport. On 25 September 2010, Intertek tested the use of biofuel on a small aircraft with success, but the fuel is still to be tested on larger commercial commerc aircraft and is thus ignored as a potential means of emissions reduction for thisbaseline projection. http://avstop.com/news_sept_2010/biofuel_powered_historic_transatlantic_flight.htm

vehicles are expected to show further increases in take-up of diesel fuelled vehicles, and a substantially increased new vehicle share of hybrids is expected after 2020, as well as a small but significant share of purely electric vehicle technology. Diesel is expected to be the dominant technology in light commercial vehicles, with some hybridisation occurring after 2027. After 2020, hybridisation of rigid trucks is expected to be available while LNG is viewed as the more viable option for articulated fleet. A mixture of LNG and CNG is viewed as the most likely option for buses after this time.

Measures

There have been several incentive programs aimed at reducing greenhouse emissions from transport. It is difficult to quantify the abatement effects of some of these programs. A summary table is provided below.

- **Table Exec 2 Impact of emissions reduction measures**

Category	Sub-category	2010	2020
Emissions saved, kt CO2-e			
	Mandatory bio-fuels	5.7	498.4
	EEO	208.8	509.4
	AFCP	- 10.7	- 9.4
	GGAP	486.5	344.9
	Total	**690.3**	**1,343.3**

Source: SKM MMA analysis

Sensitivity Analyses

SKM MMA was also requested to conduct sensitivity analyses for this work using high and low values of the following variables:

- Population (Growth increasing +/- 0.1% p.a. above baseline population growth)
- GDP (Growth increasing +/- 0.5% p.a. above baseline GDP growth)
- Fuel intensity (Private vehicle fuel intensity 15% above and below baseline fuel intensity and trucks 0.1% above and below baseline fuel intensity)
- Oil Price (High and low cases supplied by DCCEE – high case around 22% above baseline in 2030 and low case around 25% below baseline in 2030)
- Congestion parameters (+/- 50% of baseline congestion parameter)

In addition, two further sensitivity analyses were requested – an overall high case, encompassing high levels of population, GDP, fuel intensity, congestion parameters and a low oil price, as well as an overall low case, encompassing low levels of population, GDP, congestion parameters and a high oil price. The results are summarised in Table Exec 3. When taken in combination, the high case provides projections 4.6% higher than our baseline projection by 2020, and 7.6% higher than the baseline by 2030. Similarly the low case provides projections 3.2% lower than the baseline in

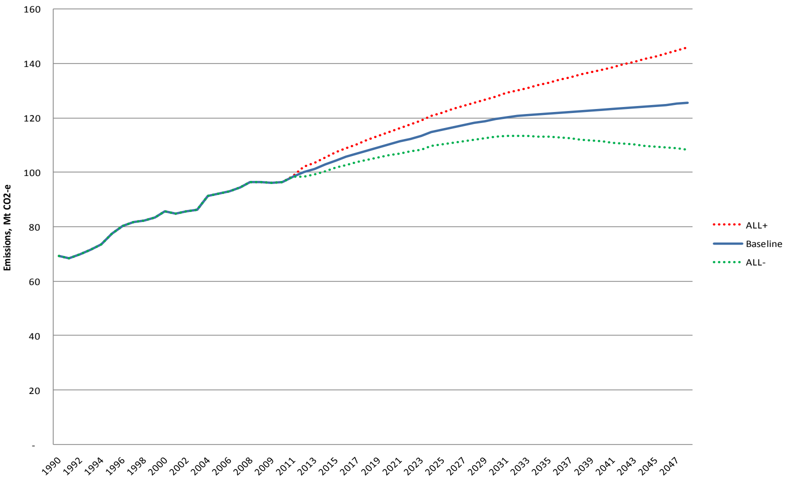
2020 and 4.9% lower than the baseline by 2030. See Figure Exec 4. When looked at individually, the parameter with the largest variation is fuel intensity, as unrealised improvements to fuel efficiency can add as much as 3.1% to the projections by 2030.

- **Table Exec 3 Summary of sensitivity analyses**

Scenario	2008	2016	2020	2030	2050
Baseline (Mt CO2e)	96	106	110	120	126
ALL-	0.0%	-2.9%	-3.8%	-5.5%	-14.7%
ALL+	0.0%	3.0%	4.1%	7.0%	17.9%
Cong-	0.0%	-0.4%	-0.8%	-1.1%	-0.9%
Cong+	0.0%	0.4%	0.8%	1.1%	0.9%
Oil-	0.0%	0.1%	0.3%	0.9%	3.9%
Oil+	0.0%	-0.1%	-0.1%	0.1%	-3.6%
GDP-	0.0%	-0.8%	-1.5%	-3.3%	-5.2%
GDP+	0.0%	0.5%	0.8%	1.3%	3.8%
Pop-	0.0%	0.6%	0.5%	0.1%	-0.5%
Pop+	0.0%	1.0%	1.2%	1.6%	1.8%
FuelInt-	0.0%	-1.7%	-1.8%	-2.4%	-6.9%
FuelInt+	0.0%	1.7%	1.8%	2.4%	6.5%

Source: SKM MMA analysis

- **Figure Exec 4 Sensitivity Analysis – overall high and low case**



Source: SKM MMA analysis

1. Introduction

SKM MMA have been commissioned by the Department of Climate Change and Energy Efficiency (DCCEE) to develop two projections of transport emissions to 2030, with accompanying sensitivity analysis on the baseline projection to consider high and low changes in GDP, oil price, population, congestion parameters and a combination of all four. The two projections required include a baseline and a business-as-usual projection, where the baseline projection includes the effect of all known government policies, while the business as usual projection excludes these impacts.

Transport sector emissions encompass emissions from the following transport modes:

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- Sea, including emissions arising from fuel uplifted for international travel (normally included under the category of international bunker fuels);
- Non-recreational off-road vehicle emissions.

The data for this review have been sourced from:

- the Australian Greenhouse Emissions Information System (AEGIS) maintained by the Department of Climate Change and Energy Efficiency (DCCEE);
- the Australian Bureau of Statistics (ABS);
- the Australian Bureau of Agricultural and Resource Economics (ABARE);
- the Commonwealth Scientific and Industrial Research Organisation (CSIRO);
- the Bureau of Infrastructure, Transport and Regional Economics (BITRE); and
- SKM MMA estimates.

Australian transport emissions include emissions from road and rail use, as well as emissions from domestic air and sea transport. In 2010 the modelling is to also include emissions from international bunker fuels, which are defined as emissions from international air and sea travel. Road transport emissions may be categorised by vehicle type, including passenger vehicles, light commercial vehicles, rigid trucks, articulated trucks, buses and motorcycles. Rail transport emissions may also be divided into passenger and freight task, with passenger rail travel divided further into heavy urban, non-urban, and light rail travel, and freight task divided further into government bulk, government non-bulk, and private freight task. Air transport emissions are divided into domestic and international components, with the domestic component further split into general air travel (charter services, helicopters, ballooning, emergency air travel, etc) and domestic air travel. Sea transport emissions are also divided into domestic and international categories.

The focus in this report is given to the Baseline scenario. The BAU scenario is calculated by evaluating the impact of various measures and adding back that impact to the Baseline scenario. Section 7 is devoted to the explanation of what these measures are, how the impacts of them have been calculated, and the impact of these measures on emissions.

2. Historical review

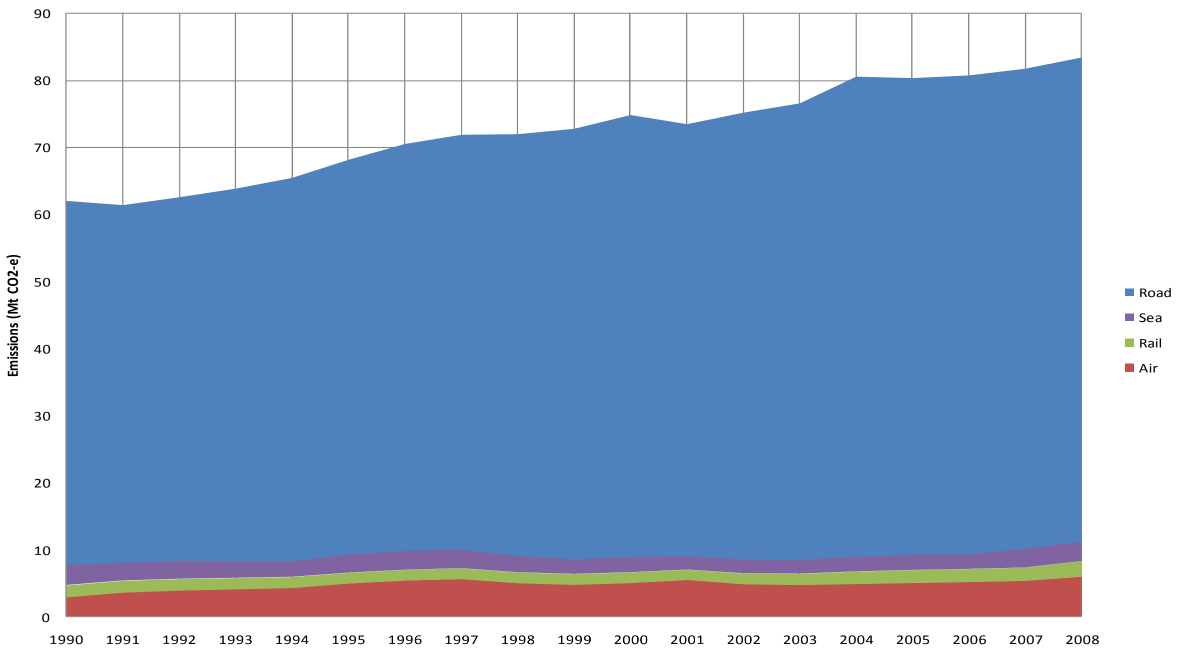
This chapter is a review of historical trends of emissions from the transport sector in Australia. The main objective of this chapter is to examine historical emissions data, with a focus on key factors that drive change in emission levels. These include trends in transport fuel activity and mode, population and GDP growth as well as transport fuel prices. There has also been some impact from emissions abatement policies that are currently, or have previously been, in operation. These policies are described for the purpose of assessing their impact on historical emissions. There is also a short discussion of committed policies that may affect levels of future emissions.

2.1. Emissions

2.1.1. Overview

As shown in Figure 2-1, the majority of emissions from the transport sector are produced by road transport, making up 87% of all transport emissions in 2007/08. The next largest sector is air transport with 7% of emissions in 2007/08. This is the fastest growing sector, having increased by an average of 4% p.a. since 1990, compared to the average for all transport of 2%. Rail and sea transport contribute around 3% and 4% respectively to emissions. Total emissions from all forms of transport have increased fairly steadily from around 62 Mt in 1990 to around 83 Mt in 2007.

▪ **Figure 2-1 Domestic transport emissions by sector**

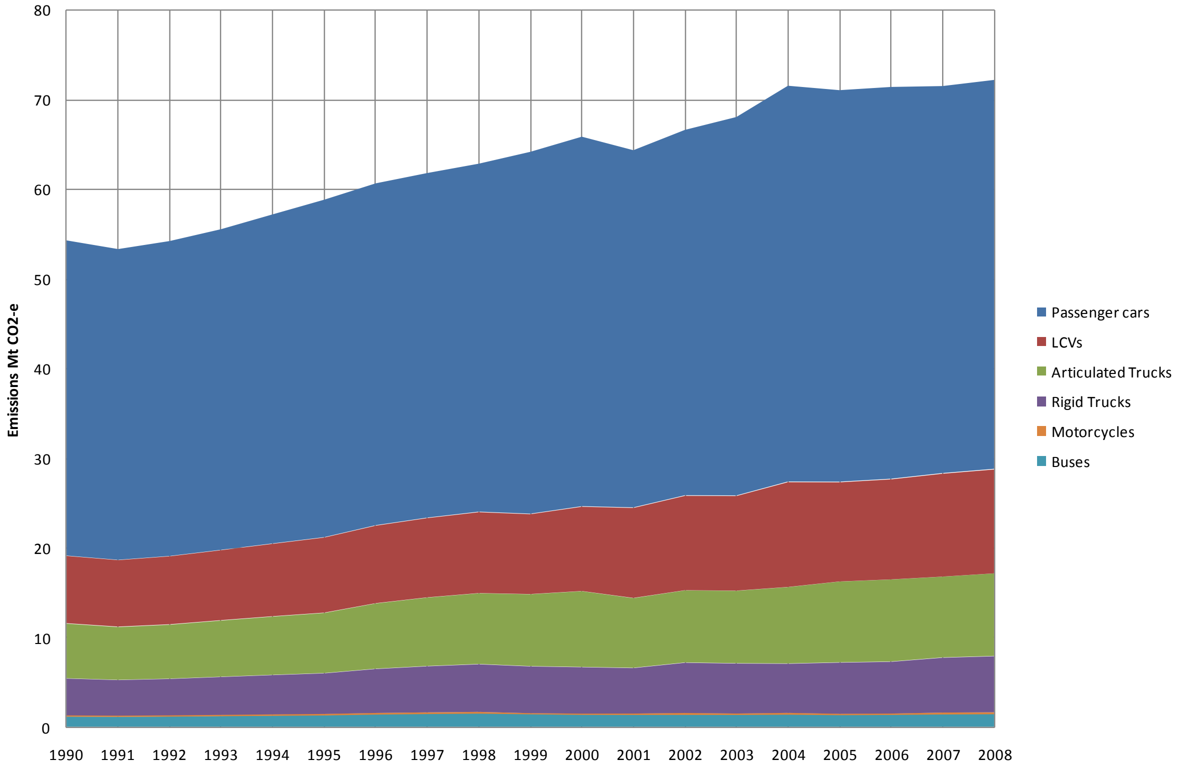


Source: AEGIS NGGI data (2009)

2.1.2. Road transport

The emissions trends for the road transport sector alone are shown in Figure 2-2 and Table 2-1. Cars are the greatest contributor to emissions, accounting for 60% in 2008. LCVs are also a significant component, contributing 16%. Rigid and articulated trucks make up 9% and 13%, respectively, and buses and motorcycles are insignificant, contributing only 2% in total. Growth in emissions has slowed somewhat since 2004, and this is caused by a similar trend in activity levels (see Figure 2-8) as well as increased reductions in energy intensity for the passenger vehicle sector at around this time (see Figure 2-3).

- **Figure 2-2 Emissions from road sector by type**



Source: AEGIS NGGI data (2009)

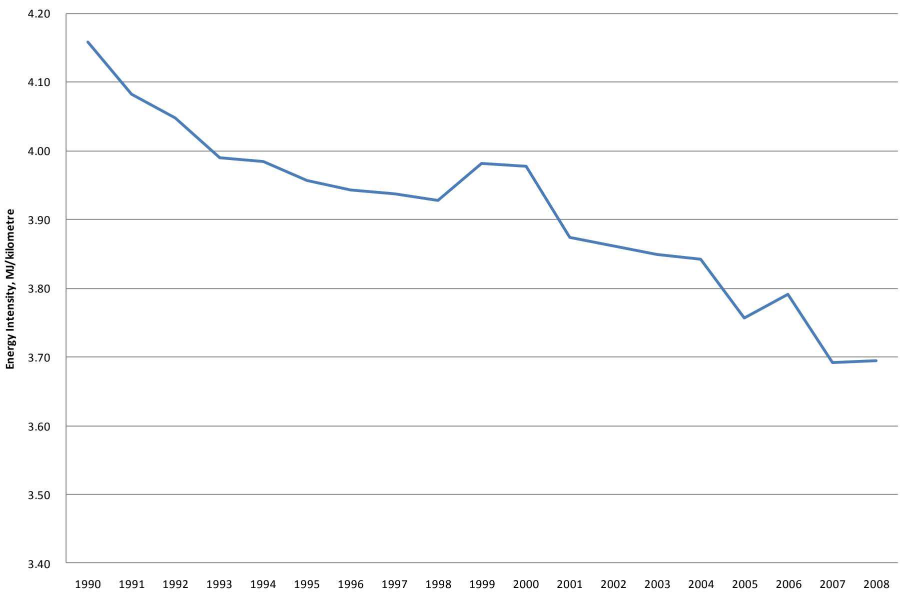
Figure 2-4 shows road transport emissions by fuel for those fuels that contribute significantly to the total. The majority of emissions, 60% in 2008, come from petrol combustion. In the same year, diesel contributed 35% and LPG 5%, while LNG accounted for less than 1%.

■ **Table 2-1 Summary of energy emissions from road transport by type**

	Emissions 1990 (Mt CO_2e)	Emissions 2008 (Mt CO_2e)	Average % of total	Average growth % p.a.
Cars	35,226	43,459	62.66%	1.19%
Light commercial	7,549	11,657	14.91%	2.50%
Rigid trucks	4,111	6,254	7.99%	2.42%
Articulated trucks	6,080	9,182	11.97%	2.39%
Buses	1,156	1,466	2.14%	1.40%
Motorcycles	209	247	0.33%	1.92%
Total	54,330	72,264	100.00%	1.61%

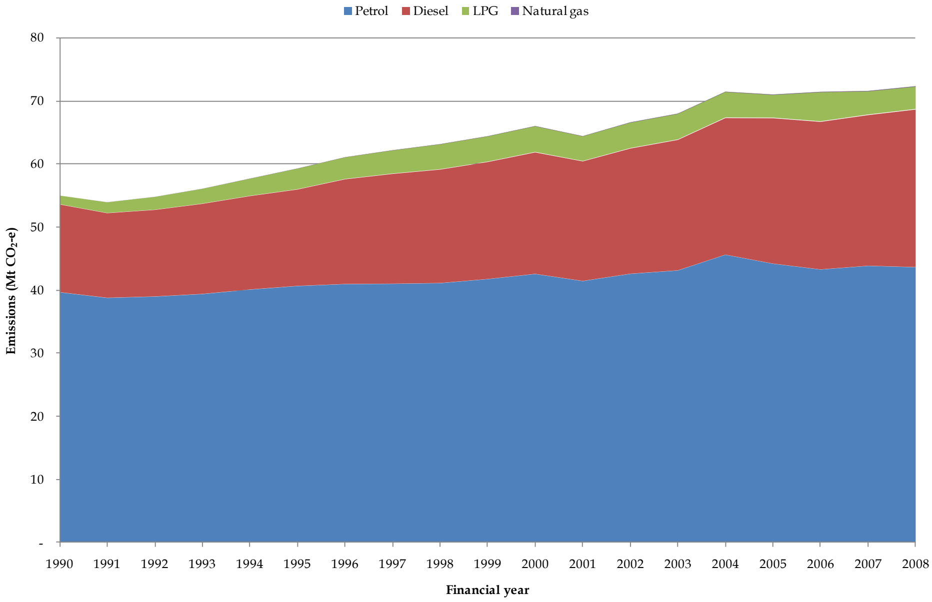
Source: AEGIS NGGI data (2009)

■ **Figure 2-3 Energy intensity of passenger vehicles**



Source: SKM MMA analysis of ABARE fuel use data and BITRE VKT data

- **Figure 2-4 Road transport emissions by fuel**



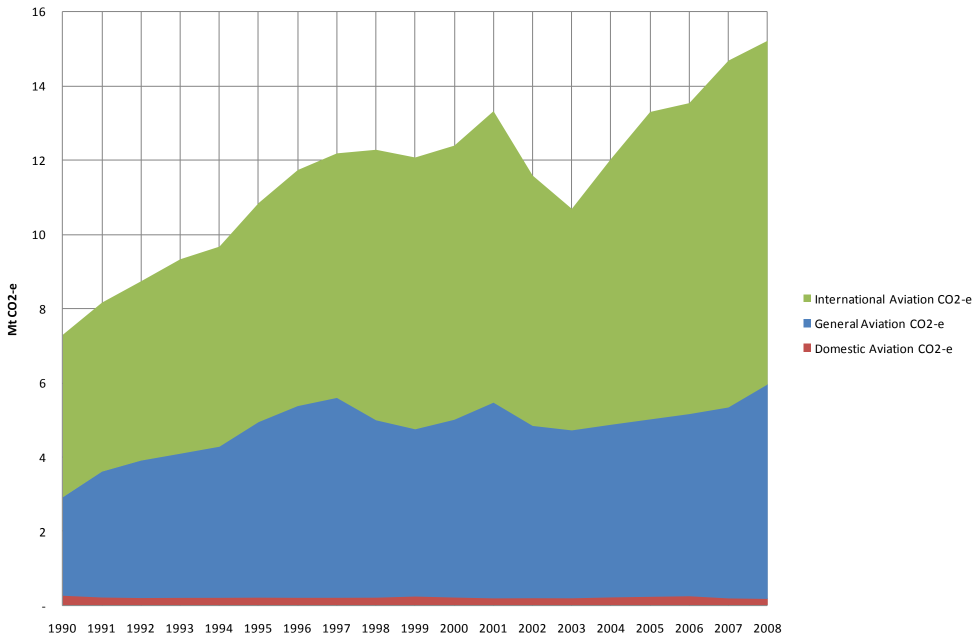
Source: AEGIS NGGI data (2009)

2.1.3. Air transport

Figure 2-5 shows emissions from air transport by fuel type, including general and domestic aviation, and international aviation. General aviation refers to the operation of civilian aircraft for purposes other than commercial passenger transport. Such purposes can include instructional flying, recreational flying of small aircraft, rescue helicopters and so forth. Fuel use in this sector is relatively small and stable. Estimates of emissions from international air travel only include emissions resulting from fuel uplifted in Australia.

The chart reveals some interesting features of the air transport sector, including that emissions from the sector have more than doubled since 1990, with emissions from international travel generally outstripping emissions from domestic travel. The steady increase in emissions from 1990 also appears to have been interrupted at around 2001, especially for international flights. At around this time, many airlines adjusted their operating practices to reduce the number of flights by increasing the proportion of filled seats on each plane (that is, increasing the load factor). The steady increase in load factor is evident in Figure 2-6.

Figure 2-5 Emissions from air transport by type



Source: AEGIS NGGI data (2009)

Figure 2-6 Change in air industry load factor over time

Source: SKM MMA analysis of BITRE data

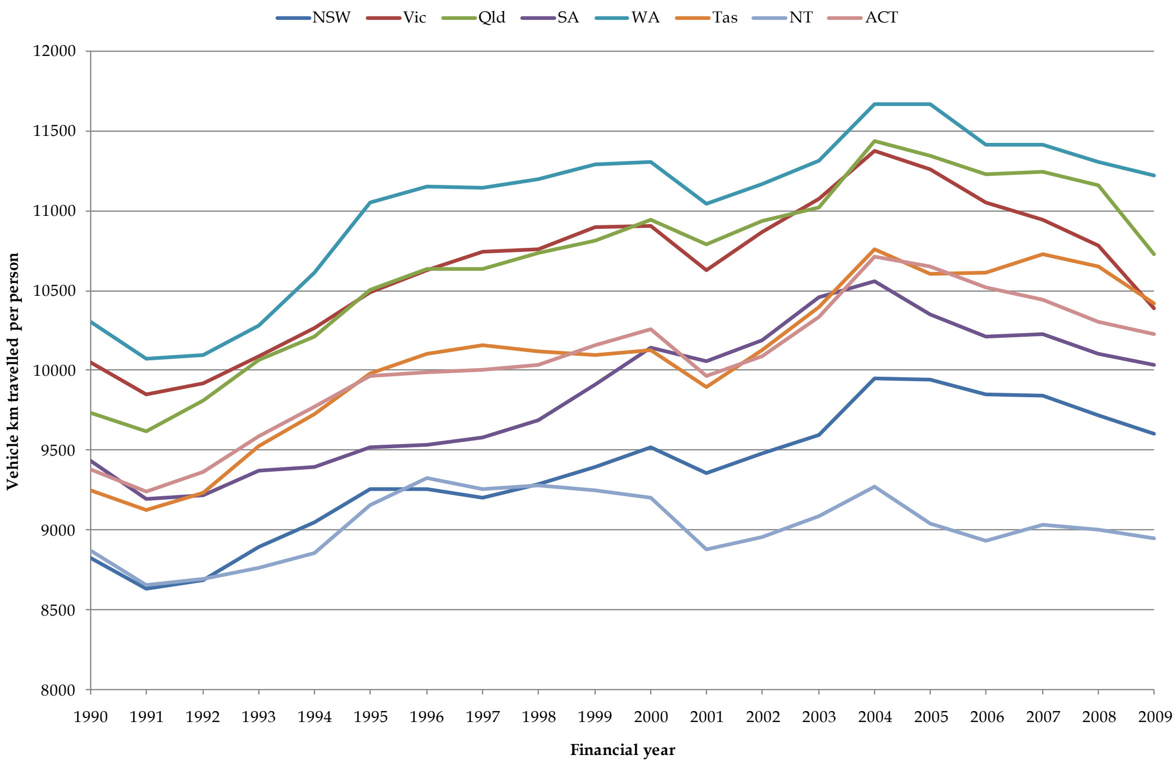
2.2. Road transport activity

2.2.1. Overview

Figure 2-7 shows vehicle kilometres travelled per person by state. In most states, the number of vehicle kilometres travelled per person has decreased since 2004. In total, vehicle kilometres travelled appear to have stabilised, as shown in Figure 2-8. There are a number of possible reasons for this decline. These include:

- Increasing oil prices around this time have caused some mode shift to public transport and cycling/walking (and this trend has been assisted by increasing population densities in cities)
- The trend for more cars per person is slowing down
- Congestion in cities
- The trend for increasing travel per person appears to have reached saturation
- The impact of the global financial crisis may have had a material effect in terms of reduced commuting to work as a number of staff may have been forced to reduce their days in the office or may be taking advantage of options to work from home. It is not possible to substantiate whether this is actually the case however.

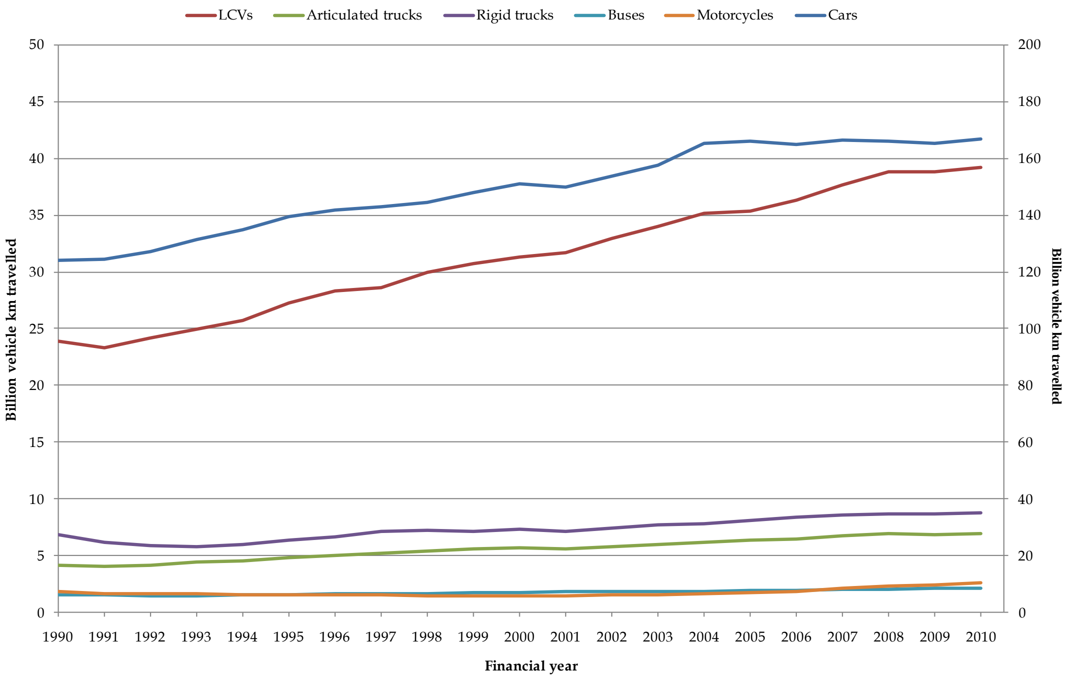
Figure 2-7 Australian road transport activity by state



Source: BITRE

Figure 2-8 shows trends in passenger kilometres travelled for each of the road transport modes. This chart supports the assertion made above that there has been some shift to public transport since the year 2000, and it would appear that heavy rail is receiving some additional patronage. However it is unlikely that this shift in travel mode sufficiently explains the drop in passenger vehicle travel, and it also appears that passenger travel overall has dropped.

- **Figure 2-8 Road transport activity by type (cars plotted on right-hand axis)**



Source: BITRE

Figure 2-9 Passenger km travelled by mode of transport (passenger vehicles on right-hand axis)

Source: BITRE

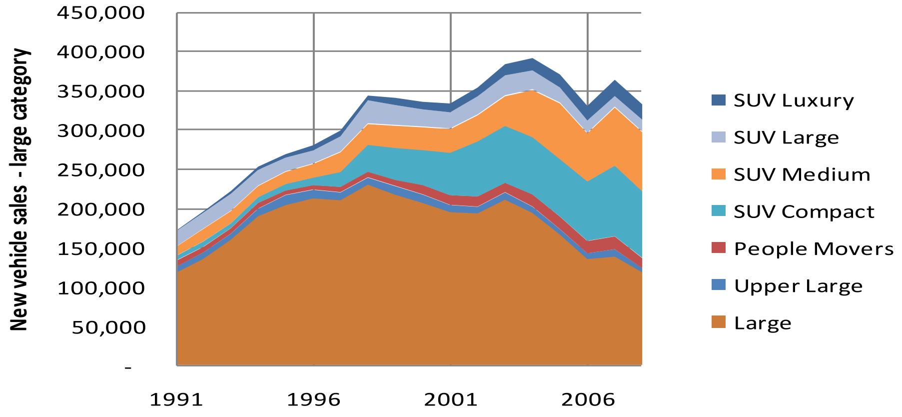
2.2.2. Trends in vehicle numbers and characteristics

The number of motor vehicles in Australia has grown by 3% in the period 2004-2009, and as at March 2009 there were around 16 million motor vehicles. The majority of these (12 million) are passenger vehicles, and the next largest category is light commercial vehicles (2 million). The other categories together comprise around 1 million vehicles. Since 1998, the average age of Australian vehicles has been decreasing, whereas the average age of vehicles had been increasing before this time.

According to data supplied by the Federal Chamber of Automotive Industry (FCAI), new passenger vehicle sales in 2008 were 791,223 and sales for new light commercial vehicles and heavy commercial vehicles (including buses) were 185,016 and 35,925 respectively. Since 1991, growth in new vehicle sales has been significant at 4.1% p.a., with growth for passenger and commercial vehicles at 2.5% p.a. and 5.8% p.a. respectively.

Of the new passenger vehicle sales, 194,678 were SUVs, a category of passenger vehicle which has received much attention as a result of this category's recent trends towards increased sales. Indeed, the SUV's sales have increased on average by 10.2% p.a. since 1991, greater than any individual category of vehicle over the same period. However, from 1998, large vehicles of typically equivalent or lesser fuel efficiency have seen significant loss of market share implying that the rising market share of the SUV has displaced other large vehicles rather than the small to medium sedans often assumed. The fuel efficiency of such SUVs as sold in 2008 was around 10.9 l/100 km compared with 11.5 l/100 km of other large category vehicles. The number of large category vehicles sold including SUVs actually appears to have levelled out since 1998, implying an overall loss in market share of these vehicles compared with small and medium sized vehicles since this time. See Figure 2-10.

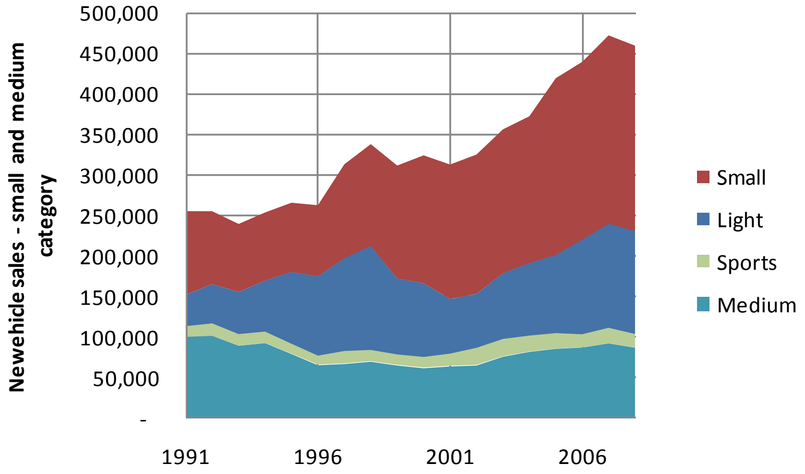
Figure 2-10 Large category passenger vehicle sales since 1991



Source: SKM MMA analysis of FCAI data

In contrast to trends in large category vehicle sales, small vehicles have enjoyed a sustained increase in growth since 1996, about 8.3% p.a, while sales of other light and medium sized vehicles have appeared to be relatively static. See Figure 2-11. Light vehicles appeared to enjoy a surge in market share when oil prices were high around 1998 and slowed down again when oil prices stabilised after this time. In recent years the sales numbers appear to be enjoying further growth consistent with changes to oil prices around this time.

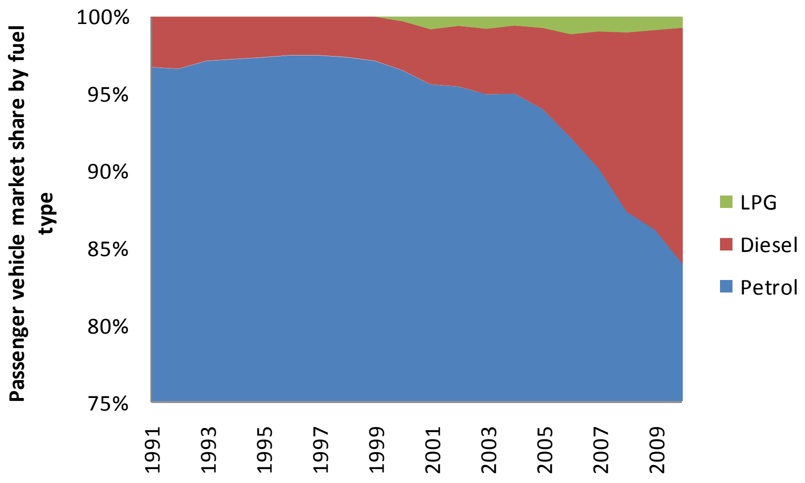
▪ **Figure 2-11 Small and medium category passenger vehicle sales since 1991**



Source: SKM MMA analysis of FCAI data

There has also been an evident trend for increased sales of diesel cars, and these vehicles are now around 15% of all new vehicle market share, with new large vehicles sales having a 27% share of diesel technology while medium and small category vehicles have a 13% and 7% share of diesel technology respectively.

▪ **Figure 2-12 Market share of new passenger vehicle sales by fuel type**



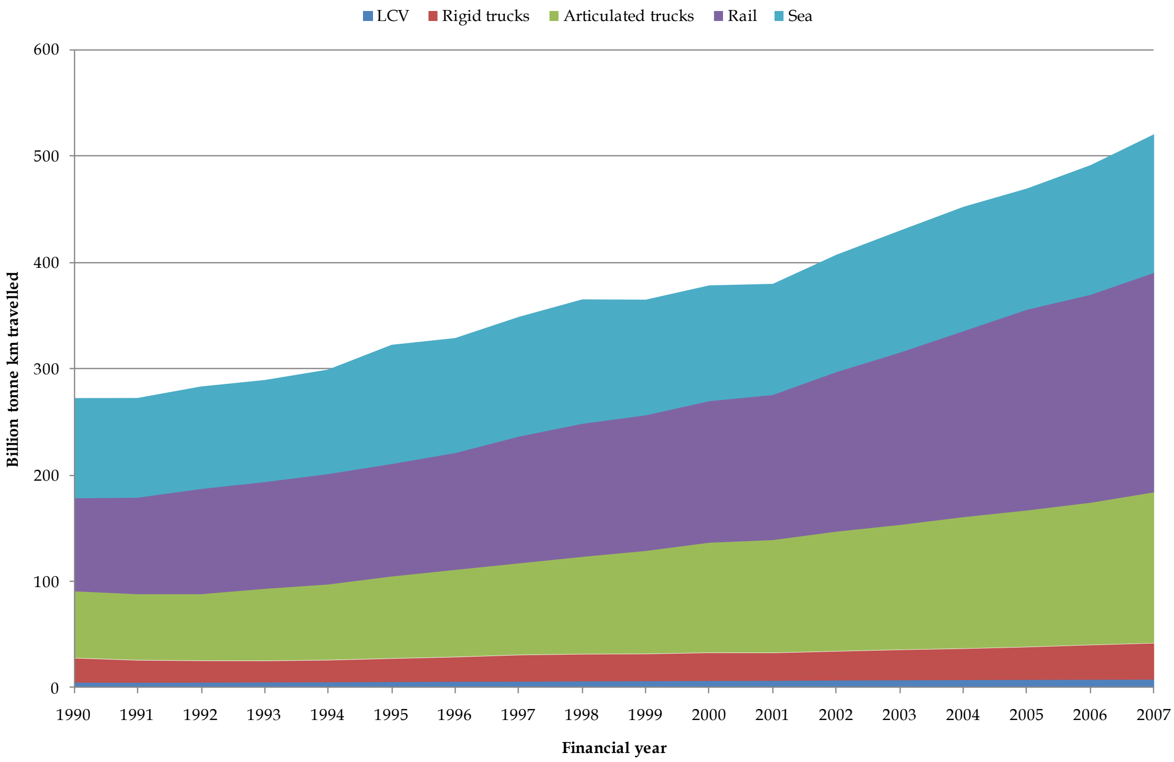
Source: SKM MMA analysis of FCAI data

2.3. Freight task and activity

In 2006-07, domestic freight activity was 507 billion tonne-km, comprising 199 billion tonne-km by rail, 182 billion tonne-km by road, and 126 billion tonne-km by shipping. The rail and road components have grown steadily since 1999-2000 (by 49% and 35% respectively), whereas growth in coastal shipping has been smaller (only 16%) and the sector has experienced reductions in some years.

Figure 2-13 shows the freight task in tonne kilometres travelled. The largest component of the road task is taken up by articulated trucks, and this sector has also shown rapid growth since the early 1990s.

- **Figure 2-13 Freight task**

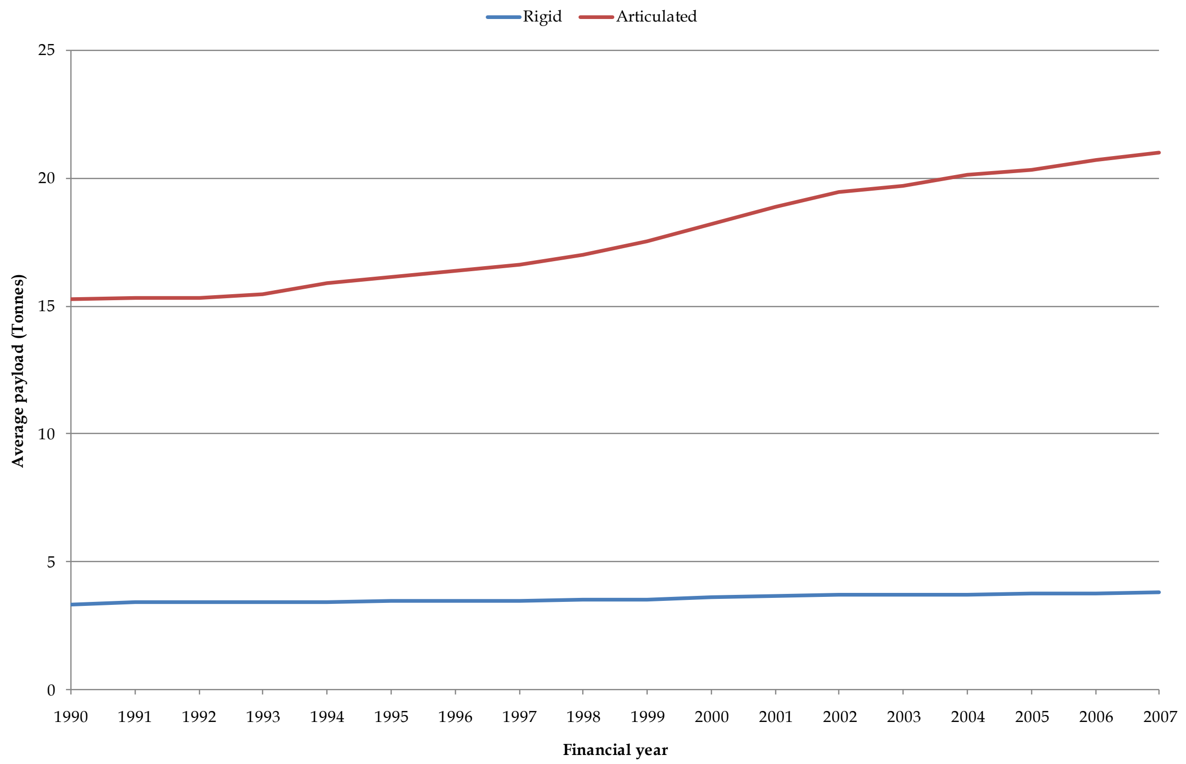


Source: BITRE

Figure 2-14 shows an estimate of the average payload (that is, the total task divided by the total activity) for rigid and articulated trucks[2]. For articulated trucks, the ratio of freight task to kilometres travelled has increased substantially over the period shown, implying that payloads have become heavier. Better logistics planning may also bring about increased efficiency with regard to payloads in freight vehicles. The ratio for rigid trucks has also increased slightly.

2 Note that the activity level is the amount for all use of trucks, not just freight use. However, trucks are used almost exclusively for freight, so the impact of non-freight use of trucks is minor.

Figure 2-14 Average payloads for rigid and articulated trucks



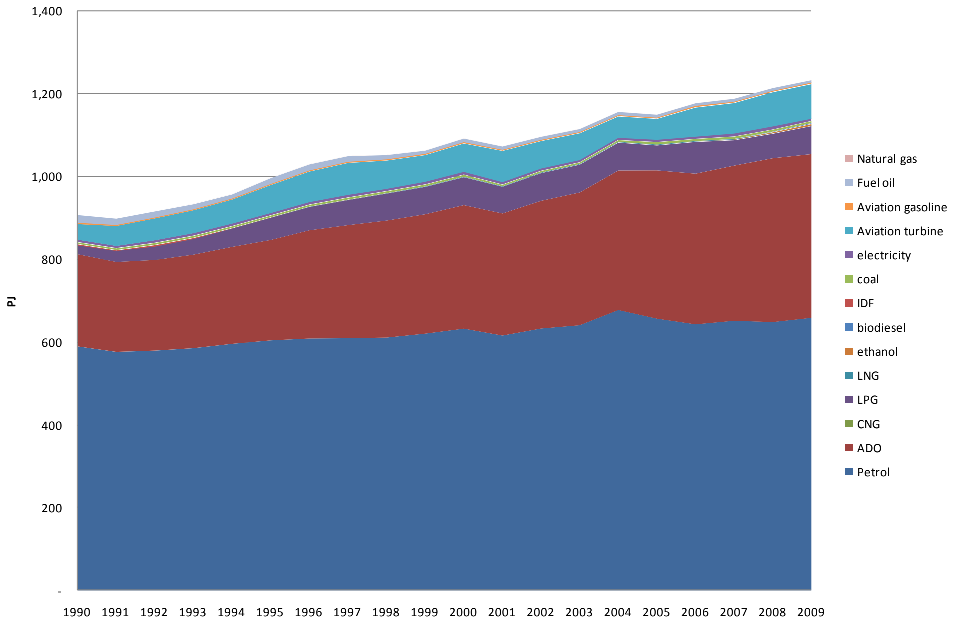
Source: BITRE, SKM MMA analysis

2.4. Fuel use and fuel intensity

Figure 2-15 shows the trend in consumption of various fuel types since 1990. The most notable feature is the strong increase in automotive diesel consumption in particular, and to a lesser extent growth in LPG, compared to the relatively constant use of other fuels. There are two likely contributors to the increase: the increase in road freight, shown in Figure 2-13, and the increase in sales of diesel passenger vehicles, as described in Section 2.2.2.

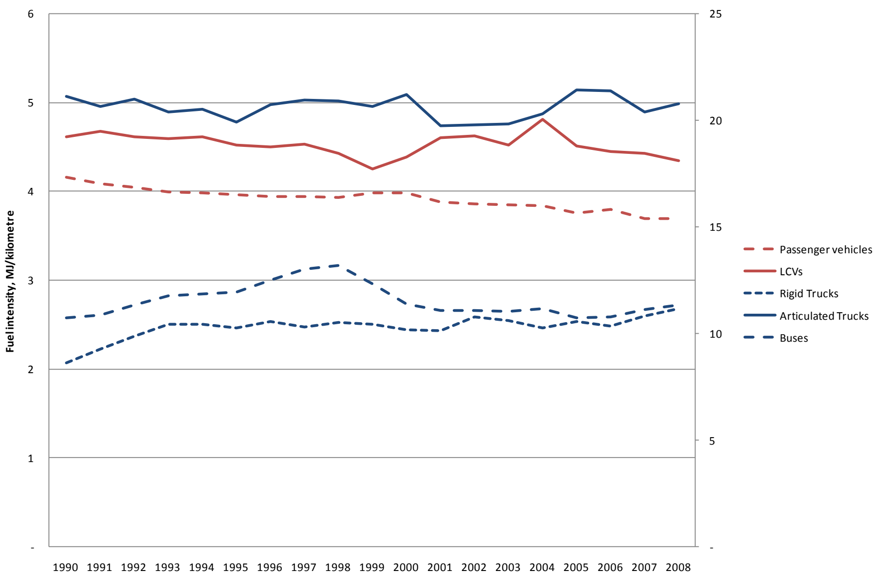
Figure 2-16 shows the trend in energy intensity for each road vehicle type. For most vehicle types there is no clear change in energy intensity (and if there is there seems to be enough noise in the series to mask it), although there does appear to be a definite downward trend for passenger cars (this series sees an average compound annual improvement of -0.7% p.a. since 1990). This does not necessarily mean that vehicles being sold today are less efficient than those sold some years ago, since most vehicles in each category will have been in some part impacted by increasing levels of congestion. That is, the efficiency of vehicles in test environments will often be higher than the efficiency realised in congested conditions.

■ **Figure 2-15 Trends in fuel use**



Source: ABARE

■ **Figure 2-16 Trends in fuel intensity (large vehicles plotted on secondary axis in blue)**

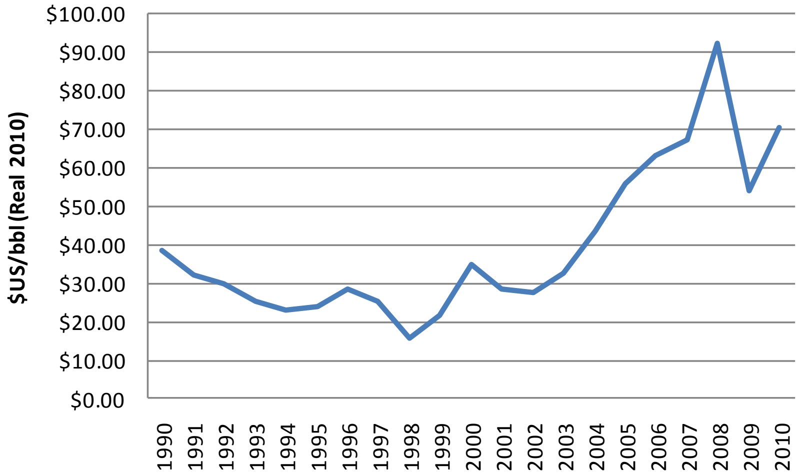


Source: SKM MMA Analysis

2.5. Fuel Prices

Figure 2-17 shows the trend in crude oil prices since 1990. Prices since 2004 have been well above the levels from previous years. This price rise is consistent with a drop in private vehicle km travelled per person (see Figure 2-7). The price rise also correlates to a decrease in the fuel intensity of new cars, primarily as a result of people choosing smaller and more fuel economic types of new cars. This relationship between oil price and fuel intensity of new cars has also been documented by BITRE (6).

▪ **Figure 2-17 Crude oil prices**



Source: http://inflationdata.com/inflation/inflation_rate/historical_oil_prices_table.asp

3. Assumptions overview

The principal assumptions underlying this body of work are outlined in this section.

3.1. Data Sources

3.1.1. Fuel Use

All fuel use data is derived from ABARE fuel use estimates for the year 2008-09. As military fuel use is not typically included in NGGI calculations, military fuel use is deducted from general fuel use. DCCEE factors were used to bring back ABARE fuel use estimates to those that match general fuel usage conditions. These are shown in Table 3-1. Deductions for small marine craft, non recreational off-road vehicles and utility engines were transferred from road fuel use to other fuel use.

Table 3-1 DCCEE assumptions made about ABARE fuel consumption

	General use	Military	Small marine craft	Off-road vehicles	Utility engines
Road transport automotive gasoline	96.81%	0.06%	2.39%	0.1%	0.63%
Road transport ADO	99.5%	0.5%			
Water transport ADO	60%	40%			
Water transport fuel oil	99.95%	0.05%			
Air transport aviation gasoline	96.5%	3.5%			
Air transport aviation turbine fuel	92%	8%			

Source: Table 3.A.12, Australian National Greenhouse Accounts, National Inventory Report 2008

3.1.2. Emissions

Emissions were derived from NGGI emissions estimates for the year 2007/08. As these estimates are expected to undergo an increase in the 2008-09 report (as a result of retrospective changes to ABARE data for this year), these values were adjusted by the difference in emissions from ABARE fuel use in 2008/09 and 2007/08. It was assumed that the emissions increase would apply equally to all road sub sectors in relative terms.

3.1.3. Activity data

Vehicle kilometres travelled (VKT) data to 2008/09 was provided by BITRE. Passenger kilometres travelled (PKT) and tonne-kilometres for the road, air and sea sectors was also sourced from BITRE[3]. Relevant activity statistics for the rail sector were sourced from the Australian Railway Association (ARA).

3.2. General

The most significant drivers of transport sector activity are generally understood to include population, GDP (typically used as a measure of wealth) and oil prices. In this work, electricity price is also considered.

Electricity prices will be of increasing importance to the transport sector, in particular as hybrid technology gains momentum, as it has begun to do in Japan and the US[4]. In particular, it will be the price differential between electricity costs and oil based fuel costs that will drive choices between oil driven and electrically driven vehicle technologies in the future, as well as the relative price stability of each fuel type. In particular the price stability of oil may be adversely affected by the status of global fuel supply security.

Fuel price stability or the lack thereof, is extremely important to business, as fluctuations in business costs can severely undermine the profitability of any venture, especially those with fixed price contracts or limited ability to pass on the full extent of their costs to consumers. Stability in fuel prices is also important to private individuals, especially those who reside in areas of low public transport infrastructure. While the impact of potential price instability of each fuel type has not been modelled, it is a factor that is increasingly important and needs to be noted when reviewing results. Electricity prices are expected to be relatively stable in the future when compared with oil prices. Australia is fortunate in this regard as it has an abundant supply of both fossil and renewable fuel sources.

A summary of these assumptions is given in Table 3-2. Population and GDP have been provided by the Federal Treasury. It is evident that population and GDP are projected to grow, with population growth declining from around 1.5% p.a. in 2009/10 to 1.2% p.a. in 2029/30, and GDP growth declining from around 3.6% p.a. in 2009/10 to around 2.6% p.a. in 2029/30.

Oil prices have been provided by BITRE and are shown in Figure 2-3. Electricity prices are sourced from SKM MMA and are shown in Figure 3-2. Oil price growth in only the last 4 years has been significantly more variable than electricity price, with a range between -30% p.a. and 60% p.a. for oil relative to a range between -1% and 7% p.a. for electricity. Oil prices also continue to increase post 2020, although this growth declines slowly from 1.8% p.a. in 2021 down to 0.5% p.a.

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[3] Bureau of Infrastructure, Transport and Regional Economics, 2009, *Australian transport statistics yearbook 2009*, BITRE, Canberra ACT and Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2009, *Greenhouse gas emissions from Australian transport: projections to 2020*, Working paper 73, Canberra ACT

[4] Hybrids are estimated to make up over 10% of sales in Japan, and around 2.8% of sales inthe US. Hybrids can refer to either plug in forms (taking electricity from the grid) or forms employing regenerative braking. SKM MMA understands that the form employing regenerative braking is referred to here.

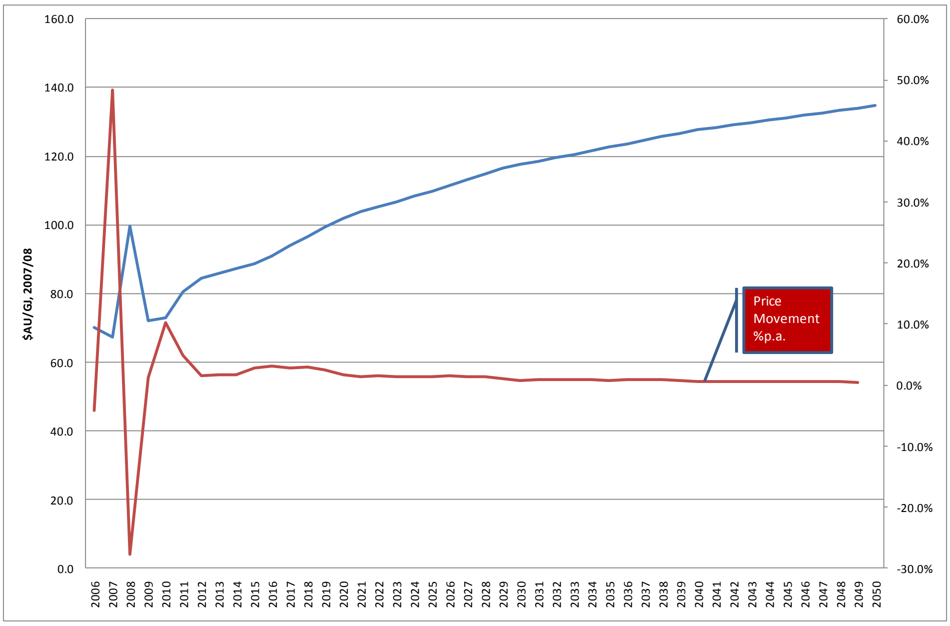
in 2050. Electricity prices by contrast remain relatively stable post 2020, with little to no growth beyond this time. Growth trends between 2012 and 2020 are broadly similar for both fuel sources.

Table 3-2 Summary of key assumptions

	Annual % change (1990-2000)	Annual % change (2000-2008)	Annual % change (2008-2020)	Annual % change (2020-2030)
GDP	3.4%	3.3%	3.2%	2.2%
Population	1.2%	1.5%	1.5%	1.0%
GDP/person	2.2%	1.8%	1.7%	1.1%
Oil Price	-1.1%	14.1%	0.2%	1.2%

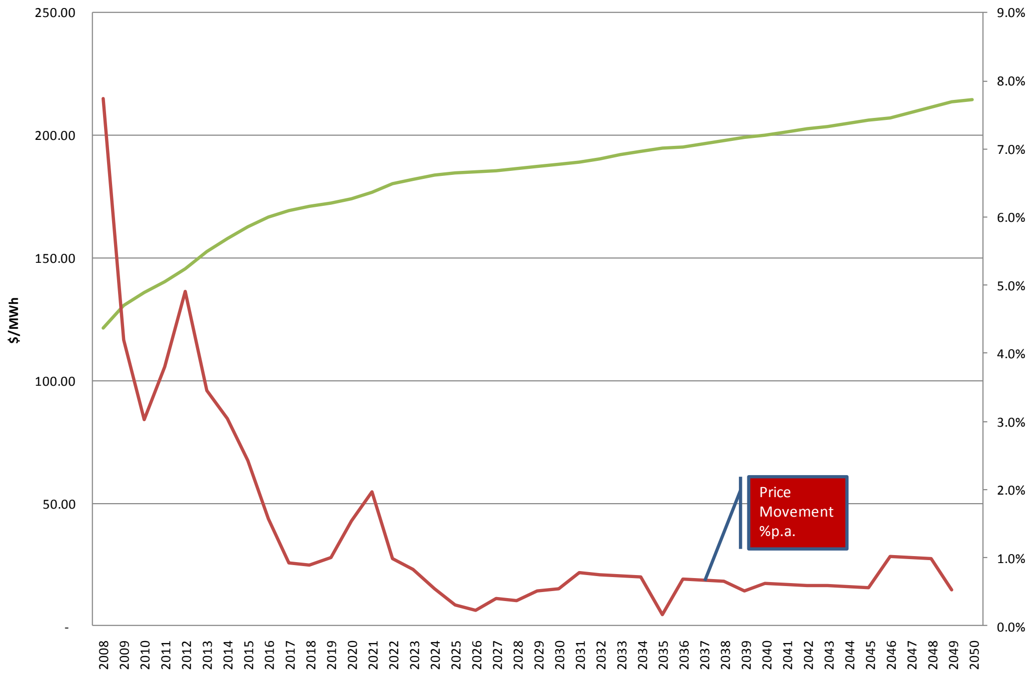
Source: SKM MMA analysis of oil prices consistent with the 2009 International Energy Agency (IEA) World Energy Outlook and GDP and population from the Treasury consistent with the Pre-Election Economic and Fiscal Outlook (PEFO) 2010 and Intergenerational Report (IGR) 2010.

Figure 3-1 Oil price projections



Source: 2009 International Energy Agency (IEA) World Energy Outlook

■ **Figure 3-2 Electricity price projections**



Source: SKM MMA analysis

For modelling associated with international air and sea travel trends, SKM MMA used world GDP projections based on Carnegie's policy outlook published April 2010[5]. Further detail regarding Carnegie's approach may be found in the appendix. The projections post 2009 are effectively a 3.9% p.a. growth in world GDP up to 2030, followed by a 3% p.a. growth in world GDP beyond this time to 2050.

3.3. Fuel Emissions Factors

Fuel emission factors are based on those provided in the Department of Climate Change's Factors and Methods Workbook. For convenience the appropriate table is replicated here – it is based on Table 4 from that document.

[5] Carnegie Policy Outlook: The World Order in 2050, April 2010, Uri Dadush and Bennett Stancil

Table 3-3 Fuel combustion emission factors – transport fuels

Fuel combusted		Energy content factor (GJ/kL unless otherwise indicated)	Emission factor kg CO_2e/GJ (relevant oxidation factors incorporated)			
			CO_2	CH_4	N_2O	Sum
General transport						
Gasoline (other than for use as fuel in an aircraft)		34.2	66.7	0.6	2.3	69.6
Diesel oil		38.6	69.2	0.2	0.5	69.9
Gasoline for use as fuel in an aircraft		33.1	66.3	0.04	0.7	67.0
Kerosene for use as fuel in an aircraft		36.8	68.9	0.01	0.7	69.6
Fuel oil		39.7	72.9	0.06	0.6	73.6
Liquefied petroleum gas		26.2	59.6	0.6	0.6	60.8
Biodiesel		34.6	0	1.2	2.2	3.4
Ethanol for use as fuel in an internal combustion engine		23.4	0	1.2	2.2	3.4
Compressed Natural Gas		39.3×10^{-3} GJ/m^3	51.2	5.5	0.3	57.0
Post-2004 vehicles						
Gasoline (other than for use as fuel in an aircraft)		34.2	66.7	0.02	0.2	66.9
Diesel oil		38.6	69.2	0.01	0.6	69.8
Liquefied petroleum gas		26.2	59.6	0.3	0.3	60.2
Ethanol for use as fuel in an internal combustion engine		23.4	0	0.2	0.2	0.4
Heavy vehicles conforming to Euro design standards						
Euro iv	Diesel oil	38.6	69.2	0.05	0.5	69.8
Euro iii	Diesel oil	38.6	69.2	0.1	0.5	69.8
Euro i	Diesel oil	38.6	69.2	0.2	0.5	69.9
Liquefied natural gas (extract from Table 2)		25.3	51.2	0.1	0.03	51.3
Black coal (used in shipping and rail, extract from Table 1)		27	88.2	0.03	0.2	88.4

Source: National Greenhouse and Energy Reporting (Measurement) Determination 2008 (Tables 1,2 and 4)
Note: All emission factors incorporate relevant oxidation factors (sourced from the DCC's National Inventory Report).

4. Activity and Task Projections

The assumptions appendix describes how activity projections were obtained in further detail. For convenience a summary is presented here.

4.1. Private road and rail travel

For each mode of passenger travel, activity per person will be determined by projecting travel under each mode using GDP/person, using a logistic function. Further detail may be found in the appendix. Summarised projections are shown in Table 4-1 and Table 4-2 below. Softer growth in travel projections post 2020 are consistent with softer growth in GDP during the same period, and may also indicate some response to higher oil prices.

- **Table 4-1 Projections of non freight road VKT**

	Projections of passenger vehicle VKT (billions)					% change, annualised			
Year	1990	2008	2020	2030	2050	1990-2008	2008-2020	2020-2030	2030-2050
Cars	124.0	165.9	207.0	234.6	289.4	1.63%	1.86%	1.26%	1.05%
Motorcycles	1.8	2.3	2.7	3.0	3.7	1.34%	1.27%	1.25%	1.05%
Buses	1.5	2.0	2.6	3.0	3.7	1.51%	2.10%	1.36%	1.08%

Source: SKM MMA analysis

- **Table 4-2 Projections of non freight rail PKT**

	Projections of passenger rail PKT (billions)					% change, annualised			
Year	1990	2008	2020	2030	2050	1990-2008	2008-2020	2020-2030	2030-2050
Urban Heavy	6.3	9.0	10.7	12.1	14.9	1.97%	1.45%	1.25%	1.05%
Non urban Heavy	1.7	2.1	2.5	2.9	3.5	1.32%	1.45%	1.25%	1.05%
Urban Light	0.5	0.6	0.7	0.8	1.0	1.32%	1.45%	1.25%	1.05%

Source: SKM MMA analysis

4.2. Domestic freight

4.2.1. Task projections

Historically, domestic freight has grown in proportion with growth in GDP, making it a simple task to project total domestic freight. In this sense, GDP serves as a proxy for the tonnage of goods transported, and the model therefore assumes that distances travelled for each tonne will not change substantially relative to the past. It is assumed that the projections of domestic freight task are therefore only limited by the capacity of the freight transport network to enable delivery of goods. As existing networks strain to meet additional demand, there are a number of possible outcomes.

These include: expanding existing systems (i.e., with new rail/trucks/ships, rail lines, roads and ports); increasing transport productivity (i.e., larger vehicles, better logistical planning, or reducing demand for just-in-time inventory management); reducing distances from production sites to consumers; and reducing production (and hence GDP). Of these options, SKM MMA consider the last to be the least likely, while the first two options will impact on efficiency but will not impact freight task levels. Reducing travel distances is also very limited as an approach to reduce tonne-kilometres, and may only apply to a small number of new and existing industries that have the flexibility to locate production near to consumers. Therefore, SKM MMA consider it unnecessary to dampen the projections of domestic freight tonne-kilometres.

The main modes for domestic freight are road, rail and sea. A small amount of non-bulk freight is transported by air, and the amount of freight travelling this way is limited by the substantially higher cost of air transport[6]. This freight largely consists of items requiring speedy delivery to avoid spoilage, such as food items (although some parcel component is also included). Hence this form of freight is not truly competitive with road, rail and sea freight, and is therefore not included in the current analysis. SKM MMA understand that air freight typically accompanies passenger travel, although some may be included in the very small category of air travel called general air travel[7]. Therefore, SKM MMA have chosen not to model air freight specifically. Road freight delivered by rigid trucks was also excluded from analysis because the share of freight is relatively small in comparison with better organised fleet and was considered to be less competitive with rail and sea modes.

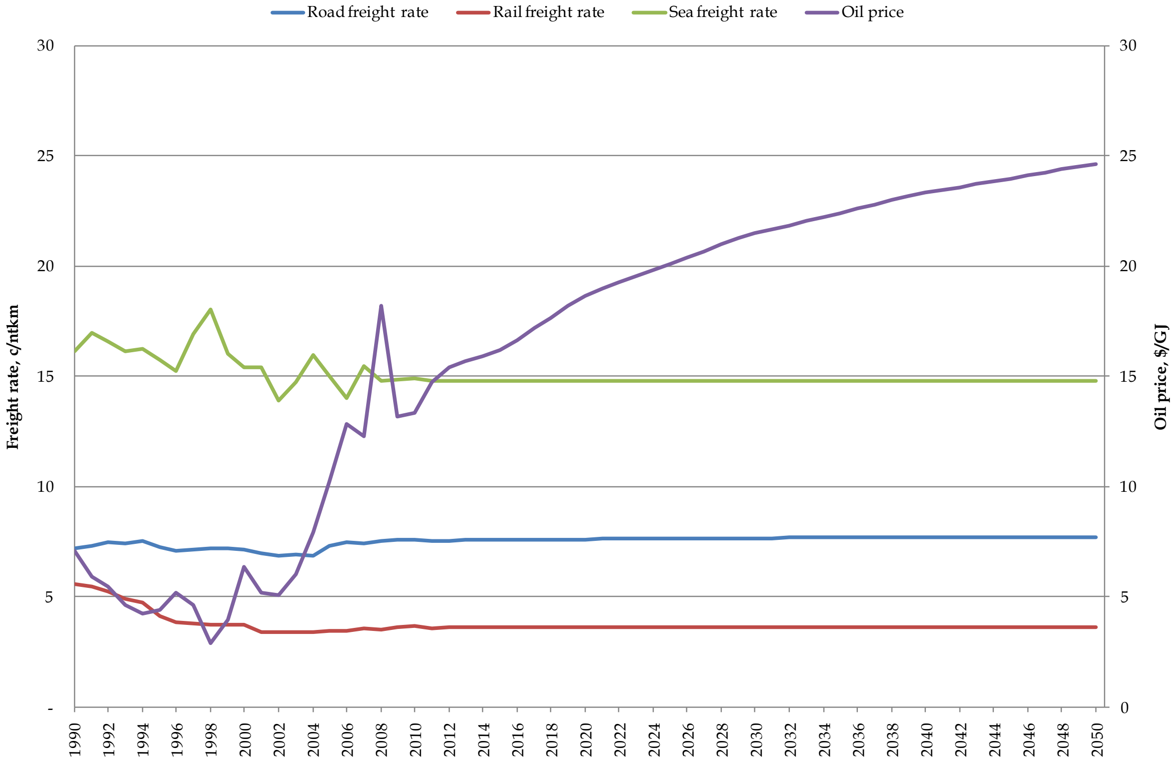
Mode shares for road, rail and sea have been determined using a multinomial logit model, with freight rates and infrastructure investment used as the independent variables. This type of model simultaneously estimates shares subject to the limitation that the sum of all shares must add to 1.

Projections of freight rates are based on oil price projections, and the projection of each mode's freight rate is dependent on the fuel intensity of that mode, which is in turn dependent on productivity improvements in the mode. Figure 4-1 shows the freight rate projection based on the assumption that productivity improvements continue as in the past. The freight rates for rail and sea are essentially constant, due to the relatively low fuel intensity of these modes.

6 Air is often a mode of transport for higher value goods. Should the expected value of transported goods substantially increase, air will become more important as a transport mode. SKM MMA currently have no evidence that the value of goods has increased substantially and therefore has not investigated this further.

7 While a limited number of aircraft may be dedicated to freight, a purely freight service carries high risk for airlines in times of poor economic prosperity (due to the link with GDP). The presence of freight improves a carrier's financial risk profile when that freight accompanies passenger travel (since passenger travel can also be driven by marketing programs).

Figure 4-1 SKM MMA freight rate projections

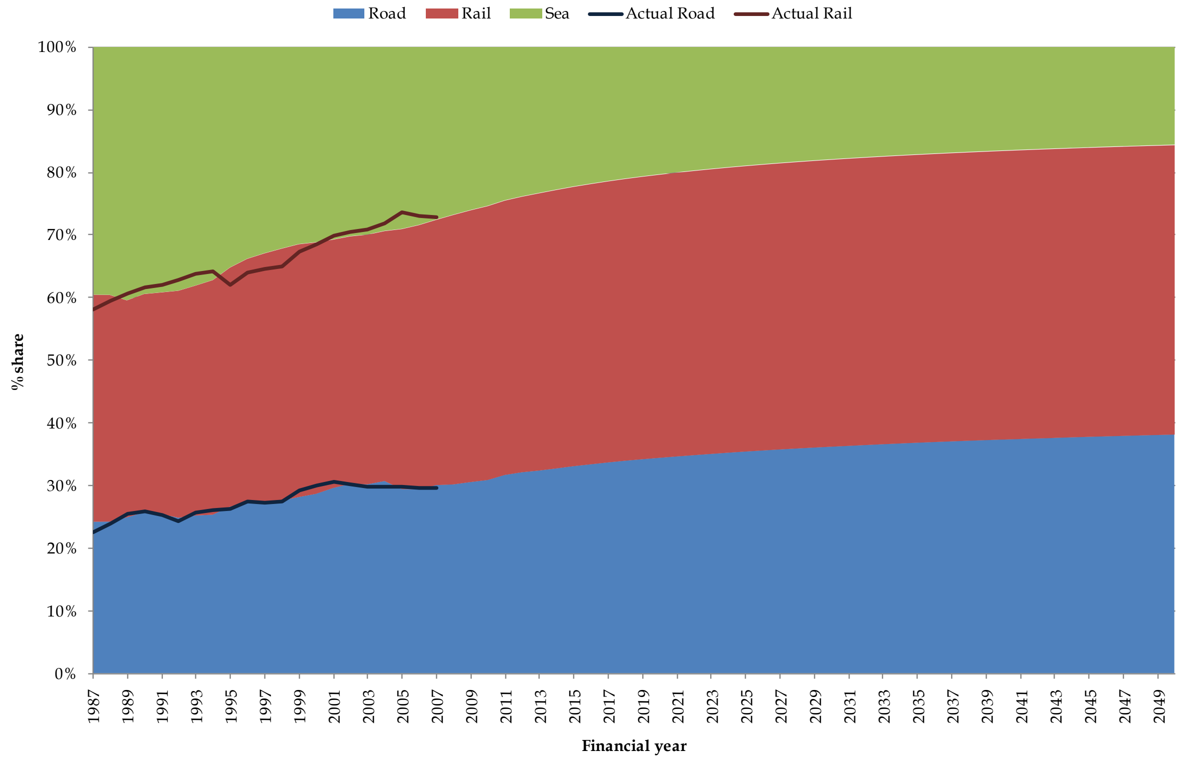


Source: SKM MMA analysis

Infrastructure investment was also used as an independent variable, because it determines the extent to which road transport offers an advantage over other modes in flexibility and location. Road is the most flexible of all three modes: vehicles are able to cover short and long haul distances, they can be flexibly scheduled with low impact to other services, they can reach areas that other modes cannot reach, and road vehicles are often required to be used in conjunction with other modes (for example, to carry goods to a port or railway station). Also, for some expensive goods, the relative expense of road relative to other modes is negligible compared to the value of the items being transported, so road will always be the mode of choice for some forms of freight transport. The value of road as a mode of transport is therefore a reflection of the infrastructure investment that has been made in the past. Forward projections were made assuming that current levels of investment will be maintained.

Derived mode shares are shown in Figure 4-2, with actual mode shares imposed on the chart for comparison. Projected mode shares reveal that oil price impacts will have a minimal impact on road share, primarily because of the greater flexibility of road transport. There is expected to be an increase in the rail mode share however.

■ **Figure 4-2 Domestic freight mode share projections[8]**



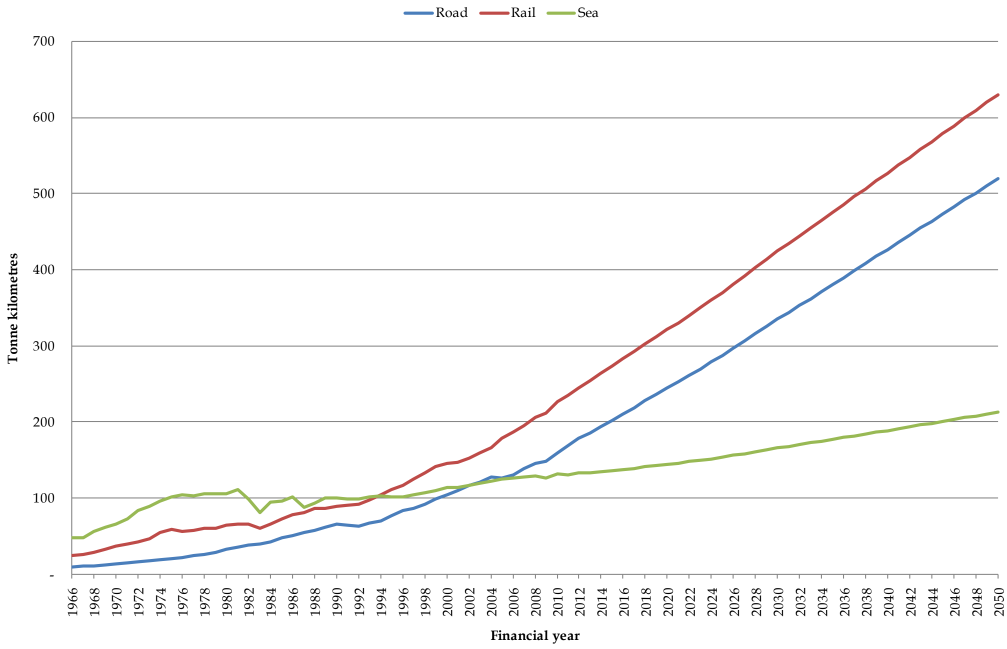
Source: SKM MMA analysis

4.2.2. Domestic freight tonne-kilometres by mode (road, rail and sea)

Multiplying the mode share by the domestic freight tonne-kilometres projection provides a projection of activity for each mode. The overall projection of activity in terms of tonne-kilometres shows a quite dramatic increase in tonne-kilometres travelled, and this trend is evident in all modes; see Figure 4-3 through to Figure 4-6. Figure 4-6 also includes projections of tonne-kilometres for LCVs and rigid trucks, which have been obtained by projecting data with GDP.

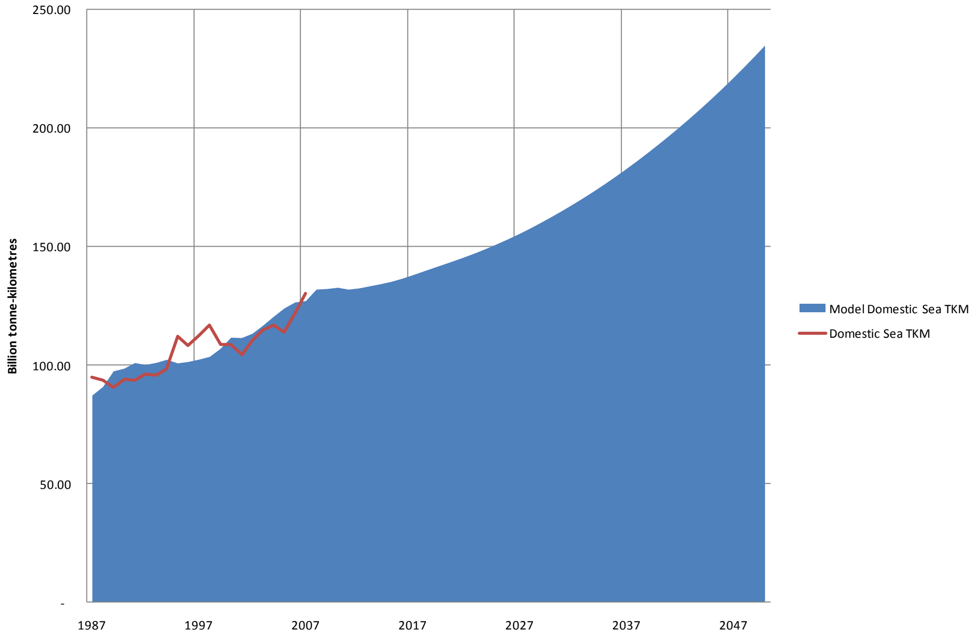
8 Excludes LCVs, rigid trucks and air transport.

Figure 4-3 Projection of domestic freight activity



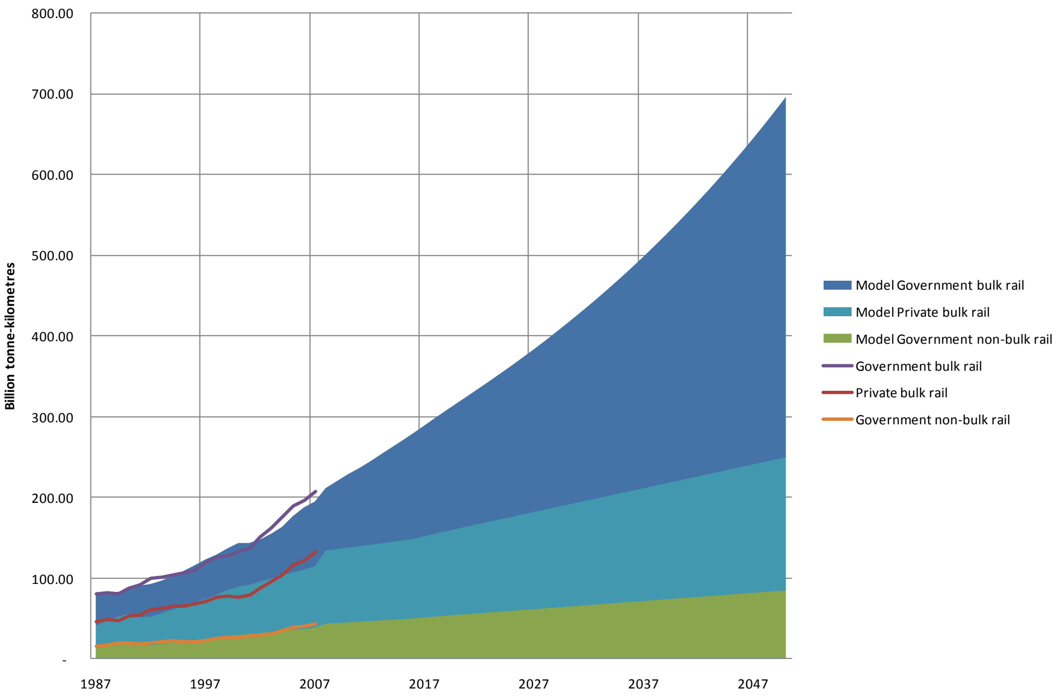
Source: SKM MMA analysis

Figure 4-4 Projection of sea freight activity



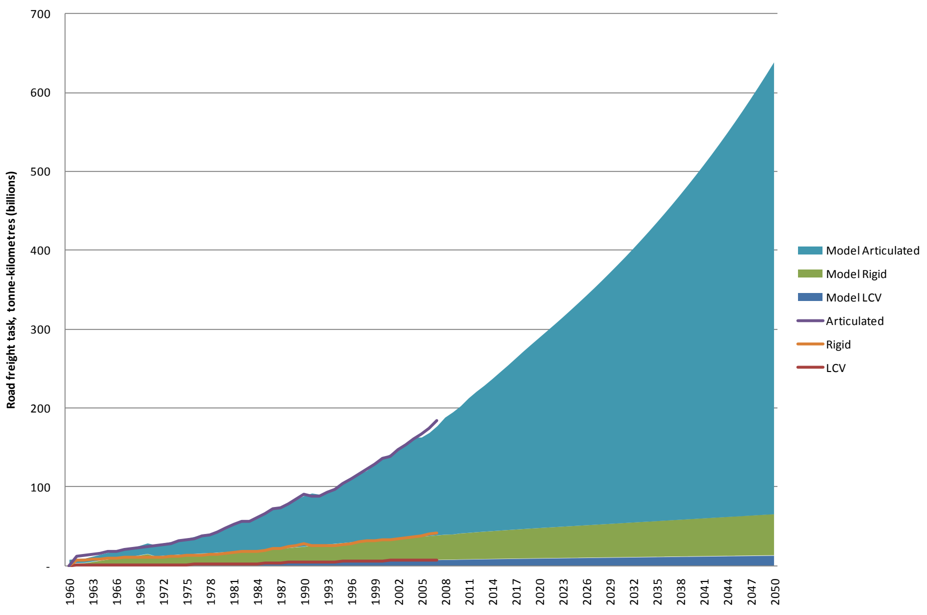
Source: SKM MMA analysis

■ Figure 4-5 Rail tonne-kilometres



Source: SKM MMA analysis

■ Figure 4-6 Road tonne-kilometres



Source: SKM MMA analysis

4.2.3. Road freight VKT

Road freight emissions are modelled against vehicle kilometres travelled (VKT) rather than tonne-kilometres, because vehicle fuel efficiency is expressed in terms of litres per 100 kilometres, rather than on a tonne-kilometre basis.

For rigid trucks, SKM MMA have opted to model VKT against GDP, as this sector of the road freight industry has been relatively stable with regard to the way that freight is transported.

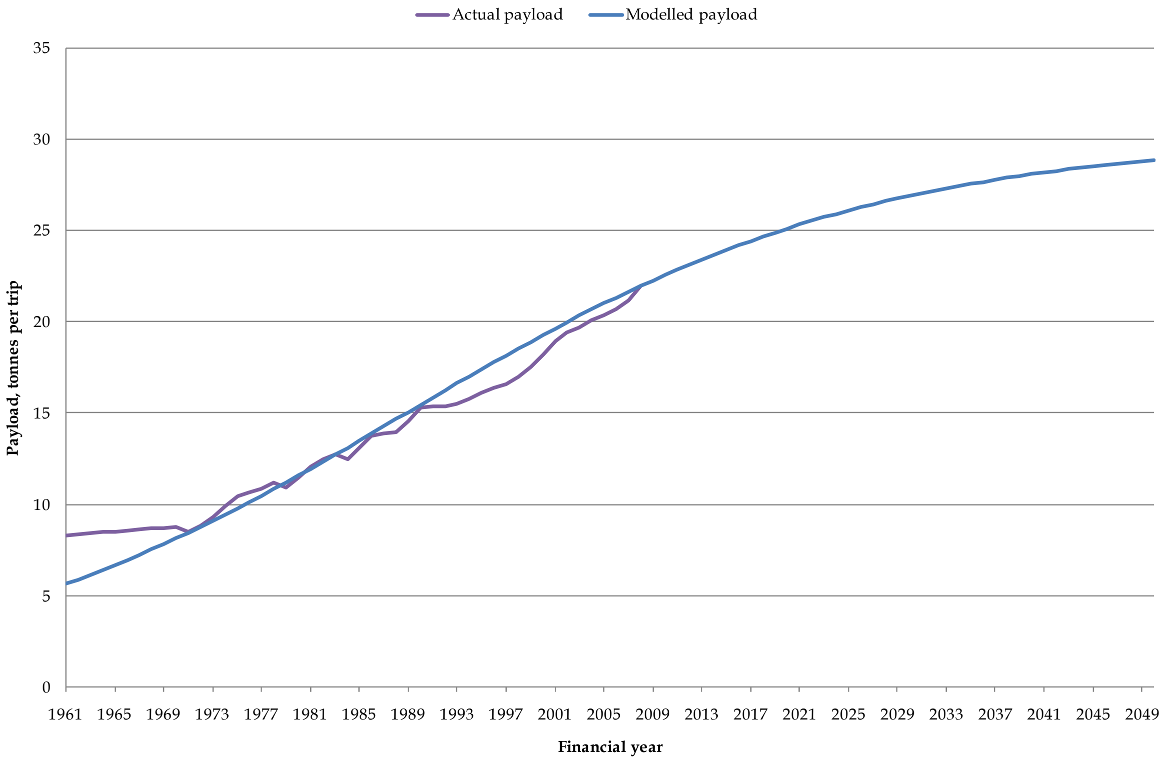
For light commercial vehicles, modelling VKT against GDP is also possible, though the period before 1971 shows a very different relationship of VKT with GDP than the period after 1971. If these early years are included in the model, then GDP alone does not adequately predict recent years of LCV VKT. This is probably because the modelling fails to capture relatively recent changes to production and warehouse logistical planning, which favour just-in-time methods. The popularity of just-in-time methods has also had the effect of increasing the proportion of larger light commercial vehicles in the light commercial fleet. SKM MMA therefore exclude these early years in the LCV VKT modelling in order to capture the effect of just-in-time methods in the projections.

Modelling VKT of articulated trucks could also be done using GDP, but this would ignore the effect of the operational efficiency improvements that have occurred, and would assume that these improvements could be sustained in the future. For example, some of the operational efficiency improvements have come about as a result of upsizing the fleet, typically to B-doubles, and in some cases to B-triples, road trains and to larger performance-based-standards-aligned vehicles. The fuel efficiency on a tonne-kilometre basis is better for these vehicles than for the standard articulated vehicle, and freight companies may also save on labour costs. B-doubles and B-triples require a road system built to a specific standard, partly to avoid the vehicles damaging the roads, and partly to ensure safety of all vehicles using those roads. This means that these vehicles will typically have more restricted routes than other types of articulated trucks, and therefore uptake of these vehicles may reach an upper limit at some time in the future. Another means of attaining improved operational efficiency is logistic improvements. For example, trucks reaching their destination could conceivably carry some form of alternative freight back to a depot to minimise the proportion of un-laden vehicles on the road. The increasing concentration of freight-intense regions (for example, Altona North in Melbourne and Kewdale-Forrestfield in Perth) and “freight villages” (for example, Somerton and Minto intermodal terminals in Melbourne and Sydney respectively) provide evidence that this could occur to a greater extent than at present, which could reduce VKT on the roads without reducing the tonne-kilometre task levels.

To address the issue of changing operational efficiency, SKM MMA have assumed that an upper limit exists on efficiency improvement. Efficiency is measured in terms of average payload, that is, the ratio of tonne-kilometres to vehicle kilometres travelled. Figure 4-7 shows the projection of average payload. The increase over time reflects the steadily increasing tonnage being carried in this road sector. Rather than assuming this increase will continue indefinitely, SKM MMA have opted to apply an upper limit. The projections therefore assume that some productivity increases will continue to occur but these will be capped.

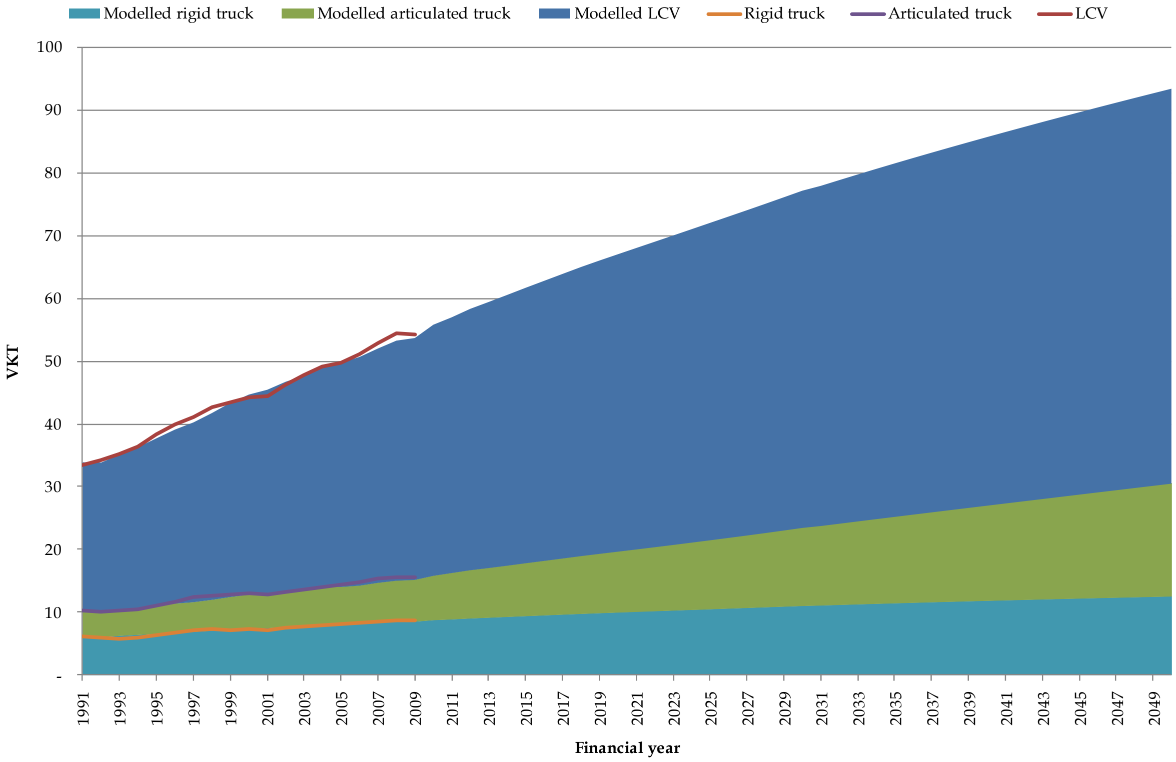
The SKM MMA estimate of VKT for articulated trucks is obtained by taking the ratio of tonne-kilometres and average payload. A review of all VKT task estimates can be seen in Figure 4-8, with actual data superimposed on the area chart as a line.

Figure 4-7 Average payload for road freight vehicles



Source: SKM MMA analysis

Figure 4-8 VKT projections of road freight vehicles



Source: SKM MMA analysis

4.3. Vehicle Stock

4.3.1. Private vehicles per person

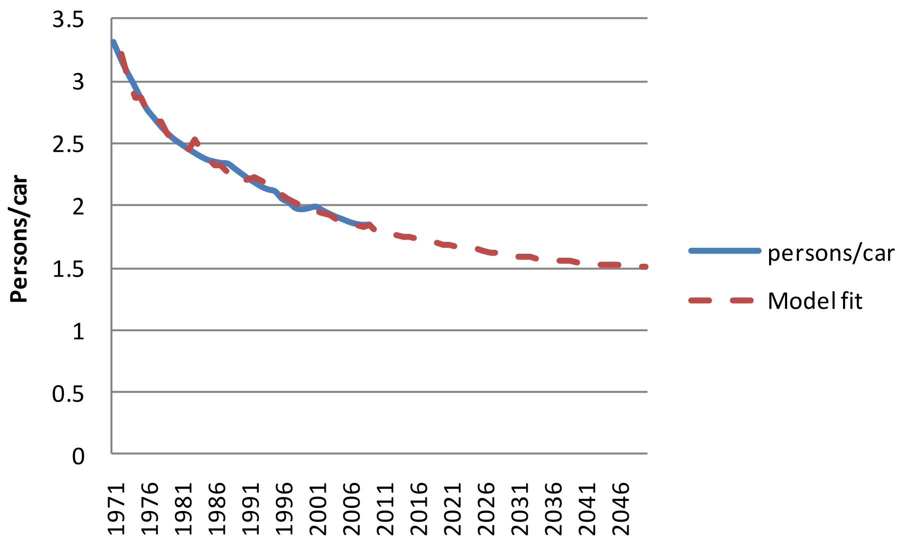
The number of cars per person is projected using GDP/person and oil price as the drivers. This model is used for the business as usual and baseline scenarios, and the results are shown in Figure 4-9. The predicted slowing of the decrease in persons per car reflects the near-saturation levels of car ownership in Australia. In some scenarios car ownership may be less strongly related to oil price than it is currently (for example, where there is a high penetration of electric vehicles), and in such cases care should be taken in deriving vehicle ownership figures.

The vehicles per person relationship allows us to forecast the total stock of vehicles, and this latter forecast, when combined with the vehicle attrition model, allows us to predict new vehicle sales.

4.3.2. Motorcycles per person

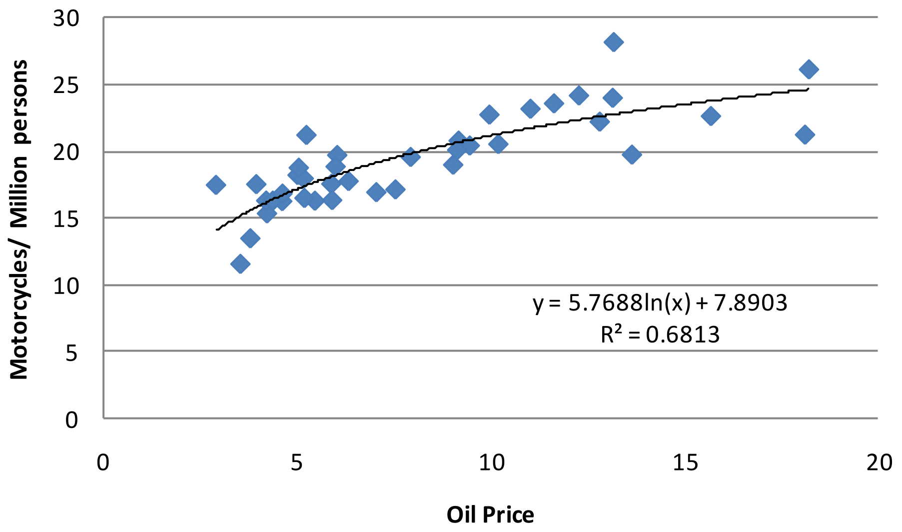
Sales of motorcycles have been increasing steadily for over ten years, and the number of motorcycles appears to be more dependent on oil price than GDP, most likely because they are an option taken either for leisure, or for cost saving when oil prices are high. Figure 4-10 shows the correlation between oil price and motorcycle ownership.

- **Figure 4-9 Vehicles per person**



Source: SKM MMA analysis

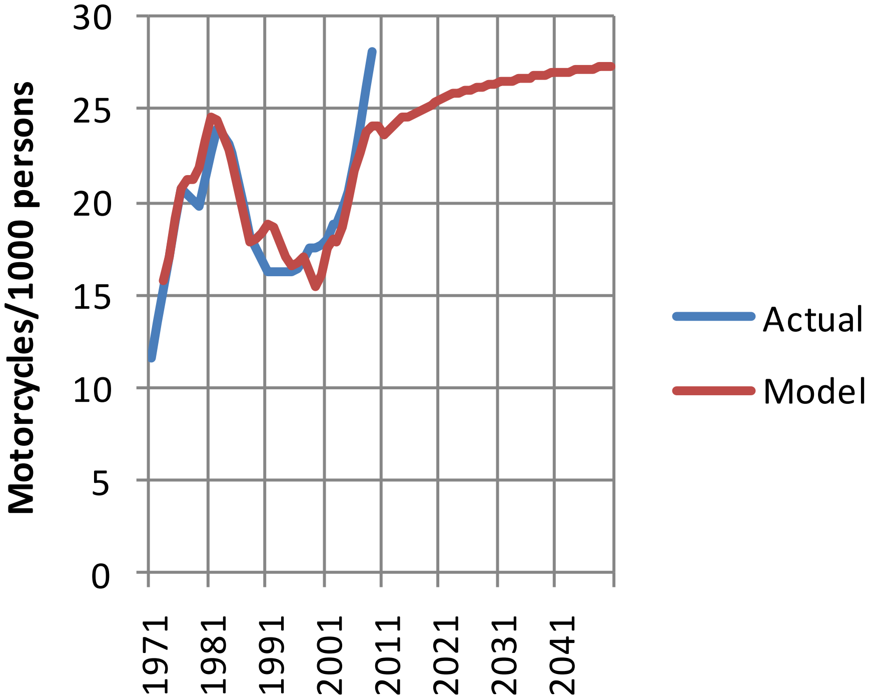
- **Figure 4-10 Motorcycles per thousand persons**



Source: SKM MMA analysis

Further analysis revealed that motorcycle registrations appear to depend on oil prices over the previous 3 years, and this relationship was used to project motorcycle registrations.

- **Figure 4-11 Motorcycles per thousand persons**



Source: SKM MMA analysis

4.4. Stock of buses and freight vehicles

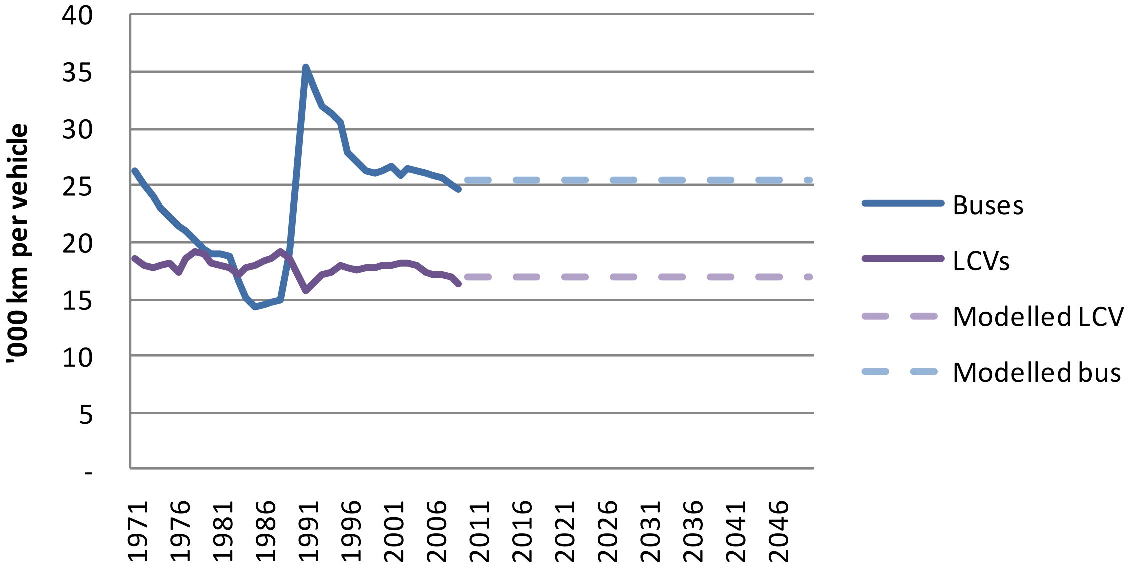
Freight vehicles and buses are less sensitive to discretionary demand than private vehicles. It is therefore sensible to project the stocks of these vehicles from total VKT, after dividing by average VKT/vehicle. Average VKT/vehicle can be projected using historical trends. From Figure 4-12 through to Figure 4-14, it can be seen that vehicles have gradually been worked harder over time in most cases, reflecting the capital expense associated with each vehicle. Also, in most cases, this effect appears to be levelling out. This analysis implies that the lifetimes of buses and freight vehicles may become shorter than they have been the case previously, because vehicles will wear out faster if they are used more heavily.

For the purpose of the current study, SKM MMA has used an average of the last 5 years' values to project VKT/vehicle, except in the case of articulated vehicles. In this case, a projection was applied based on trend.

Once an estimate of VKT/vehicle is available, it is a straightforward matter to calculate total vehicle stocks from VKT estimates. These results are shown in Figure 4-15, Figure 4-16 and Figure 4-17.

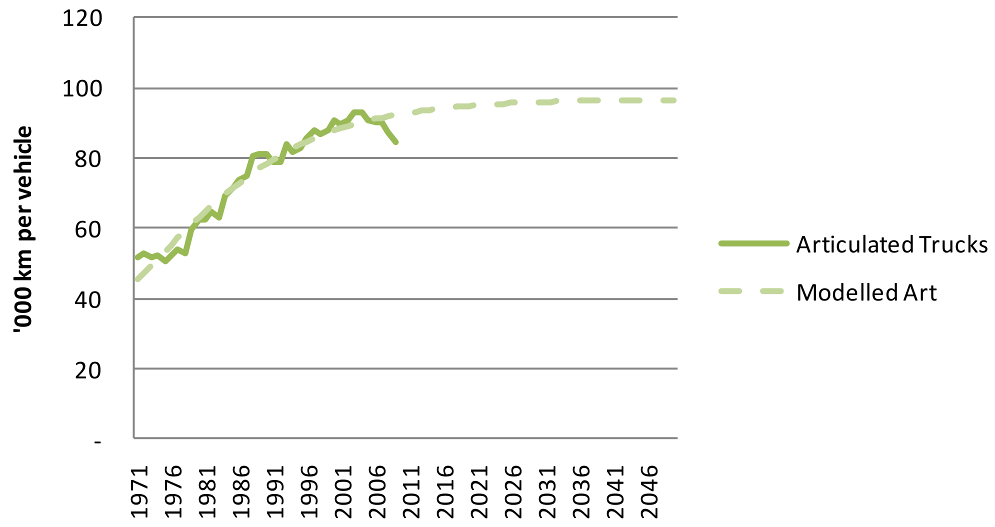
Advice from industry experts within SKM indicates that this is a sound approach, but query the low average VKT estimates that apply to articulated trucks. There are two possible explanations for this, including overstated fleet (because a large proportion are primary producer vehicles that are not used very much) or understated mileage estimates, which could be caused by a variety of reasons. For the current analysis SKM MMA had to adjust vehicle lifetime parameters to derive results that allowed for a closer fit to historical emissions data. The articulated vehicle average kilometres shown in this report will therefore not adequately represent real life.

- **Figure 4-12 Average VKT/vehicle, buses and light commercial vehicles**



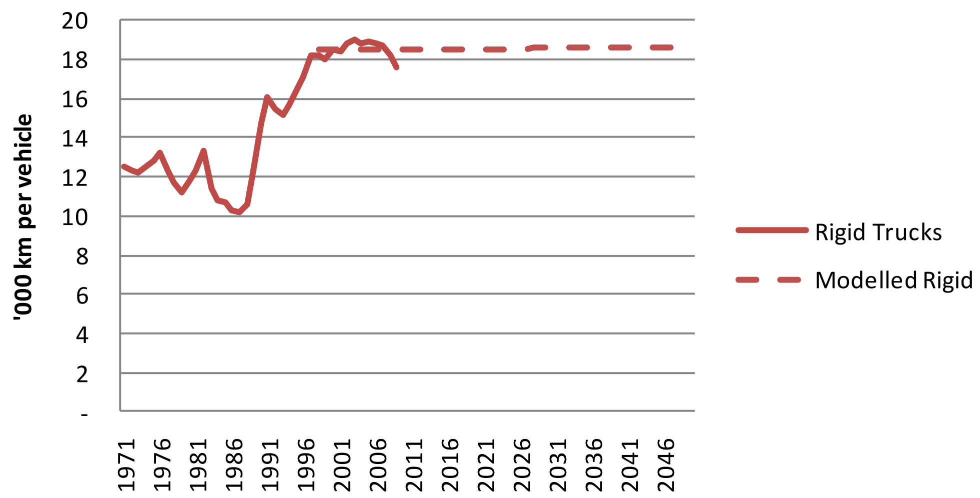
Source: SKM MMA analysis

■ **Figure 4-13 Average VKT/vehicle, articulated trucks**



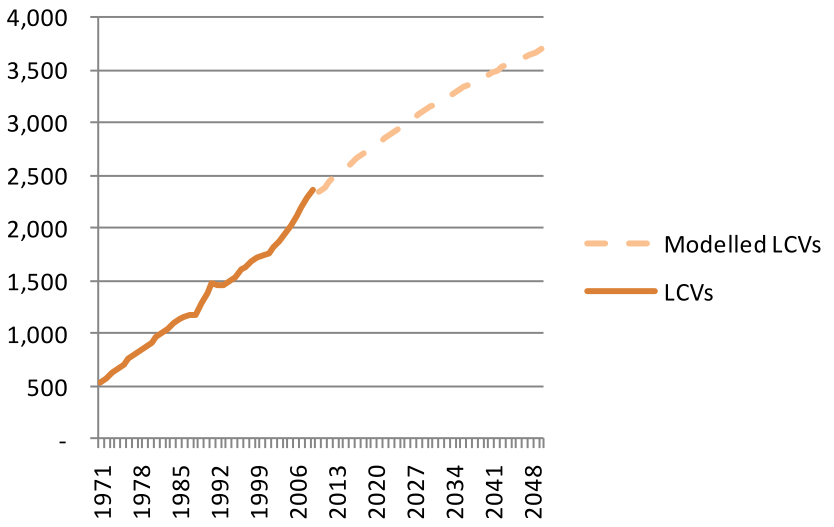
Source: SKM MMA analysis

■ **Figure 4-14 Average VKT/vehicle, rigid trucks**



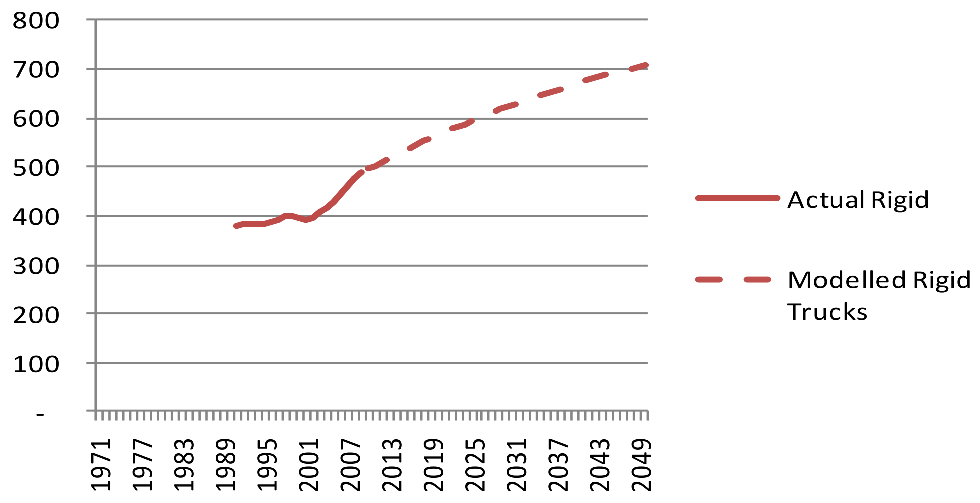
Source: SKM MMA analysis

- **Figure 4-15 Light commercial vehicle stock projections ('000s)**



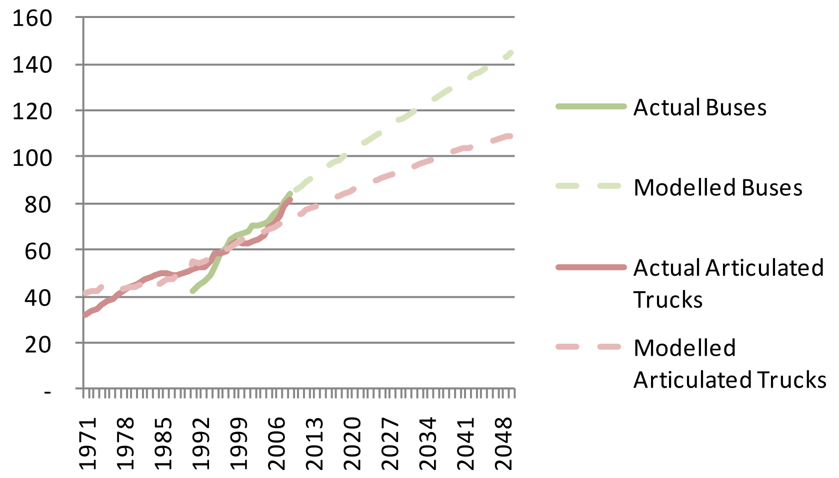
Source: SKM MMA analysis

- **Figure 4-16 Rigid truck stock projections ('000s)**



Source: SKM MMA analysis

▪ **Figure 4-17 Bus and articulated truck stock projections ('000s)**



Source: SKM MMA analysis

4.5. Air travel

4.5.1. International air travel

International air travel emissions are calculated from first projecting seat numbers and then multiplying this by fuel intensity projections[9].

Projections of seat flights are determined from first projecting passenger flights and then applying an estimate of load factor. Historically, load factors have been increasing for both the international and domestic air travel markets, implying that planes are more fully loaded; that is, the ratio of total flights to total passengers is decreasing. Load factors have been assumed to depend on oil prices, as the aviation industry will continue to push operational efficiency even further as fuel prices rise. See Figure 4-18, which also shows the load factor projections using this method.

Passenger numbers, and consequently seat numbers, are projected forward using world GDP; see Figure 4-19.

Historical fuel intensity per seat is shown in Figure 4-20, including the SKM MMA projection to 2050. Note that historically there has been a decline in fuel use per passenger over time. This may be due to passengers making shorter trips, or it may be due to improvements in aircraft efficiency. With current data SKM MMA are unable to verify whether the projections are feasible, if only because it is not possible to identify changes in travel patterns.

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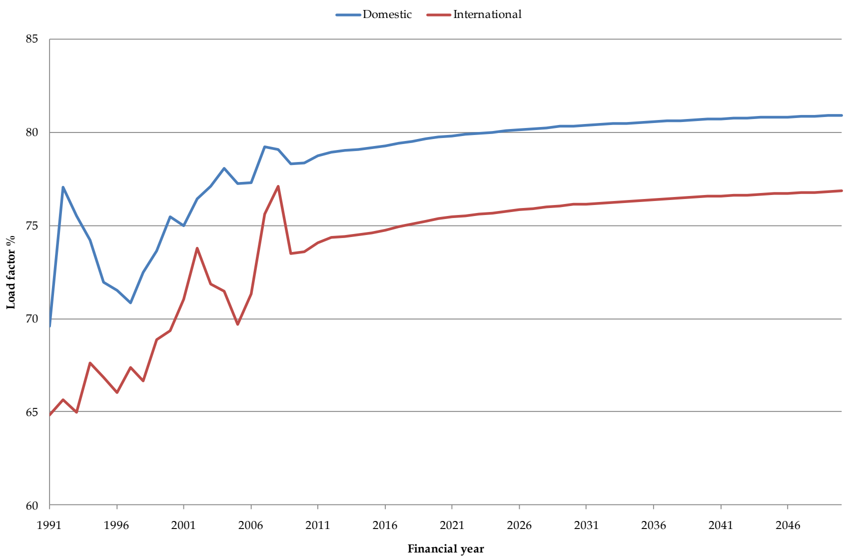
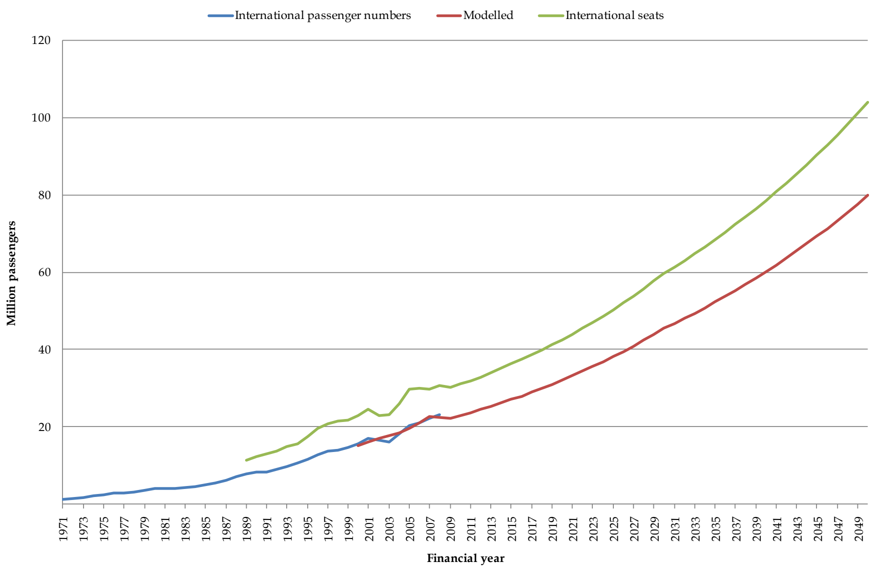
[9] SKM MMA are unable to find estimates of historical passenger-km or historical seat-km for the international aviation sector in the available literature.

- **Figure 4-18 Load factor projections – international and domestic air travel**



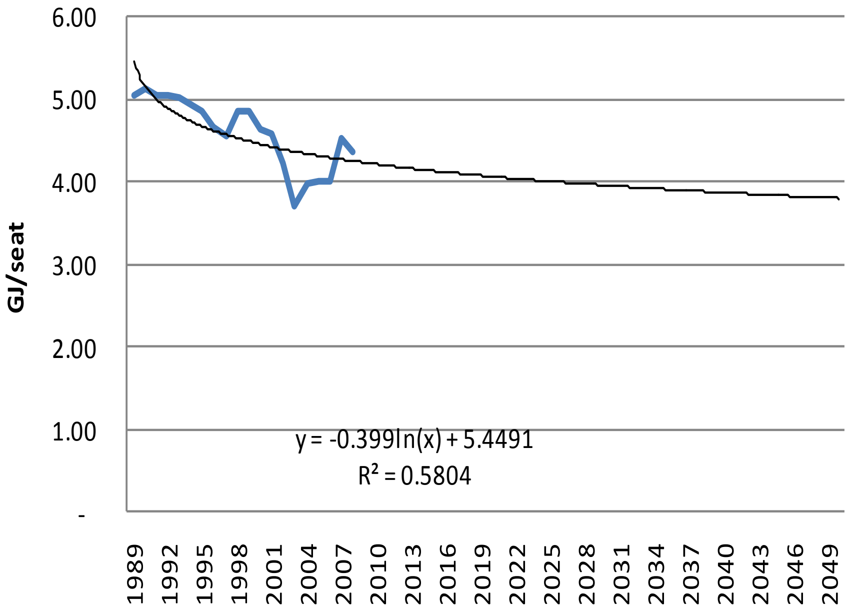
Source: SKM MMA analysis

- **Figure 4-19 International air passenger and seat projections**



Source: SKM MMA analysis

Figure 4-20 International air fuel intensity projections



Source: SKM MMA analysis

4.5.2. Domestic air travel

The standard approach for projecting air travel emissions is to estimate fuel use per seat kilometre and apply that to a projection of seat kilometres. The projection of seat kilometres is in turn derived from historical data on to load factors and revenue kilometres.

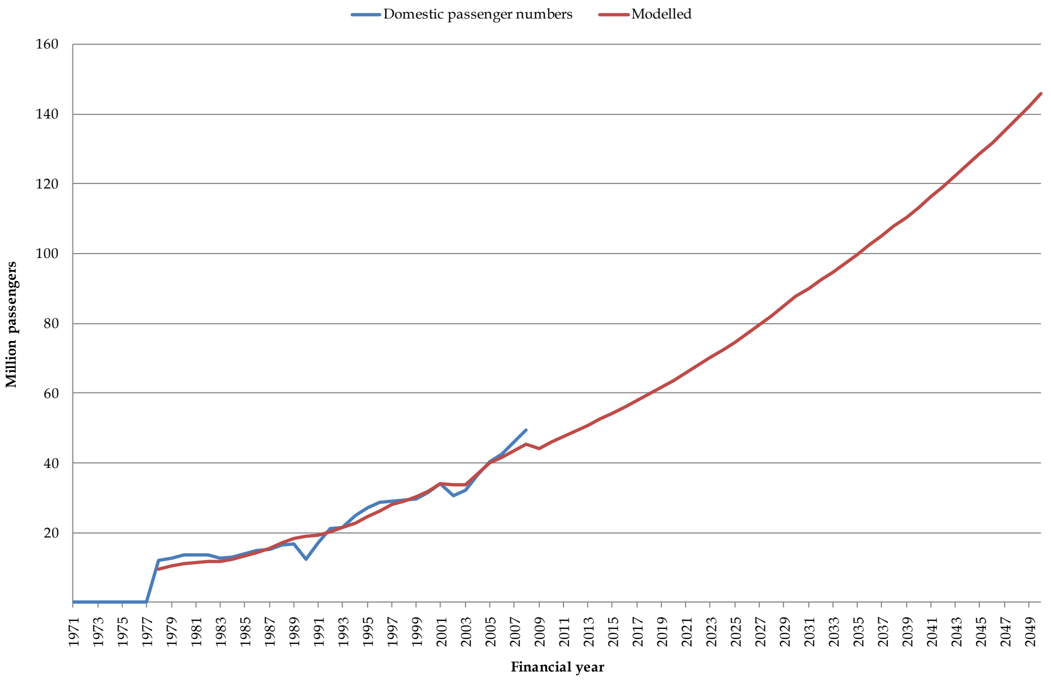
The implication of this approach is that emissions projections are dependent on passenger travel forecasts, both in terms of numbers and in terms of average distances travelled.

In terms of passenger numbers, domestic air travel can be split into two categories; domestic travel of passengers from one Australian region to another, and domestic air travel arising from passengers connecting to international services. It is important to distinguish the two because they are caused by different drivers: Australian wealth or international wealth, respectively. For this modelling SKM MMA use Australian GDP and world GDP as measures of wealth.

SKM MMA understands that BITRE's approach to modelling of domestic air travel activity depends mostly on being able to estimate the split between these two components of domestic air travel. This approach appears to be sound. However, it was infeasible for SKM MMA to attempt to estimate the split between components, because to do so would require data that is not publicly available. Moreover, the analysis would probably be extremely detailed and therefore not practicable in the project time frame. SKM MMA's approach is therefore to use international passenger numbers as a predictive variable in the estimation of private passenger numbers, in conjunction with GDP. The results are shown in Figure 4-21. Private passenger numbers were used to estimate private passenger kilometres after review of travel distances, which are shown in Figure 4-22. From the chart it is evident that passenger distances have been steadily increasing. An analysis of trips from the year ending December 2008 to the year ending December 2009 revealed that the cities which showed the highest increases in trips included Perth, Karratha, Newman, and various parts of Queensland. It would appear therefore that the increase in air travel distances may be an effect of the mining boom, where towns are usually a long way from major cities. SKM MMA have therefore used GDP/person and oil price as independent variables for this exercise. From each of these a projection of revenue passenger kilometres can be derived, from which an estimate of seat kilometres may be derived.

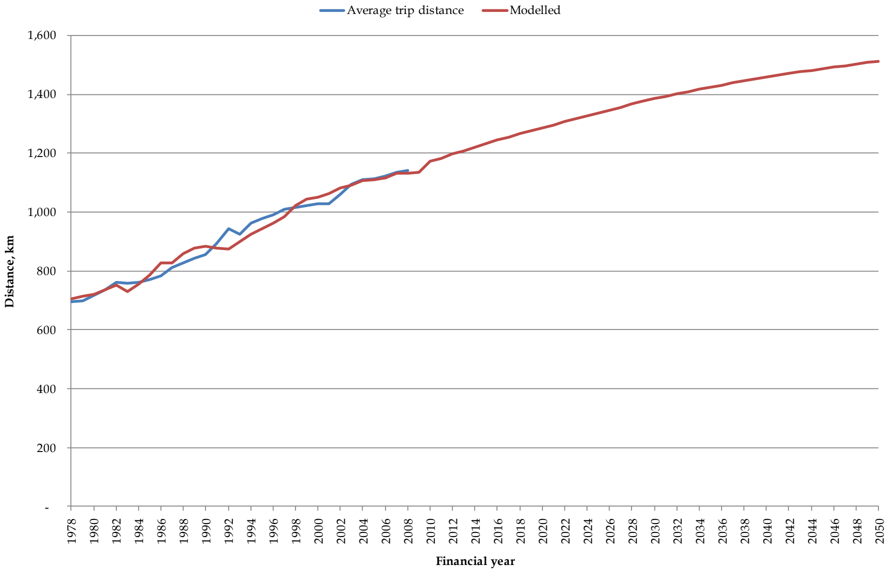
Figure 4-23 shows fuel intensity based on historical data as well as a possible trend that could be used to create a forecast.

- **Figure 4-21 Projected private passenger numbers**



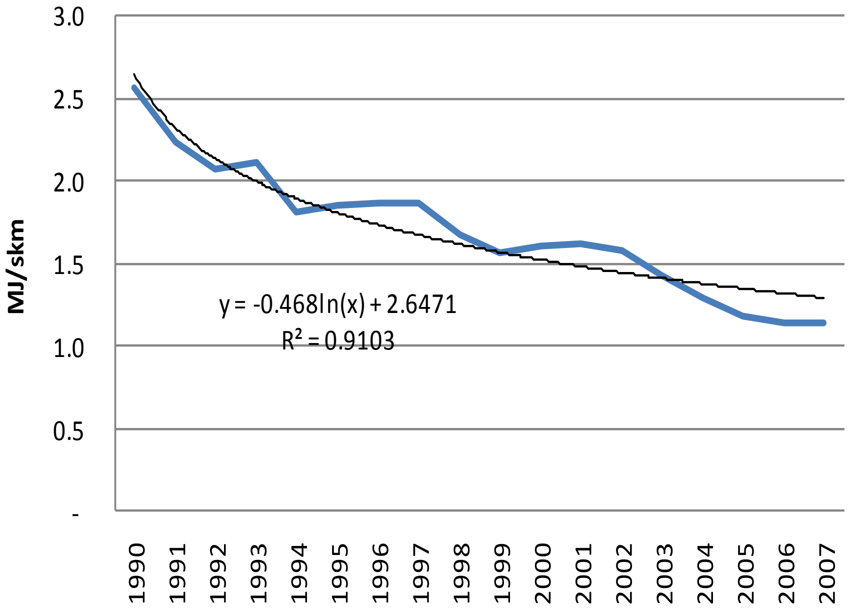
Source: SKM MMA analysis

Figure 4-22 Projected average travel distances



Source: SKM MMA analysis

Figure 4-23 Historical fuel intensity



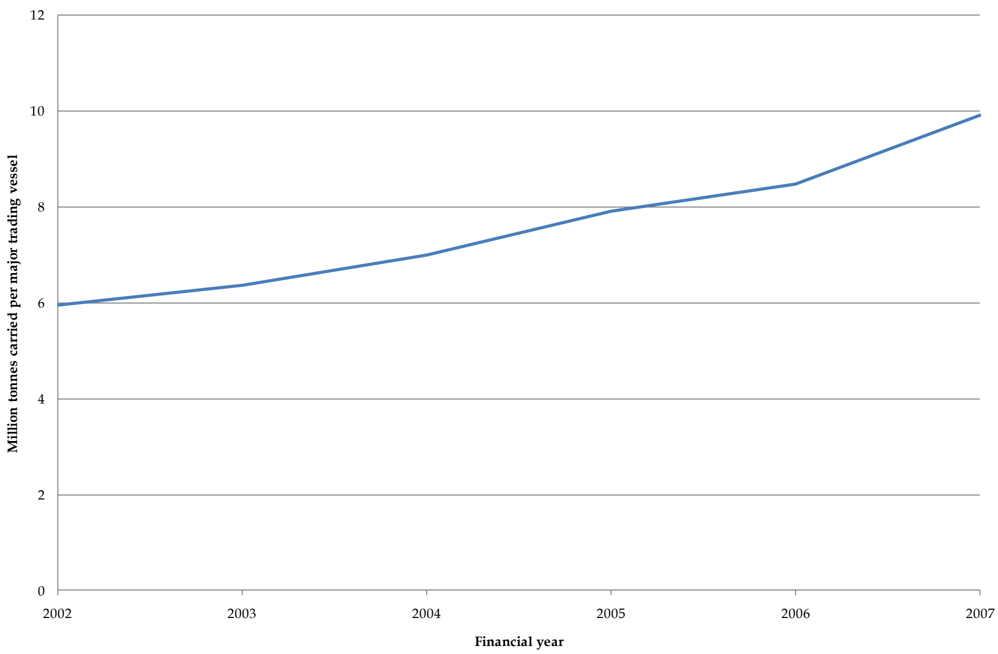
Source: SKM MMA analysis

4.6. International sea travel

SKM MMA were unable to find estimates of tonne-kilometres for international sea travel but were able to find estimates of tonnage delivered to and from Australia by sea. SKM MMA also found evidence of productivity improvement in this sector: tonnage levels per major trading vessel increased in the period 2002 to 2007; see Figure 4-24. Presumably it is these productivity improvements which have led to lower fuel use per tonne over time, as is the case in the air travel sector. See Figure 4-25.

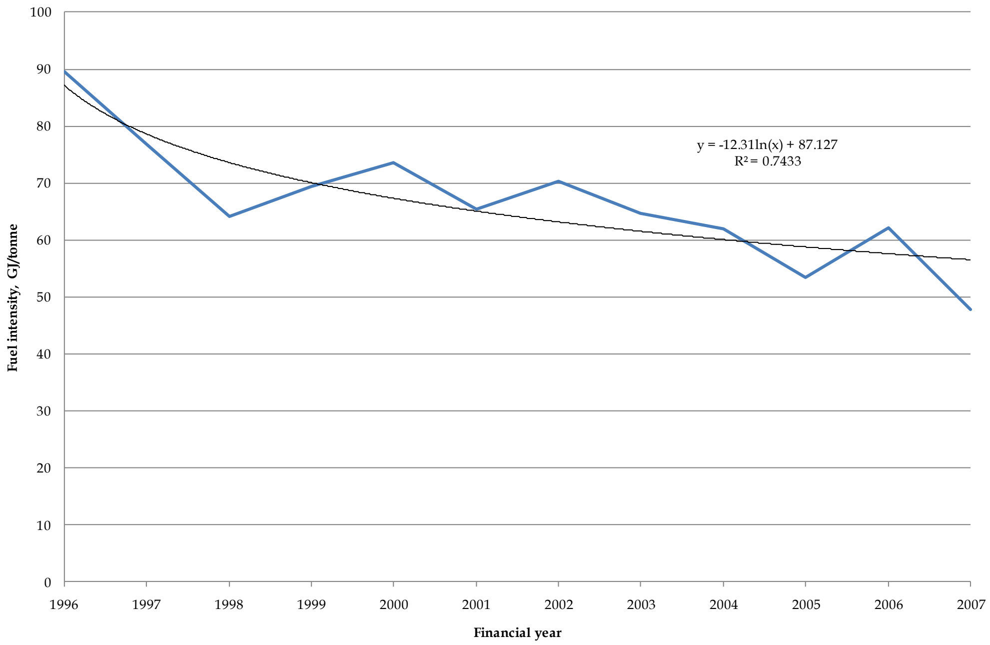
The modelling therefore will be based on fuel use per tonne, projecting this forward to 2050 and applying it to projected maritime tonnage projections. Emissions are derived from fuel use by applying the appropriate emissions factors. Maritime tonnage projections were obtained by trending historical tonnage with world GDP; see Figure 4-26. A reduction in tonnage occurred due to the impact of the global financial crisis in 2008.

- **Figure 4-24 Productivity improvements in international sea freight**



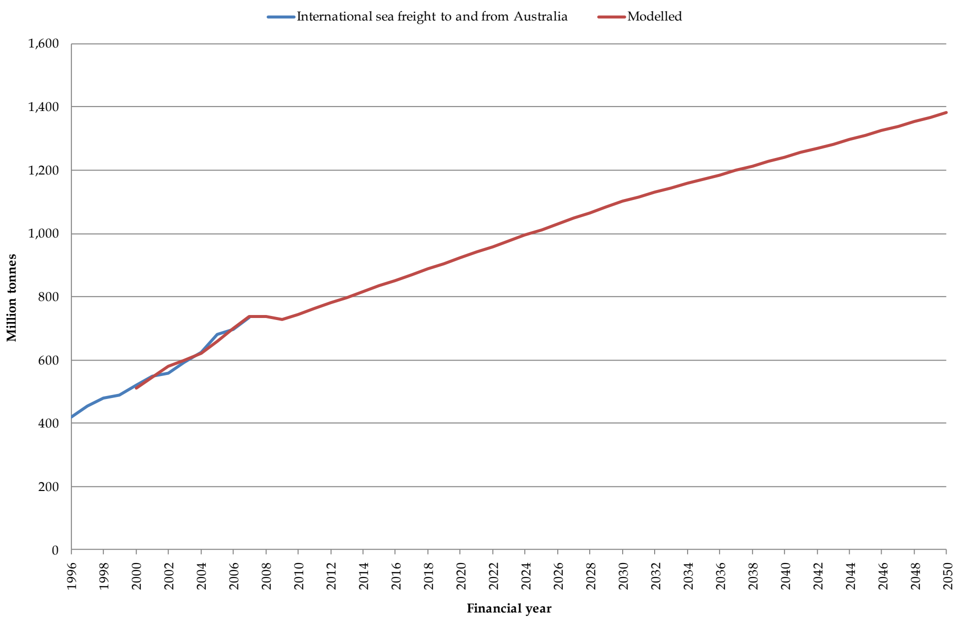
Source: SKM MMA analysis

Figure 4-25 Fuel intensity of international maritime sector



Source: SKM MMA analysis

Figure 4-26 International maritime tonnage projections



Source: SKM MMA analysis

5. Technology uptake model

The model developed by SKM MMA enables projection of uptake of various technologies in the road fleet via analysis of expected trends in fuel costs, capital cost of vehicles and change in vehicle efficiency.

5.1. SKM technology review – an overview

The technology uptake model was built on assumptions based on recent market trends, and SKM analysis of technology trends. A summary of assumptions is provided here.

The technologies under review in the passenger and light commercial vehicle market included petrol and diesel engines, electric hybrid versions of these, LPG engines and electric vehicles. Bus and freight vehicles also included CNG and LNG. Petrol or diesel electric hybrid vehicles were assumed to include some plug-in capability from 2017, with energy consumption from the grid relatively low in early years and increasing over time. The various technologies are summarised in Table 5-1.

▪ **Table 5-1 Technologies considered in the SKM MMA analysis**

Technology	Definition	Vehicle classes applicable
Petrol	Any vehicle using petrol as a fuel. Also known as the Internal Combustion Engine (ICE).	All
Diesel	Any vehicle using diesel as a fuel. Diesel technology is now the most common engine for heavy vehicles worldwide, as well as light vehicles in much of the world. These engines typically deliver greater fuel economy, greater engine life, lower noise output, fewer exhaust emissions and better driving smoothness compared to petrol engines.	All
LPG	Any vehicle running from liquefied petroleum gas (LPG), which is a mixture of propane and butane that is compressed to around 800 kPa.	Private and light commercial vehicles
Petrol Hybrid	Modern hybrid cars generally use a petrol fuelled internal combustion engine to drive a generator which charges onboard batteries. The batteries are	Private and light commercial vehicles, as well as rigid trucks and

Technology	Definition	Vehicle classes applicable
	the primary power source, and petrol may also be used to boost the engine capacity when additional power is needed. Braking is also regenerative, and thus charges the batteries. Recent developments include electric traction which increases the speed at which petrol is required for boosted power. It is assumed that plug in capability will be introduced in most models from around 2017.	buses
Diesel Hybrid	Diesel electric hybrids have only more recently been under development, and fuel economy is quoted to be around 25% better than the equivalent petrol electric hybrid.	Private and light commercial vehicles, as well as rigid trucks and buses
LNG	Any vehicle running on liquefied natural gas (LNG), which is basically natural gas cooled to temperatures below -161˚C, which reduces its density to around 25 kPa. Space requirements for carrying LNG are broadly similar to that for diesel, but the technology requires relatively expensive cryogenic vessels for storage to maintain the temperature required for liquefaction. LNG is not reliant on the existence of natural gas pipelines in the place of refuelling.	Buses, rigid and articulated fleet
CNG	Any vehicle running on compressed natural gas (CNG), which is basically natural gas stored at high pressure, typically 20-28 MPa. The limiting factors for this fuel is a need for more frequent refuelling as a result of a shorter driving range, potentially longer time taken to refuel, as well as reduced carriage space. Vehicles may be refuelled from connections to a natural gas pipeline if desired. With Australia's abundant reserves of natural gas this technology has much to offer in the right circumstances.	Buses and rigid trucks, possibly applicable to short haul articulated fleet

Technology	Definition	Vehicle classes applicable
Electric	This term refers to vehicles which rely on charging batteries from purely external sources. A number of options exist, including charging from homes and offices, or from public recharging points which can substantially reduce the amount of recharging time (a few minutes compared to overnight charging). Primary limitations affecting uptake of this technology is the relatively high difference in capital cost as well as reduced driving range and recharging network availability.	Private and light commercial vehicles; easier to gain benefits in the lighter categories of each of these

Source: SKM analysis

Capital costs assumed are shown in Figure 5-2 through to Figure 5-4. A key assumption is that capital costs of alternative technologies will drop to match the capital cost of conventional petrol vehicles by 2025 in most cases. The main exceptions to this rule are for LPG, LNG, CNG and electric vehicles where the capital costs are assumed to remain substantially higher than the cost of conventional vehicles. With the LPG, LNG and CNG vehicles, it is no surprise that capital costs are higher than conventional technologies because these fuels tend to require larger fuel tanks to accommodate a lower energy density fuel, and in addition may require extra insulation or other equipment for safety, storage, operation or handling reasons.

Where the costs of alternative technologies do drop to match the cost of conventional technology, this has occurred because of scale economies. As alternative technologies become a conventional part of the market it is expected that costs will drop.

Efficiencies of petrol, diesel and hybrid new passenger vehicles are shown in Figure 5-5. In the case of hybrid vehicles an additional electricity component is also included, which will create additional fuel cost for these vehicles. The chart provides an indication of relative efficiency in each of small, medium and large private vehicles by each technology, and also provides an indication of the rate of expected improvement of each technology. In the case of private vehicles, efficiency of petrol vehicles is expected to improve by around 1% p.a., while efficiency of diesel vehicles is expected to improve by around 1.1% p.a. When the energy content of the fuel is also considered, diesel vehicles are around 20% more efficient than petrol vehicles overall[10]. Hybrids

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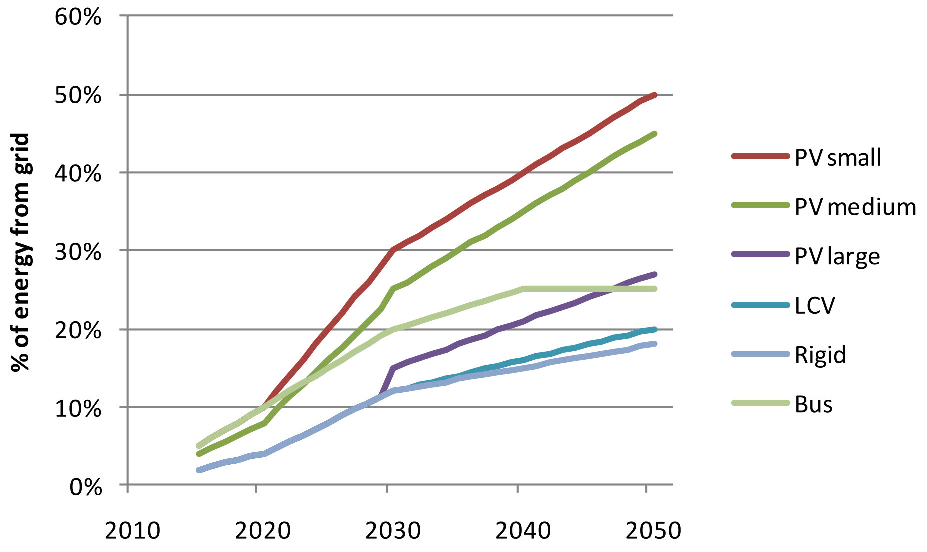
[10] Diesel vehicles are 20% more efficient than petrol vehicles on a joule for joule basis. Many texts quote efficiency values that are somewhat higher – between 25-30% typically, because these are based on liquid fuel volumes and the energy density of diesel fuel is somewhat higher than the energy density of petrol fuel.

are also expected to improve their efficiency faster than conventionally fuelled vehicles, with annual improvements of the order of 1.3-1.5% p.a., with the base year fuel efficiency typically around 30% better than conventional technology.

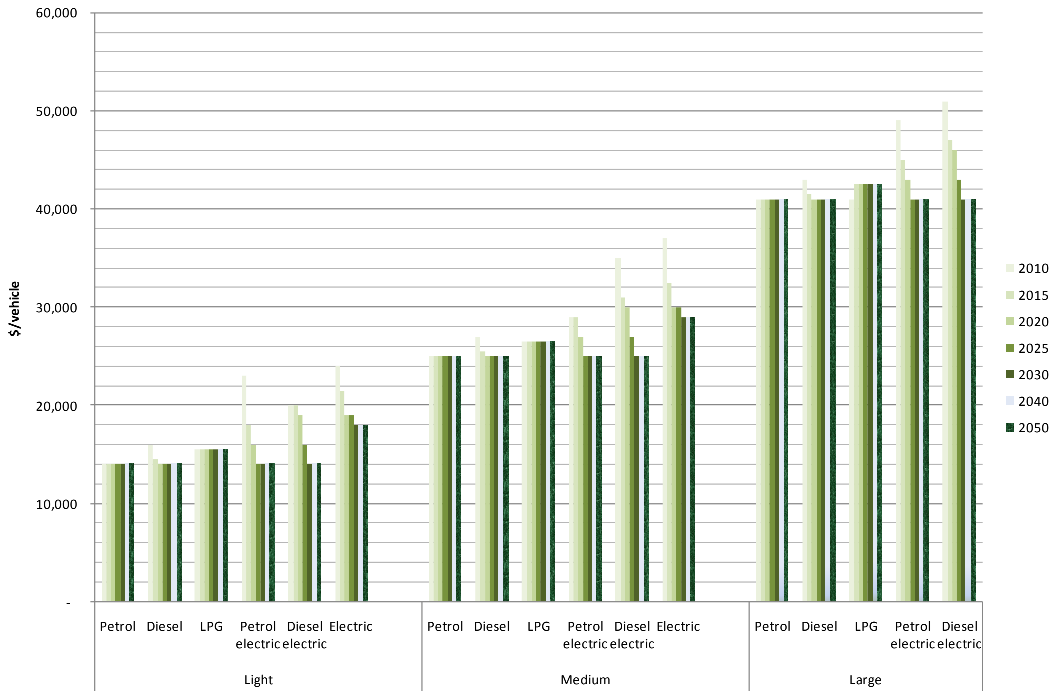
In addition to thermal fuel sources, hybrids are expected to eventually include plug-in technology, with the smallest vehicles able to extract around 5% of their power requirements from the grid in 2015, increasing the availability of this source of fuel to 50% by 2050. As vehicle size increases, hybrids are less able to source such large amounts of fuel consumption from the grid, and maximum levels of electricity as supplied from the grid by 2050 are reached at 45% for medium sized cars, 27% for large cars, 25% for buses, 20% for light commercial vehicles, and 18% for rigid trucks. See Figure 5-1.

- **Figure 5-1 Expected energy derived from grid by hybrid vehicles**



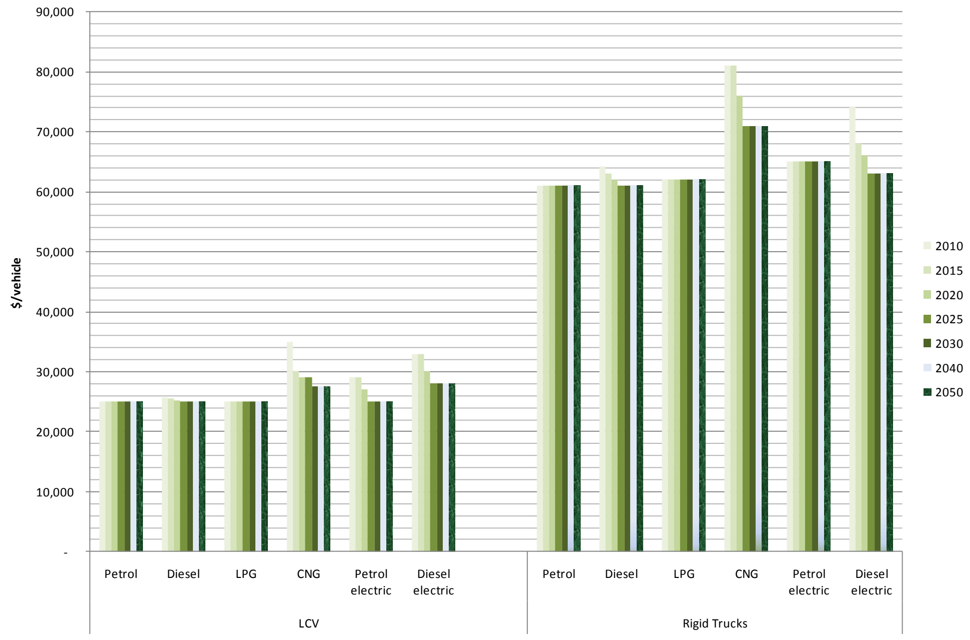
Source: SKM analysis

■ **Figure 5-2 Capital costs – private vehicles**



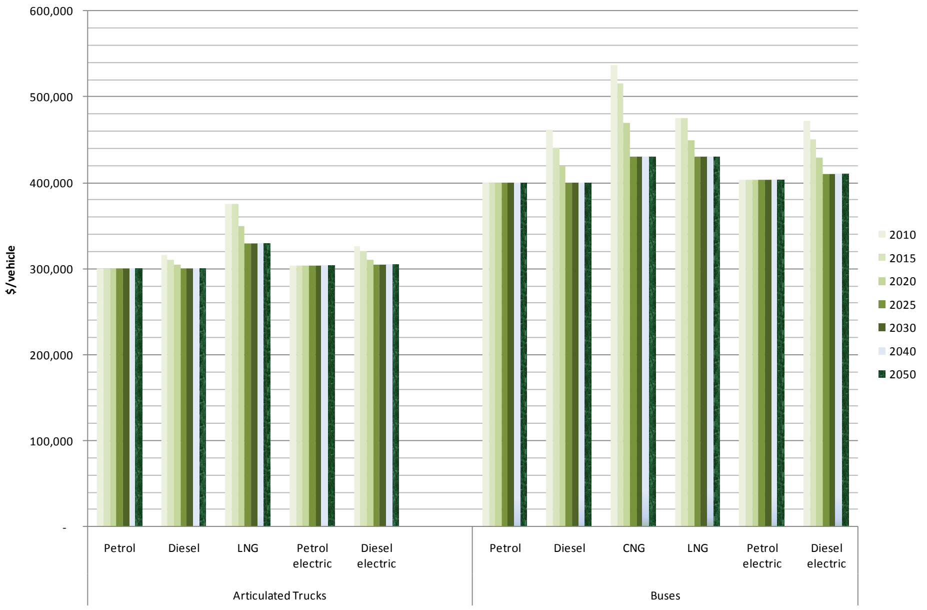
Source: SKM MMA analysis

■ **Figure 5-3 Capital costs – light commercial vehicles and rigid trucks**



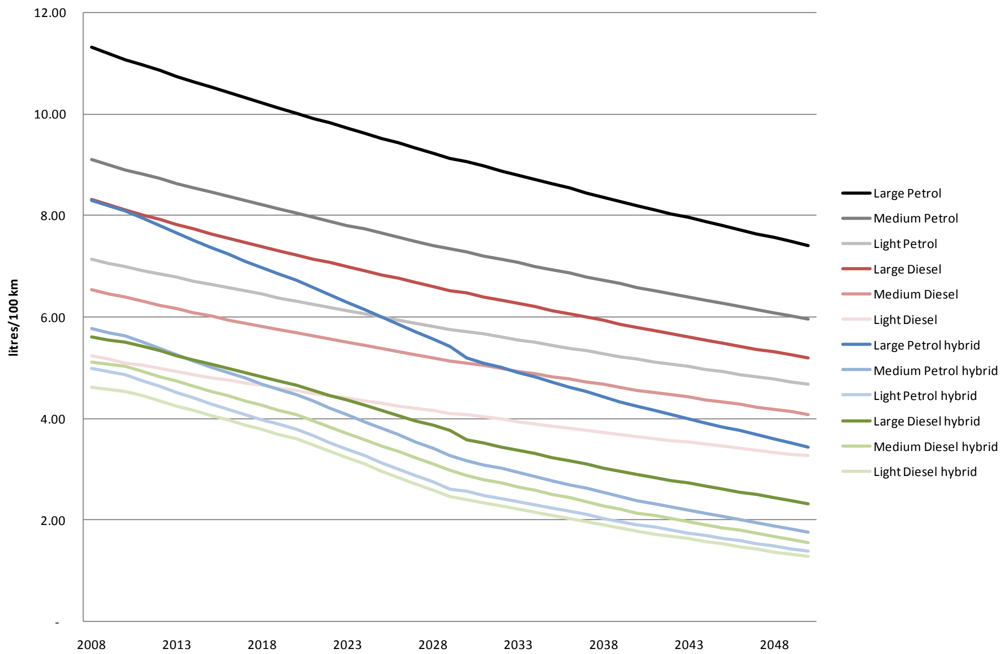
Source: SKM MMA analysis

■ **Figure 5-4 Capital costs – articulated trucks and buses**



Source: SKM MMA analysis

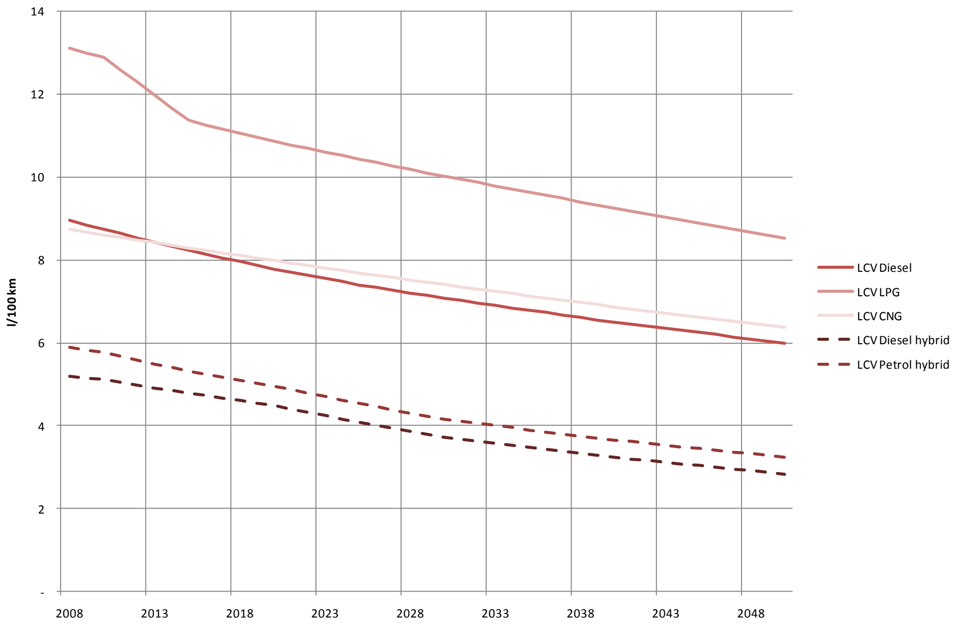
■ **Figure 5-5 Vehicle efficiency – private vehicles by size – petrol and diesel with hybrids (l/100 km)**[11]



Source: SKM MMA analysis.

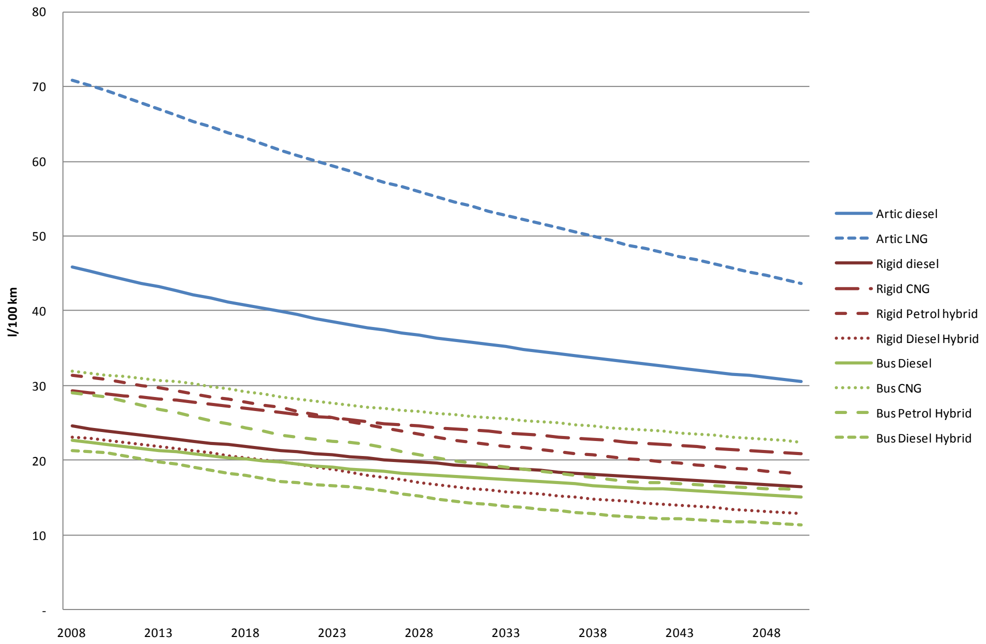
11 Note that hybrid vehicles also include a grid electricity component which is not included in this chart

■ **Figure 5-6 Vehicle efficiency – light commercial vehicles (l/100 km)** [12]



Source: SKM MMA Analysis

■ **Figure 5-7 Vehicle efficiency – rigid trucks, buses, articulated trucks** [13]



Source: SKM MMA analysis

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12 Note that hybrid vehicles also include a grid electricity component which is not included in this chart

13 Note that hybrid vehicles also include a grid electricity component which is not included in this chart

5.2. SKM MMA technology market share model

The model developed by SKM MMA enables projection of uptake of various technologies in the road fleet via analysis of expected trends in fuel costs, capital cost of vehicles and change in vehicle efficiency. The model calculates the net present cost of a choice of vehicles available for each given year of the forecast, and evaluate the proportion of vehicles chosen to be lowest cost for a range of VKT levels. These VKT levels are assumed to follow a log normal distribution, which is a distribution typically chosen for values which are bound at the low end by zero and are skewed towards higher values at lower levels of probability.

For such an analysis, trends in vehicle efficiency and projections of fuel cost are critical, because vehicle consumers are more likely to choose low capital cost vehicles if their perceived future travel kilometres are low, but are more likely to choose options which offer better running cost if they perceive their future travel kilometres are high. One disadvantage of this model is that it to some extent assumes that consumers will have perfect foresight – and while perfect foresight is achievable for the capital cost component of a vehicle it is very difficult to achieve with regard to running costs of a vehicle, in particular those relating to fuel expenses. Consumers may not have an accurate perception of movements in oil prices for example relative to movements in alternative fuel prices, or may not have an accurate understanding of their travel requirements beyond 5 years. This means that the economically most efficient solution will not necessarily match reality, and therefore there will be, by necessity, an interpretive element of such a model.

For the net present cost analysis, a vehicle life of 3 years was assumed for private vehicles, and 5 years was assumed for commercial vehicles. While these values are far less than the actual expected life of a given vehicle, they represent the most relevant period in which a consumer might want to evaluate fuel costs – that is, they represent periods in which a consumer is most likely to require some form of payback relative to additional capital costs incurred in switching to an alternative technology.

For the net present cost analysis, a discount rate of 10% was assumed. This rate is above standard home loan rates that are around at present (approx 7.5%), so is therefore a reasonable and convenient proxy that might be used over such a long timeframe. A higher discount rate will also have the impact of understating fuel savings further into the future relative to savings in capital cost, and is therefore a more conservative choice that is better able to reflect the lack of certainty over fuel savings that might be evident to a consumer.

5.2.1. Fuel cost projections

Fuel price projections for this work need to be appropriate to Australian retail conditions to most accurately reflect each vehicle technology cost profile. SKM MMA's approach for this task is to predict future prices for petrol, diesel and bio-fuels from current prices by applying predicted crude oil price changes.

Historical retail fuel prices (petrol and diesel) have been obtained from the Australian Institute of Petroleum (AIP), where the values are compiled by ORIMA Research Pty Ltd, and are based on daily retail prices in each state/region, with the national average weighted by vehicle numbers as per ABS Report 9309.0. These historical values are shown in Figure 5-8. Historically diesel prices have been higher than petrol prices (at least over the last 4 years) as a result of high demand for diesel fuel in Asia and Australia, and this has been exacerbated by the mining and commodities boom, with diesel prices in 2009/2010 being on average about 2 cents higher than petrol prices. This means that diesel is cheaper per kilometre travelled, because it is more energy dense than petrol, typically containing around 12.9% more energy per litre (based on national greenhouse accounts factors[14]). Vehicles using diesel are typically less fuel intensive also, implying that diesel requires around 20% less energy per kilometre travelled.

For the purposes of this review, SKM MMA have assumed that bio-fuels in the form of biodiesel and ethanol use will be niche market fuels with relatively low availability compared to conventional fuel. Bio-fuels have therefore been ignored in the technology market share study, and have instead been incorporated later into the modelling assuming that bio-fuels will be evenly distributed over each road sector using either petrol or diesel. SKM MMA note that the ethanol component of E10 (which comprises 10% of the fuel) is excise-free, but this subsidy is being phased out between 2011 and 2015, which will of course increase the price. Historically, E10 has been around 10% cheaper than petrol[15], and this reflects to some extent the lower energy value of this fuel relative to petrol. Should bio-fuels be included in the technology market share modelling, it would likely result in unpredictable results as a result of close shadowing of bio-fuel prices to fossil fuel prices.

SKM MMA assume that LPG pricing will also follow trends in crude oil prices, even though a more precise method would be to use the Saudi Aramco contract prices, which are typically quoted in US dollars per tonne. SKM MMA estimate that the loss of precision is likely to be small because the international oil price will be strongly correlated with Saudi Aramco contract prices. SKM MMA note that LPG is currently excise-free, and excise is planned to be phased in between 2011 and 2015, at a cost of 2.5c/l in 2011, increasing to 12.5c/litre in 2015[16]. The predicted changes in oil price are applied to a current estimate of at-pump LPG prices[17], and the appropriate fuel excise is added to produce a forecast of LPG prices.

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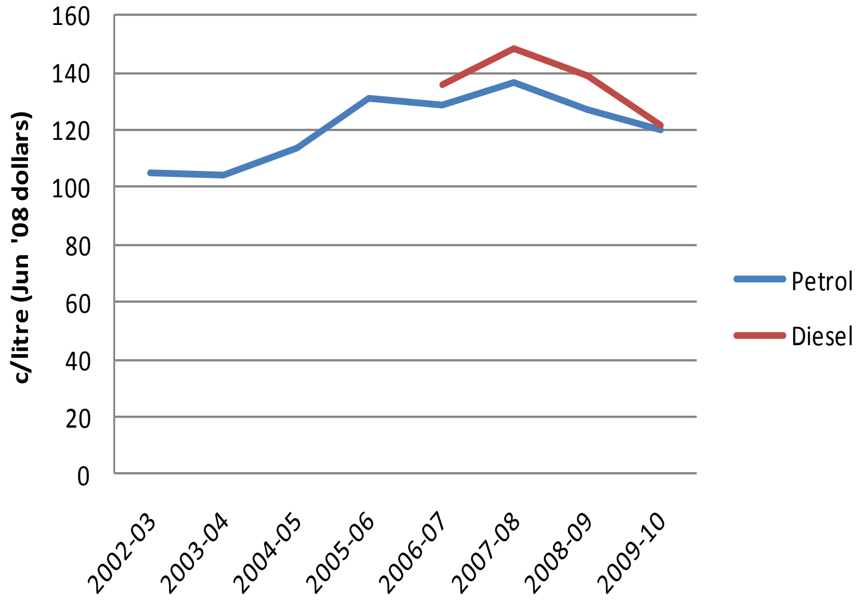
14 http://www.aip.com.au/pricing/facts/Facts_about_Diesel_Prices.htm
15 http://www.accc.gov.au/content/item.phtml?itemId=906872&nodeId=fbbcde6af404bd00f5bf348481c2fa7d&fn=Chapter%209.pdf
16 http://www.ret.gov.au/resources/Documents/transport_fuels/LPG-Fact-Sheet-June-2010.pdf
17 The RET fact sheet described above quotes 51c/l for the June 2009 quarter.

Figure 5-8 provides historical estimates of petrol and diesel fuel prices based on the AIP data.

- **Figure 5-8 At-pump fuel prices**



Source: SKM MMA analysis of AIP data

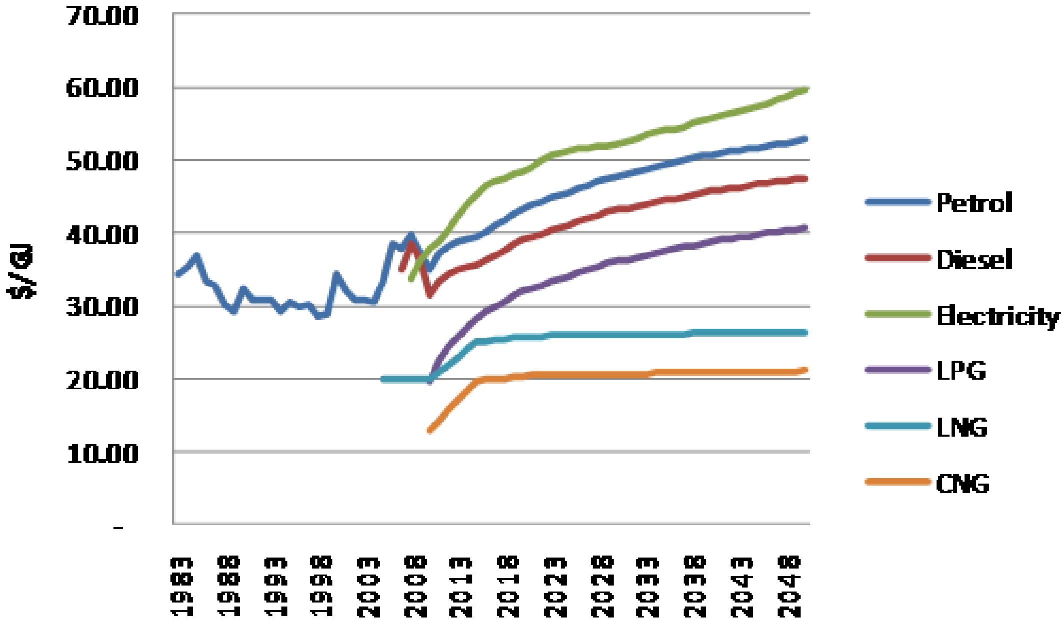
Electricity prices were derived from electricity wholesale market new entry price curves from the stationary energy model developed by SKM MMA for DCCEE. Estimates of costs attributable to distribution and transmission, transmission and distribution losses, market operation and retail margins were added.

LNG and CNG prices were derived from the SKM MMA gas model, which is also an input to the electricity market modelling. Changes to future expected gas prices were applied to current estimates of LNG prices available to the market.

Figure 5-9 displays a comparison of petrol, diesel, LPG and electricity prices used in the technology market share modelling. The prices reflect a continuation of the rising oil prices experienced in recent years for those fuels whose prices shadow international trends in oil prices (i.e. petrol, diesel and LPG). Notably prices for LNG appear to be the most stable, reflecting Australia's vast gas supplies. Electricity prices are expected to increase to a similar trend with oil until 2023, after which time these prices will stabilise while oil prices are expected to continue rising (reflecting worldwide shortages in this fuel). The reason for the increase in electricity prices relates to increased costs of labour and materials required for new electricity plant.

There are likely to be regional variations with regard to electricity and gas costs, and this variation may be larger than variation that might be seen in the oil derived fuels. The modelling conducted by SKM MMA uses Australian averages and effectively ignores regional variations that may bias the results in different states.

- **Figure 5-9 Fuel price projections**



Source: SKM MMA analysis

5.3. Vehicle attrition

In Appendix A.3 can be found a description of how the model retires old fleet and replaces these vehicles with new fleet. In general terms, a statistical model has been employed to simulate the retirement of vehicles at different ages, with the highest probabilities of older vehicles being retired first. This is because vehicles can be written off at any age due to accident, but can also be more likely to be written off at older ages when wear and tear is significant enough for owners to tire of lower vehicle reliability as well as higher maintenance and upkeep costs and effort. This modelling has been based on data available from the ABS. The average age to retirement of private and light commercial vehicles under this approach are 18.7 and 20.9 years respectively, while the average age to retirement of trucks and buses range between 15 and 22 years, principally because these vehicles are used far more intensively over their life. The average ages to retirement/scrapping will be higher than the average age in the fleet (currently between 10-16 years depending on vehicle type) because population growth means that the number of new vehicles being purchased is always exceeding the number of old vehicles being scrapped.

6. Results

6.1. Emissions and fuel use

Domestic transport emissions are projected to peak at 99.3 Mt CO_2e by 2030, growing by 1.1% p.a.to 2020, and then slowing down to 0.4% p.a. to 2030. Growth is expected to decline post 2030 to provide an emissions estimate of 94.4 Mt CO_2e by 2050, with average emissions decline of -0.5% p.a.

International bunker fuel emissions are expected to maintain strong growth during the forecast period to 2050, with average growth of 1.7-2.2% p.a. to 2030 followed by stronger growth post 2030 of 4.7% p.a. The dominant sector here is international air transport which exhibits strong growth over the forecast period as a result of projected increases in international passenger kilometres travelled.

Table 6-1displays a summary of SKM MMA's baseline emissions projections for the transport sector to 2050 and Table 6-2 displays a summary of corresponding energy use. Figure 6-1 and Figure-6-2 display the corresponding charts. Charts for each transport sector are provided in Figure 6-3 through to Figure 6-6.

The dominant sector for domestic transport emissions and fuel use is the road transport sector, which currently makes up around 87% of total domestic transport emissions. However, by 2020 this share is expected to drop to 86% of total domestic transport emissions and by 2030 drop further to 84% of total domestic transport emissions. By 2050, the road transport sector is expected to contribute only 75% of all domestic transport emissions. This drop in share is expected to occur as a result of improved vehicle emission and/or fuel intensity, softening of travel demand projections, and high growth in the aviation industry combined with limited technical potential to reduce emissions in that industry[18].

Table 6-2 mirrors the results contained in the emissions data to some extent, but removes the effect of low emission intensity fuels, making it easier to see what is going on in the transport sector. Fuel use is instead projected to continue escalating to 2050, peaking at 1,546 PJ in 2050, growing by 1.2% to 2020 and by 0.3% between 2020 and 2030, and 0.6% p.a. to 2050. Again, the dominant sector is the road sector; which experiences fuel use peak in 2030 and some reduction of fuel use beyond this time. Compensating for these reductions is the growth which can principally be seen in the air transport sector.

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[18] Bio-fuel is one recognised means of reducing air emissions, yet is still unproven for air transport. On 25 September 2010 Intertek tested the use of biofuel on a small aircraft with success, but the fuel is still to be tested on larger commercial aircraft and is thus ignored as a potential means of emissions reduction for thisbaseline projection. http://avstop.com/news_sept_2010/biofuel_powered_historic_transatlantic_flight.htm

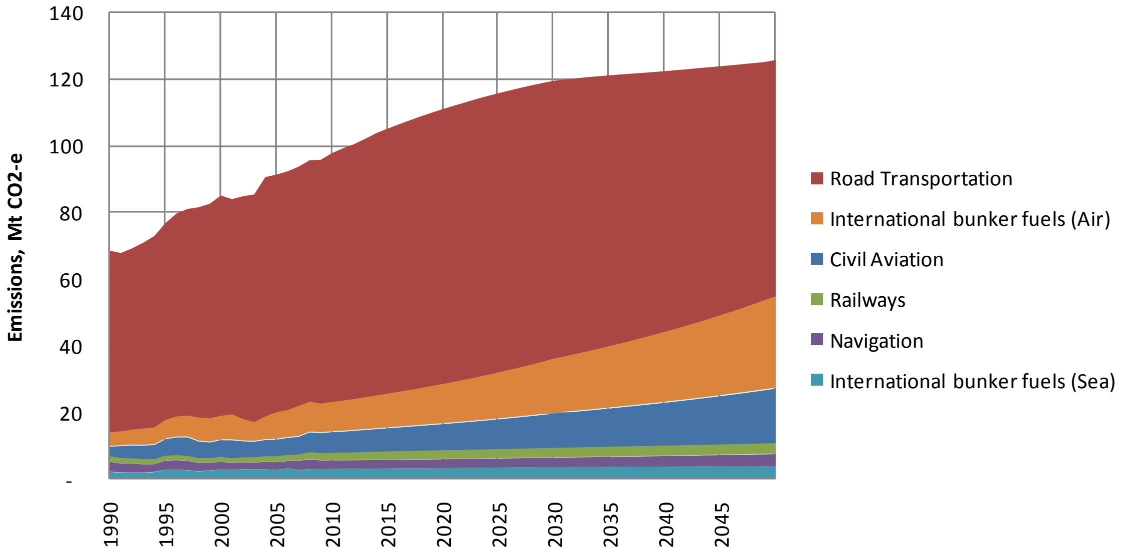
■ **Table 6-1 Summary of Baseline transport emissions projections (Mt CO_2e)**

Category	Sub-category	1990	2000	2008	2020	2030	2050
Domestic Transport Emissions							
All Domestic		62.1	74.9	83.4	95.0	99.3	94.4
Road		54.3	65.9	72.3	81.8	83.4	71.3
	Passenger	*35.2*	*41.3*	*43.5*	*45.4*	*45.2*	*35.8*
	Motorcycles	*0.2*	*0.2*	*0.2*	*0.3*	*0.3*	*0.3*
	Buses	*1.2*	*1.4*	*1.5*	*2.0*	*2.2*	*2.1*
	LCV	*7.5*	*9.5*	*11.7*	*14.4*	*14.5*	*12.0*
	Rigid	*4.1*	*5.2*	*6.3*	*7.1*	*7.4*	*7.1*
	Articulated	*6.1*	*8.4*	*9.2*	*12.6*	*13.8*	*13.9*
Air		2.9	5.0	6.0	7.7	10.1	16.1
Rail		1.7	1.6	2.3	2.8	3.0	3.3
Sea		3.0	2.4	2.9	2.7	2.9	3.6
International transport emissions							
All International bunker fuels		*6.5*	*10.2*	*12.2*	*14.9*	*19.4*	*30.6*
Air		4.4	7.4	9.3	11.7	15.9	26.8
Sea		2.1	2.8	2.9	3.2	3.5	3.8

Annual % change			1990-2000	2000-2008	2008-2020	2020-2030	2030-2050
Domestic Transport Emissions							
All Domestic			1.9%	1.4%	1.1%	0.4%	-0.5%
Road			2.0%	1.2%	1.0%	0.2%	-1.5%
	Passenger		*1.6%*	*0.6%*	*0.4%*	*0.0%*	*-2.3%*
	Motorcycles		*-1.6%*	*4.2%*	*1.9%*	*0.4%*	*0.6%*
	Buses		*1.8%*	*0.7%*	*2.6%*	*0.7%*	*-0.1%*
	LCV		*2.3%*	*2.6%*	*1.8%*	*0.1%*	*-1.9%*
	Rigid		*2.3%*	*2.4%*	*1.1%*	*0.3%*	*-0.4%*
	Articulated		*3.3%*	*1.1%*	*2.6%*	*0.8%*	*0.1%*
Air			5.5%	2.2%	2.2%	2.2%	4.8%
Rail			-1.1%	4.8%	1.6%	0.7%	1.1%
Sea			-2.5%	2.7%	-0.7%	0.6%	2.3%
International transport emissions							
All International bunker fuels			*4.7%*	2.3%	1.7%	2.2%	4.7%
Air			5.4%	2.9%	2.0%	2.6%	5.3%
Sea			3.0%	0.5%	0.8%	0.7%	0.9%

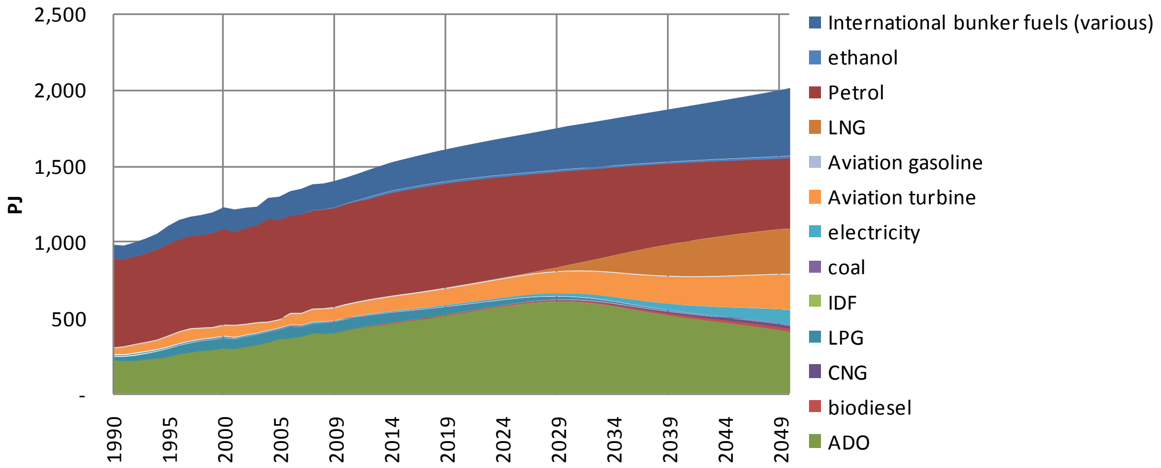
Source: SKM MMA analysis

■ **Figure 6-1 Emission projections by transport sector**



Source: SKM MMA analysis

■ **Figure-6-2 Fuel use projections for the transport sector by fuel– excludes international bunker fuels**



Source: SKM MMA analysis

SKM | MMA

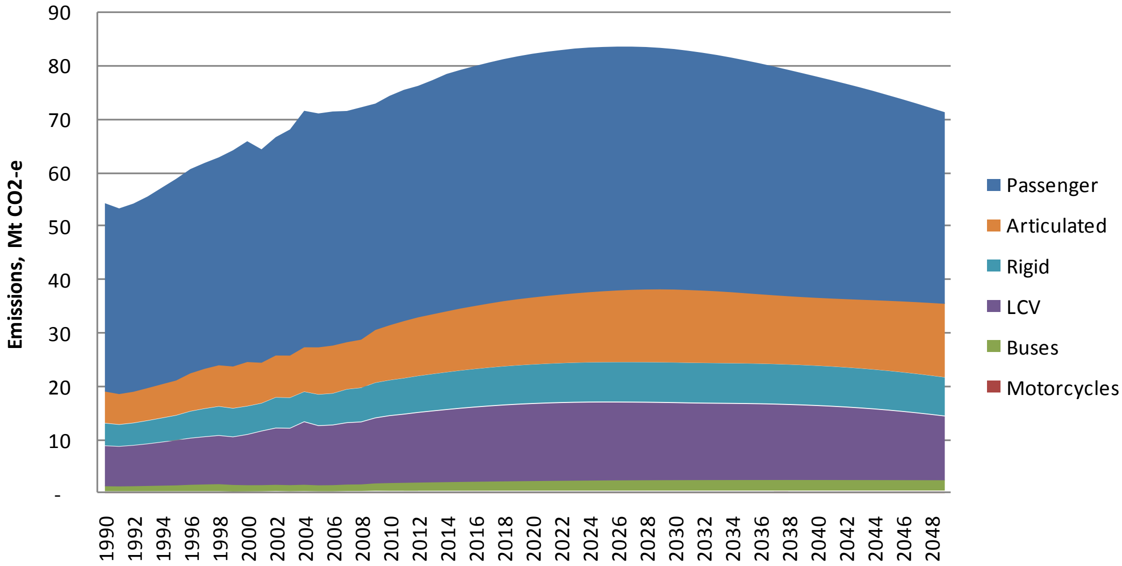
Table 6-2 Summary of baseline transport energy projections (PJ)

Category	Sub-category	1990	2000	2008	2020	2030	2050
Domestic transport fuel use							
All Domestic		903.1	1,087.5	1,209.3	1,409.8	1,481.0	1,569.6
Road		791.6	955.9	1,048.5	1,208.4	1,232.2	1,197.6
	Passenger	515.7	601.3	613.0	672.6	660.9	571.2
	Motorcycles	3.0	2.6	3.5	4.5	4.7	5.0
	Buses	16.6	20.0	22.9	30.8	36.2	56.4
	LCV	110.2	137.2	168.7	211.9	212.5	183.1
	Rigid	58.8	74.1	97.0	104.1	107.7	107.3
	Articulated	87.2	120.8	143.4	184.4	210.1	274.4
Air		42.2	72.2	85.7	113.8	149.0	237.3
Rail		30.5	29.6	41.7	50.1	59.3	83.7
	Passenger				8.5	9.6	11.8
	Freight				41.6	49.7	71.9
Sea		38.8	29.8	33.3	37.6	40.6	51.0
International transport fuel use							
All International bunker fuels		91.5	144.4	173.2	216.9	284.2	447.5
Air		63.0	106.2	133.3	173.0	236.4	395.2
Sea		28.5	38.2	39.9	43.9	47.8	52.2
Annual % change			**1990-2000**	**2000-2008**	**2008-2020**	**2020-2030**	**2030-2050**
Domestic transport fuel use							
All Domestic			1.9%	1.3%	1.3%	0.4%	0.6%
Road			1.9%	1.2%	1.2%	0.2%	-0.3%
	Passenger		1.5%	0.2%	0.8%	-0.1%	-1.4%
	Motorcycles		-1.6%	3.7%	2.3%	0.4%	0.6%
	Buses		1.9%	1.7%	2.5%	1.4%	4.5%
	LCV		2.2%	2.6%	1.9%	0.0%	-1.5%
	Rigid		2.3%	3.4%	0.6%	0.3%	0.0%
	Articulated		3.3%	2.2%	2.1%	1.1%	2.7%
Air			5.5%	2.2%	2.4%	2.3%	4.8%
Rail			-0.3%	4.4%	1.5%	1.4%	3.5%
	Passenger					1.0%	2.1%
	Freight					1.5%	3.8%
Sea			-2.6%	1.4%	1.0%	0.6%	2.3%
International transport fuel use							
All International bunker fuels			4.7%	2.3%	1.9%	2.3%	4.6%
Air			5.4%	2.9%	2.2%	2.6%	5.3%
Sea			3.0%	0.5%	0.8%	0.7%	0.9%

Source: SKM MMA analysis

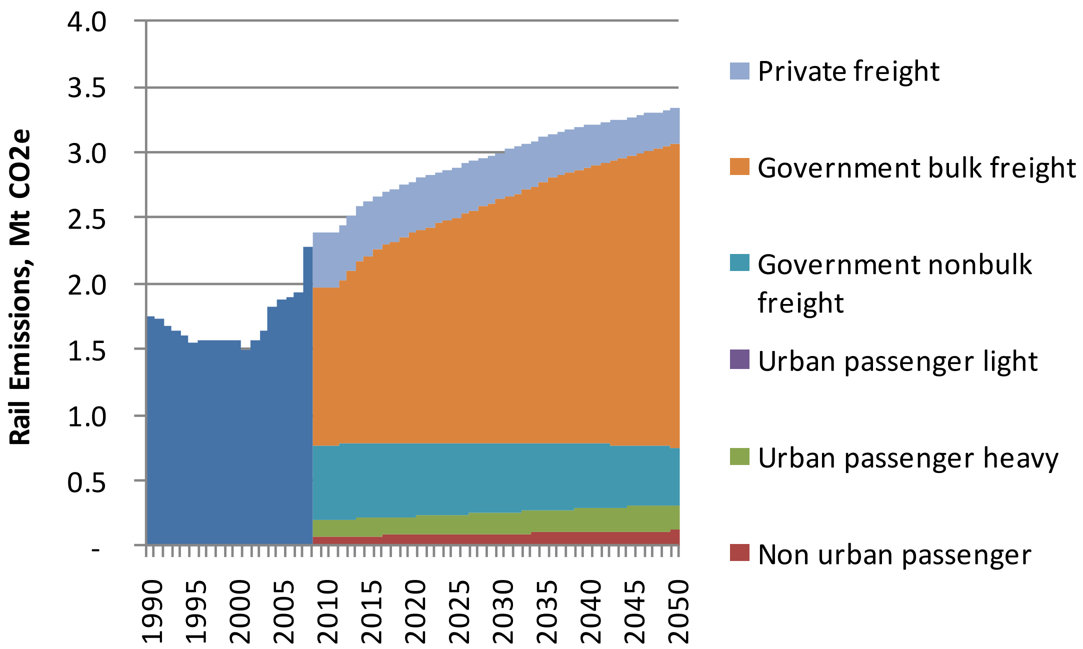
Emissions charts for each transport sector are provided below.

■ **Figure 6-3 Road emissions by vehicle type**



Source: SKM MMA analysis

■ **Figure 6-4 Rail emissions**[19]



Source: SKM MMA analysis

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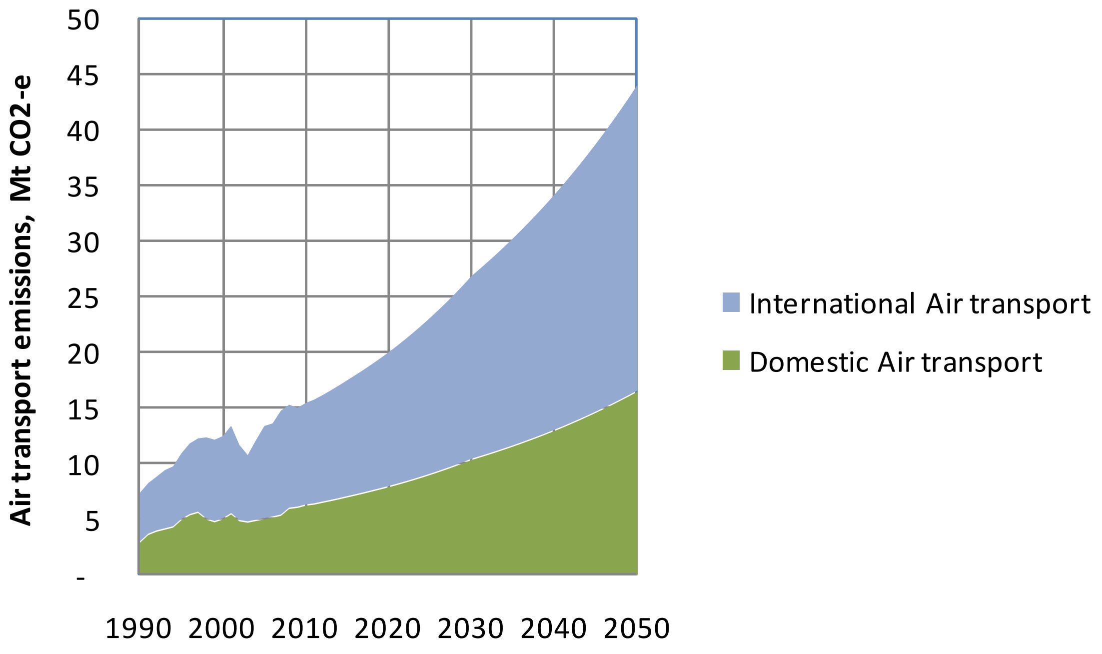
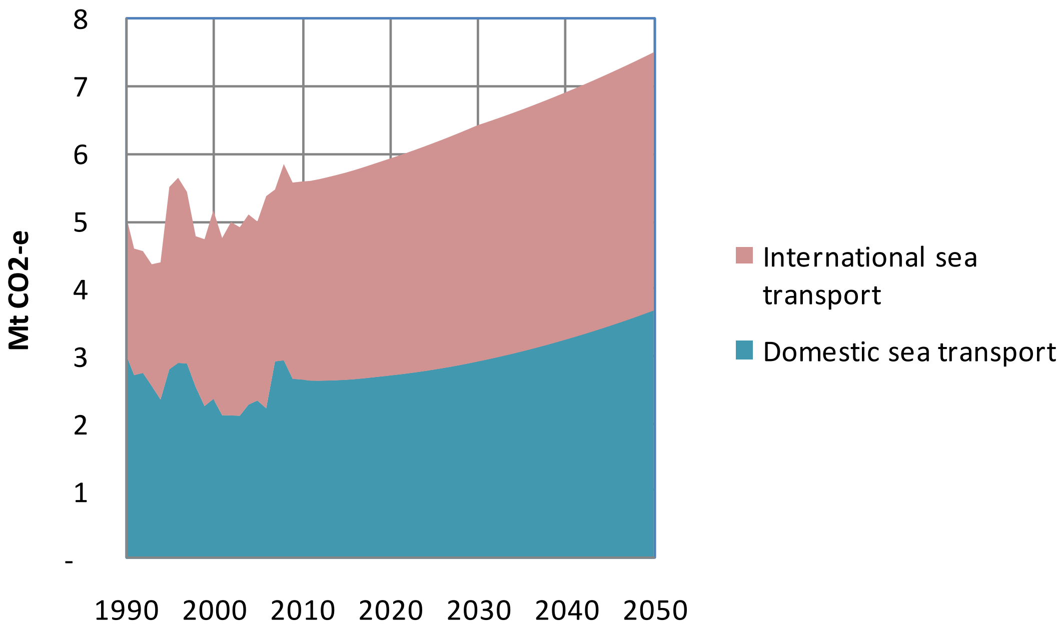
[19] Historical split of emissions by rail classification is unavailable.

- **Figure 6-5 Air emissions**



Source: SKM MMA analysis

- **Figure 6-6 Sea emissions**



Source: SKM MMA analysis

6.1.1. Road transport - activity

Trends in travel demand are mixed, but will be dominated by trends in passenger vehicle travel which currently consumes 58% of all fuel required for road transport purposes and 74% of travel demand (VKT). In terms of commercial travel demand, light commercial vehicles dominate with around 17% of all VKT which corresponds to 16% of road sector fuel use. These vehicles carry a relatively small proportion of Australian freight however. Freight vehicles include rigid and articulated trucks. These vehicles make up a relatively small portion of overall VKT (7% now, growing to 8% in 2050), but fuel use for these freight vehicles is proportionally much higher (23% now, growing to 30% in 2050).

Travel demand projections are summarised in Table 6-3. Passenger vehicle kilometres travelled are projected to increase by 1.7% p.a. to 2020, softening to 1.1% p.a. to 2030. Historically, passenger vehicle kilometres travelled have maintained softer growth than GDP/person, and since 2000, this effect has been exacerbated as a consequence of high increases in fuel prices and, presumably, the impact of saturation, or an upper limit on necessary and personally acceptable travel per person. Therefore the passenger travel projections as modelled may be conservatively high. To model commercial activity SKM MMA found GDP and oil prices to be the most useful indicators, and the results highlight the effect of GDP on travel. For example, light commercial vehicles are projected to increase at 1.6% p.a. to 2020 and then by 1.1% p.a. to 2030. GDP however is projected to grow by 3.3% p.a. and 2.2% p.a. over the same time periods. Historically growth in VKT has remained below growth in GDP; the gap between VKT growth and GDP growth has been increasing (presumably as a result of increasing oil prices which in turn are likely to incur operational efficiency improvements) and this is reflected in the projections. A similar effect is observed on rigid trucks, with growth projected to reach 1% and 0.8% p.a. for each of the respective time periods. A notable exception occurs with articulated trucks. In this case the gap between VKT growth and GDP growth shrinks over time as a result of the freight industry starting to reach upper limits to improvements in operational efficiency[20], thus allowing VKT growth to match growth in GDP by 2030.

Overall, VKT is projected to increase by 1.7% p.a. to 2020, which is consistent with historical growth which has maintained a pace of growth of the order of 1.5-2% p.a. This value is also consistent with growth in GDP/person. Beyond 2020 VKT growth is projected to soften to 1.1% p.a., also consistent with softened GDP/person projections around this time. Beyond 2030 VKT is projected to strengthen again post 2030 to 2.1%p.a., and this is caused by stronger growth in GDP/person as well as sustained growth in articulated fleet travel.

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[20] Operational efficiency refers to measures taken by the transport industry to move greater loads at lower cost. One example refers to the use of B-Doubles or B-Triples in place of conventional articulated fleet. Alternatively logistical means can be employed, such as increasing payloads by better utilising all available space on heavy vehicles, optimising travel routes,e tc.

▪ **Table 6-3 Summary of baseline road transport VKT projections**

Category	Sub-category	1990	2000	2008	2020	2030	2050
Road		162.2	198.7	224.7	279.2	317.5	396.2
	Passenger	*124.0*	*151.2*	*165.9*	*207.0*	*234.6*	*289.4*
	Motorcycles	*1.8*	*1.4*	*2.3*	*2.7*	*3.0*	*3.7*
	Buses	*1.5*	*1.8*	*2.0*	*2.6*	*3.0*	*3.7*
	LCV	*23.9*	*31.3*	*38.9*	*47.4*	*53.7*	*66.4*
	Rigid	*6.8*	*7.3*	*8.7*	*9.9*	*11.0*	*13.1*
	Articulated	*4.1*	*5.7*	*6.9*	*9.6*	*12.2*	*19.9*
			Annual % change (1990-2000)	**Annual % change (2000-2008)**	**Annual % change (2008-2020)**	**Annual % change (2020-2030)**	**Annual % change (2030-2050)**
Road			2.0%	1.5%	1.8%	1.1%	2.2%
	Passenger		*2.0%*	*1.2%*	*1.9%*	*1.0%*	*2.1%*
	Motorcycles		*-2.3%*	*6.1%*	*1.3%*	*1.0%*	*2.1%*
	Buses		*1.3%*	*1.8%*	*2.1%*	*1.1%*	*2.2%*
	LCV		*2.7%*	*2.7%*	*1.7%*	*1.1%*	*2.1%*
	Rigid		*0.6%*	*2.2%*	*1.1%*	*0.8%*	*1.8%*
	Articulated		*3.3%*	*2.4%*	*2.8%*	*2.0%*	*5.0%*

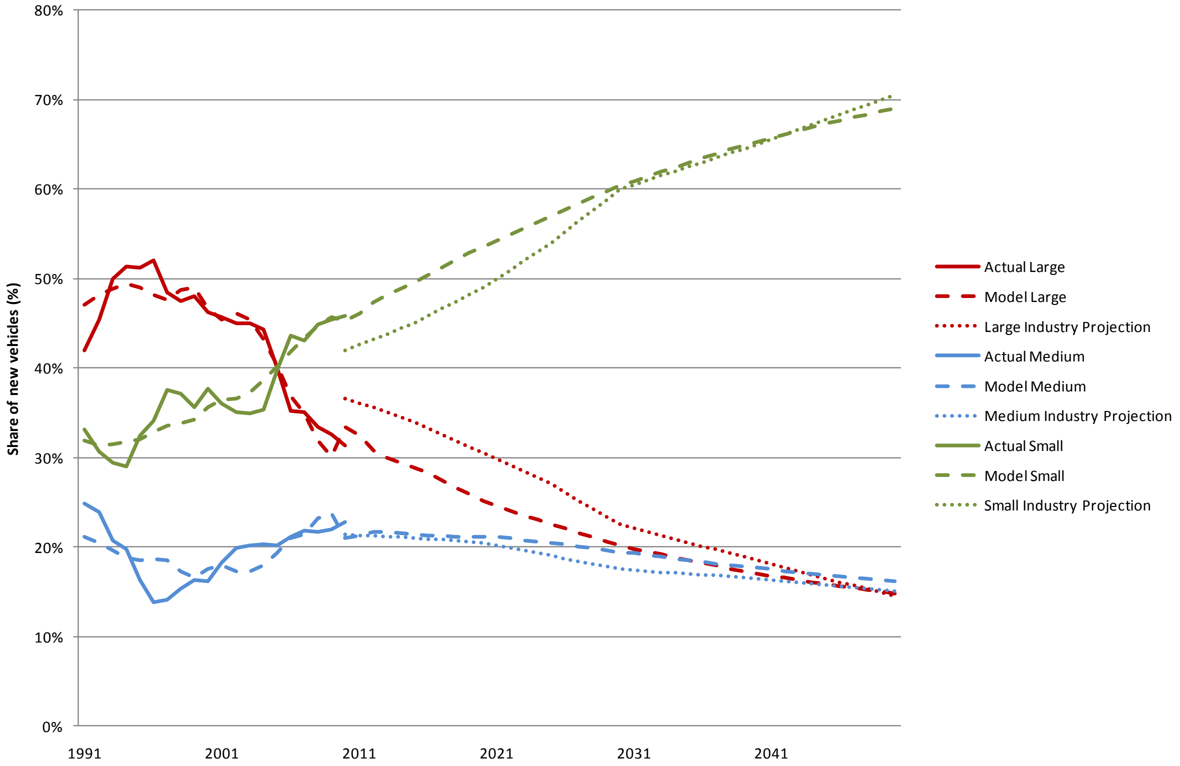
6.1.2. Road transport - fuel use

Vehicle efficiency improvements can be created by a number of means, not all of which involve application of technology improvements.

The simplest means of achieving greater vehicle efficiency is for consumers to downsize their cars, and this has occurred since 1996 with the share of new larger sized vehicles dropping from 52% in that year to 33% in 2010[21]. During the same period small vehicles increased from 34% to 45% while medium sized vehicles increased from 14% to 23%. SKM MMA has projected the trend forward using GDP, oil prices and lagged oil prices to predict future market shares of vehicle size. A multinomial logit formulation was used to create the projections. These are displayed in Figure 6-7, along with industry projections extracted from the SKM technology issues review. The industry projections were derived independently, and were based on informal discussions between SKM and various industry players, including selected vehicle manufacturers and the FCAI. It is also understood that SKM reviewed international trends when determining these projections. These compare quite favourably with modelled projections.

21 Based on MMA analysis of FCAI new vehicle sales data supplied by the FCAI.

- **Figure 6-7 Projected shares of small, medium and large passenger vehicles**



Source: SKM MMA analysis

Manufacturers can also improve fuel efficiency in new vehicles. Historically this has occurred on a voluntary basis and gains have typically been offset to some extent by improving the vehicle performance or more recently by the addition of safety features such as airbags. Typically this means that theoretical efficiency gains of nearly 2% p.a. have effectively turned into achieved efficiency improvements of around 1% p.a.

Other means of achieving greater vehicle efficiency are to turn over a fleet dominated by internal combustion petrol driven engines to alternative lower emission technologies, or in the case of most of the commercial fleet, turn over a fleet dominated by diesel engines to alternative lower emission technologies. These technologies produce lower emissions by either improving fuel efficiency or by using lower emission fuel, or a combination of both. An example of an established technology that improves fuel efficiency only (relative to the petrol fuelled internal combustion engine) is diesel technology. Diesel driven vehicles use around 20% less fuel on a joule for joule basis than the equivalently sized petrol driven vehicles. Hybridisation of petrol and diesel vehicles will also use less fuel (30% less than conventional technology typically), but electric plug in capability in the future could also mean that a portion of the fuel use could come from renewable sources. Gas based technologies (i.e. LPG, LNG, CNG) are also established technologies that can improve both fuel efficiency and use a lower emission fuel. LPG is currently 7% more fuel efficient than petrol vehicles on a joule for joule basis, and this is expected to double by 2015 because of the introduction of direct injection technology. The fuel itself has around 12% fewer emissions per joule than gasoline. LNG and CNG have an even better profile with regard to emissions intensity. LNG and CNG has around 26% and 18% fewer emissions per joule respectively when compared to gasoline. Efficiency gains can also be made faster if those vehicles travelling the longest distances switch to these alternative technologies first.

Finally, operational efficiency is a means of transporting greater quantities of freight using less energy – this occurs by transporting more freight in larger vehicles (e.g. B-doubles) or employing other means of increasing the average payload in each vehicle.

Table 6-4 displays the projected fuel intensity of the fleet by vehicle type. Over the period between 1990 and 2008 fuel intensity of passenger vehicles has improved, and the rate of improvement has increased from 2000. There are a number of events that have impacted on fuel efficiency, and these have occurred independently of specific manufacturer driven efficiency improvement[22]. These include changes to new vehicle size shares in favour of lighter and more fuel efficient vehicles, increased uptake of diesel technology, and a considerable amount of vehicle conversions to use LPG (particularly for higher usage vehicles).

The new vehicle share of small engines in favour of larger engines has increased substantially since 2004, with an apparent jump of 10% around this time. In terms of the whole fleet, this means that there are 4% fewer large vehicles on the road compared to the year 2000, 0.5% fewer medium vehicles on the road compared to the year 2000, and around 4.5% more small vehicles on the road since the year 2000. This is equivalent to 1.75% better fuel intensity between 2000 and 2008, or around 0.2% p.a. improvement in fuel efficiency over the last 8 years.

The share of new vehicles with diesel engines has increased substantially since 2004, growing from less than 5% of new vehicles to around 15% of new vehicles by 2010. The diesel share of the large vehicle category is significantly higher, taking around 29% of new vehicle share in 2010 compared with around 13% of medium sized vehicles and 7% of small sized vehicles. SKM MMA estimate that the fleet share of diesel passenger vehicles is around 5%, and that these vehicles take 6% of available fuel. Since the year 2000, this equates to 2.6% more diesel cars in the whole fleet, or a fuel efficiency improvement of around 0.1% p.a.

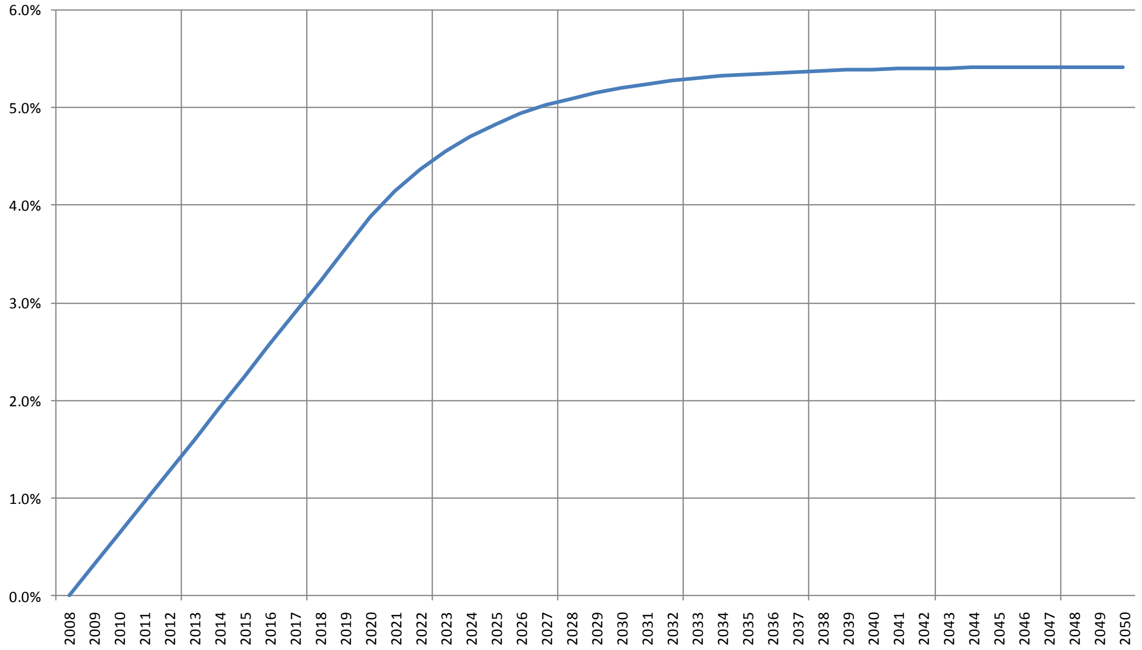
The new vehicle share of LPG engines is still quite low; however a number of existing vehicles have been converted to use LPG fuel. This has occurred as a result of a federal government rebate on LPG conversions. Estimates provided in the accompanying technical review indicate that

22 Voluntary efficiency measures include things like reducing carrying weight in vehicles, maintaining tyre pressures to appropriate levels and eco-driving.

around 0.5% of the passenger fleet is now LPG. This equates to a 0.004% p.a. improvement to fuel efficiency over the last 8 years.

This analysis also enables a rough estimate of the effect of congestion growth on fuel use. The events just described – reducing vehicle size, increasing take-up of diesel vehicles, and conversions to LPG – are expected to have improved historical efficiency by around -0.3% p.a. (adding the effects described above), implying that fleet efficiency improvements since the year 2000 have reached at least -0.7% p.a. This has occurred in the face of increasing congestion which may dampen improvements to efficiency. Assuming that realised efficiency improvements have consistently been around -1% p.a. over the last 20 years or so, the impact of congestion growth between the year 2000 and 2008 can be estimated to be around 0.3% p.a. Assuming this growth would continue in the same manner and apply over the next 40 years or so, growth in congestion could add around 13% greater fuel use by 2050. In practice this is unlikely to be fully realised if hybridisation enters the market, as regenerative braking is likely to increase the self generated power available to drivers in congested conditions. In the absence of hybridisation, most vehicles are likely to gain stop-start technology, also known as integrated starter/generator systems. Under this technology, engines are automatically turned off when the vehicle comes to a stop, and automatically restart when the accelerator is depressed. Further, traffic management measures are likely to be put in place to reduce the impact of congestion. The forward looking impact of congestion has been estimated to reach 5.4% by 2050, as displayed in Figure 6-8. Congestion impacts are not applied to heavy freight vehicles as it is assumed that congestion impacts on these vehicles is minimal due to greater levels of driving activity being on the open road and outside peak hours.

Figure 6-8 Estimated impact of congestion



Source: SKM MMA analysis

In terms of forward projections, the two most significant impacts will therefore be projections of vehicle size shares and the projection of alternative technologies including diesel technology. The impacts of these changes for the BAU and baseline scenarios are described below:

- ***Vehicle size shares*** are projected to be as shown in Figure 6-9. That is, by 2020, around 10.9% of heavy passenger vehicles around in 2008 will be displaced by 9.3% light vehicles and 1.6% of medium sized vehicles, and by 2030, a further 7.9% of heavy vehicles in 2020 will be replaced by light vehicles only. This translates to approximately a -0.3% p.a. change to fuel intensity to 2020, and an additional -0.3% p.a. change to fuel intensity to 2030. By 2050 a further 8.1% of heavy vehicles and 3.2% of medium sized vehicles that are around in 2030 will be replaced by light vehicles. This translates to an additional change to fuel intensity by 2050 of nearly -0.2% p.a. Reductions in average vehicle sizes alone are therefore sufficient to counter increases to congestion.
- ***Technology change*** is projected to be as shown in Figure 6-10 through to Figure 6-12. By 2020, there are expected to be around 10% more diesels than in 2008, and a very small share of hybrid vehicles. These displace petrol and LPG vehicles in the market, and equates to around 2% fuel intensity reduction over 12 years, which is a 0.2% reduction annually. Similarly by 2030, the number of diesel vehicles increases further to an additional 15% of petrol and LPG vehicles that were in the system at 2020 are displaced by 7% diesel, 6.7% hybrid vehicles and 1.3% electric vehicles. The net impact on fuel intensity may be calculated

as 4.7% over ten years, or 0.5% p.a. Finally by 2050, 18% of petrol vehicles and 10% of diesel vehicles that are in the system at 2030 are displaced by some form of hybrid or electric vehicle. This equates to a net saving of around 5.2% over 20 years, or 0.3% p.a. approximately.

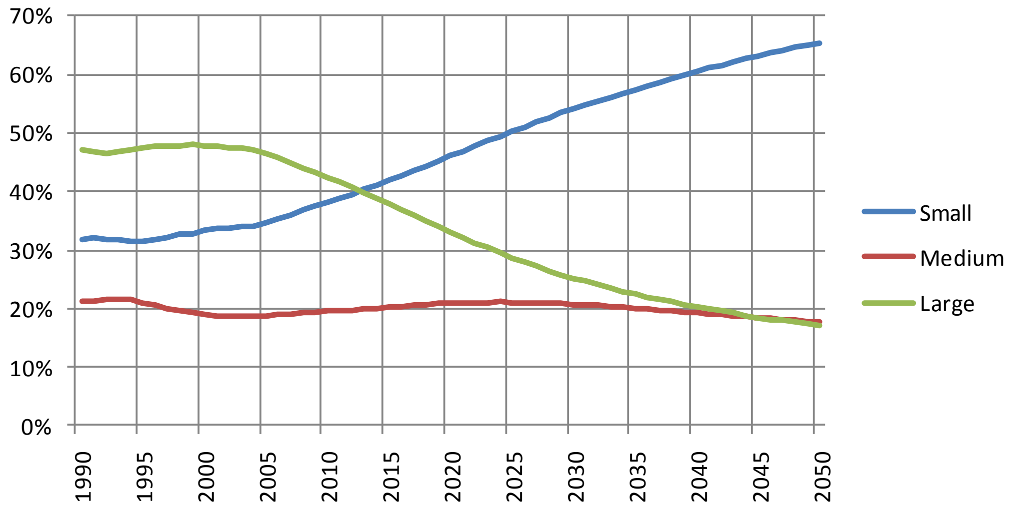
As a result of these changes to the fleet, fuel efficiency savings should be realised as per Table 6-4. In the non passenger vehicle fleet, efficiency is generally also improved. Freight vehicles and buses are expected to have all or some portion of new vehicles switching to gas fuelled alternatives, such as LNG and/or CNG. Light commercial vehicles are expected to also see increased diesel penetration before hybridisation enters the market. Refer to Figure 6-14 through to Figure 6-17.

- **Table 6-4 Summary of baseline road transport fuel intensity projections by vehicle type (MJ/km)**

Category	Sub-category	1990	2000	2008	2020	2030	2050
Fuel Intensity (MJ/km)		-	-	-	-	-	-
Road							
	Passenger	4.2	4.0	3.7	3.3	2.8	2.0
	Motorcycles	1.7	1.8	1.5	1.7	1.6	1.4
	Buses	10.7	11.4	11.3	11.9	12.2	15.3
	LCV	4.6	4.4	4.3	4.5	4.0	2.8
	Rigid	8.6	10.2	11.2	10.5	9.8	8.2
	Articulated	21.1	21.2	20.8	19.2	17.2	13.8
			Annual % change (1990-2000)	Annual % change (2000-2008)	Annual % change (2008-2020)	Annual % change (2020-2030)	Annual % change (2030-2050)
Road							
	Passenger		*-0.4%*	*-0.9%*	*-1.1%*	*-1.4%*	*-1.8%*
	Motorcycles		*0.7%*	*-2.3%*	*1.0%*	*-0.8%*	*-0.8%*
	Buses		*0.6%*	*0.0%*	*0.4%*	*0.3%*	*1.1%*
	LCV		*-0.5%*	*-0.1%*	*0.2%*	*-1.2%*	*-1.8%*
	Rigid		*1.7%*	*1.2%*	*-0.5%*	*-0.6%*	*-0.9%*
	Articulated		*0.0%*	*-0.2%*	*-0.7%*	*-1.1%*	*-1.1%*

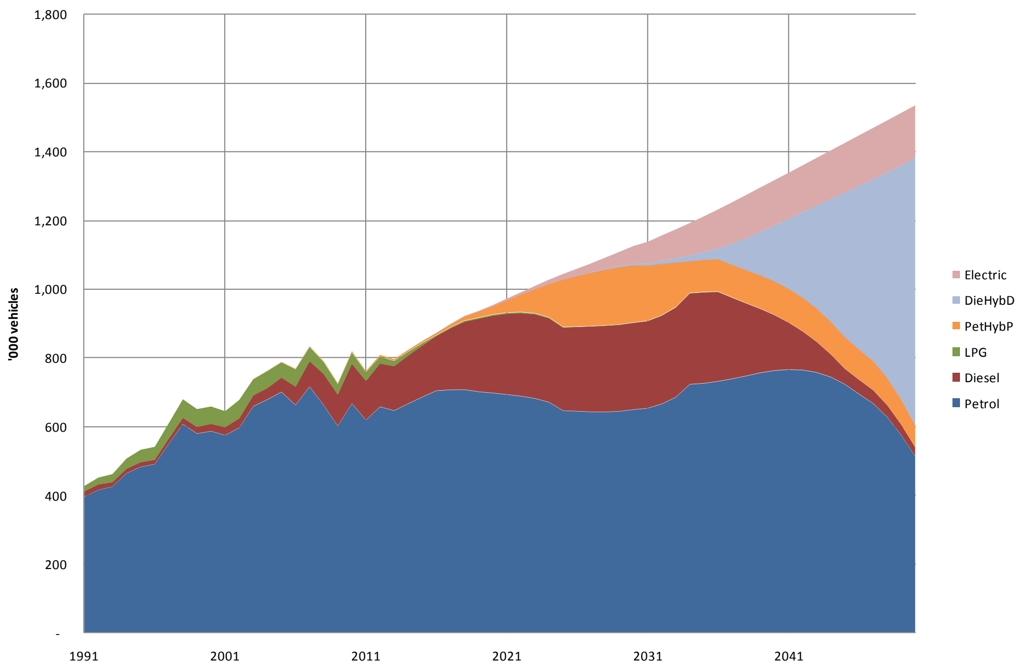
Source: SKM MMA analysis

Figure 6-9 Fleet share of vehicles by size



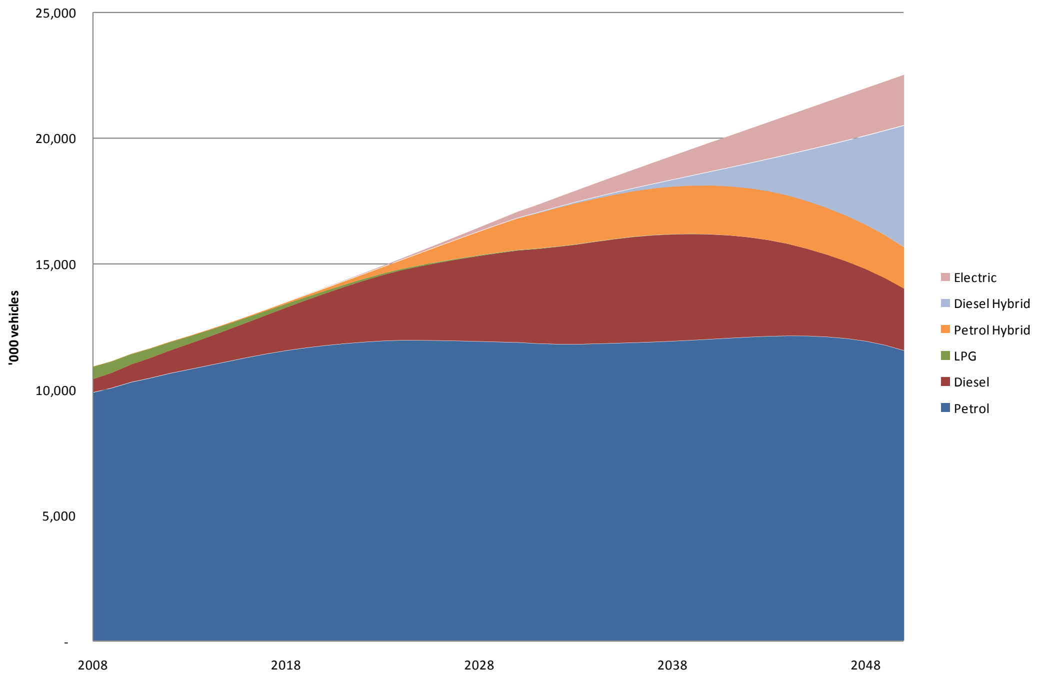
Source: SKM MMA analysis

Figure 6-10 New vehicle sales by technology



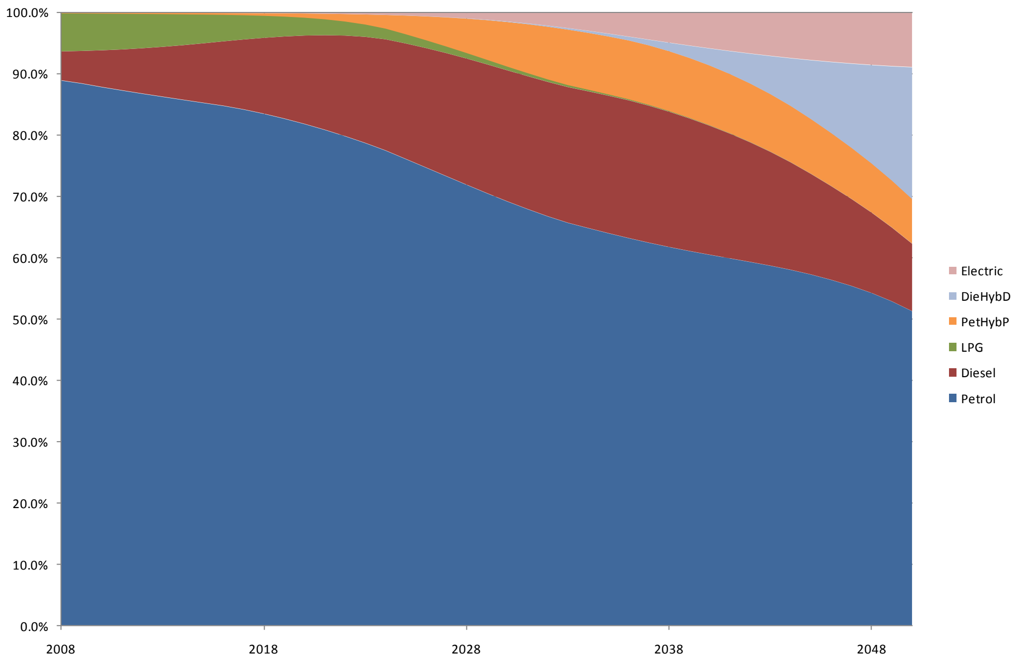
Source: SKM MMA Analysis

- **Figure 6-11 Fleet by technology**



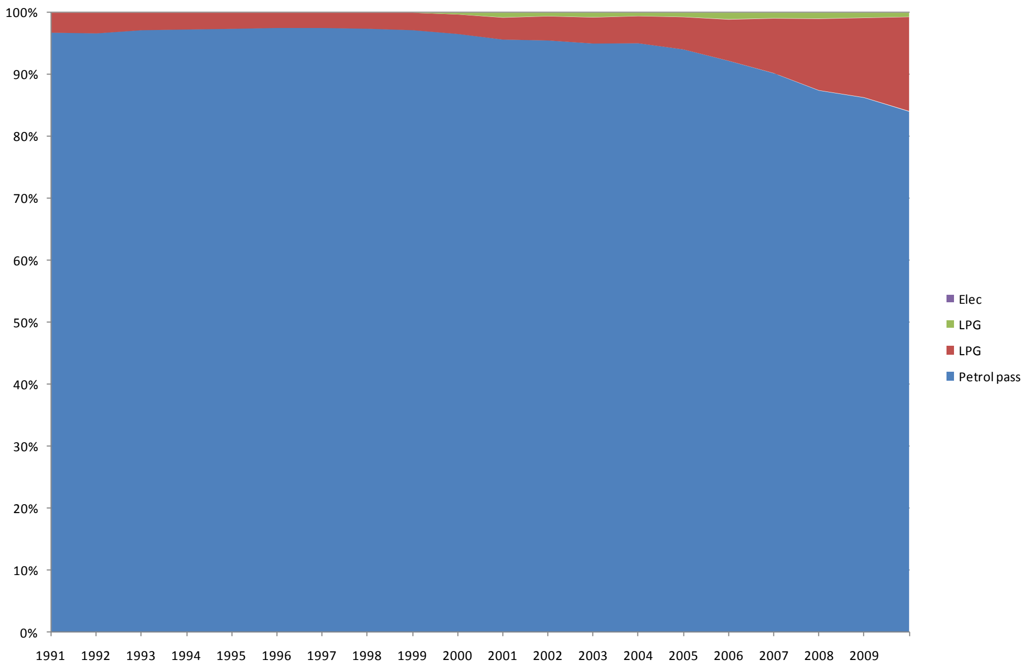
Source: SKM MMA Analysis

- **Figure 6-12 Passenger fleet technology share**



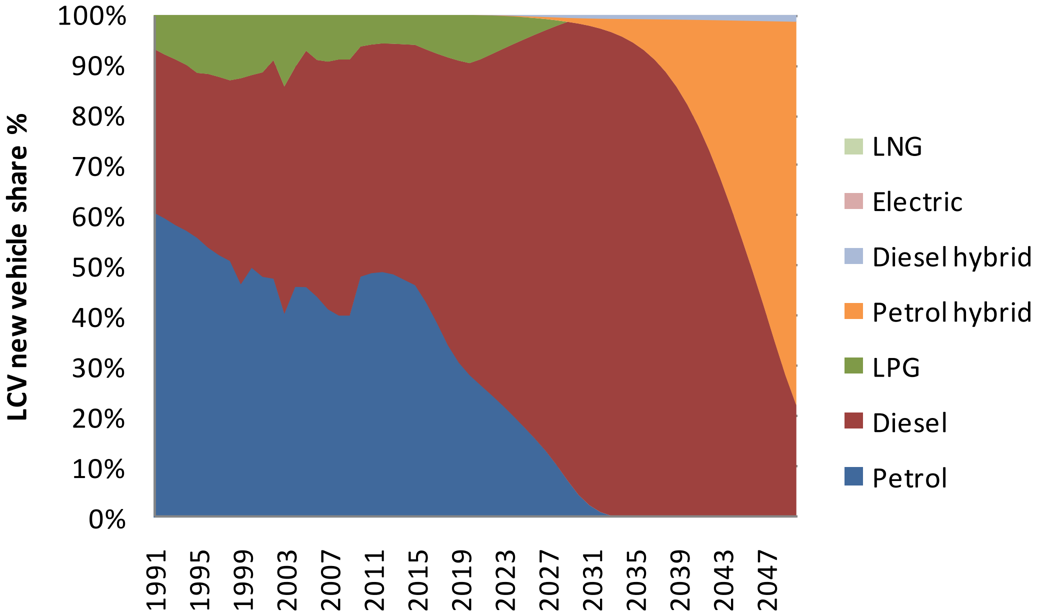
Source: SKM MMA Analysis

■ **Figure 6-13 New vehicle market share by fuel type**



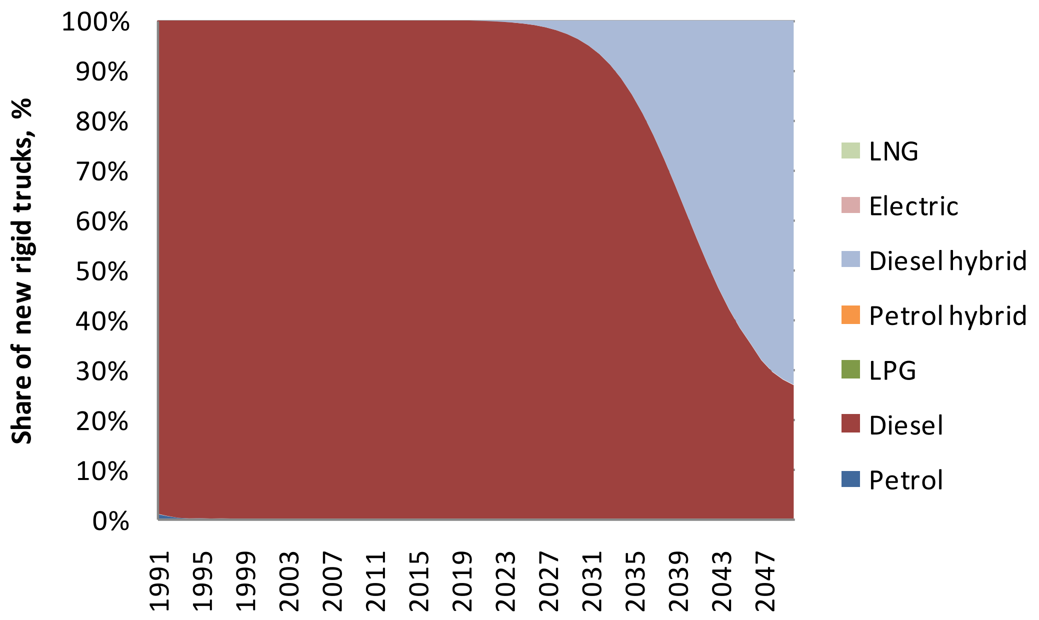
Source: SKM MMA analysis of FCAI data

■ **Figure 6-14 Technology mix of LCVs**



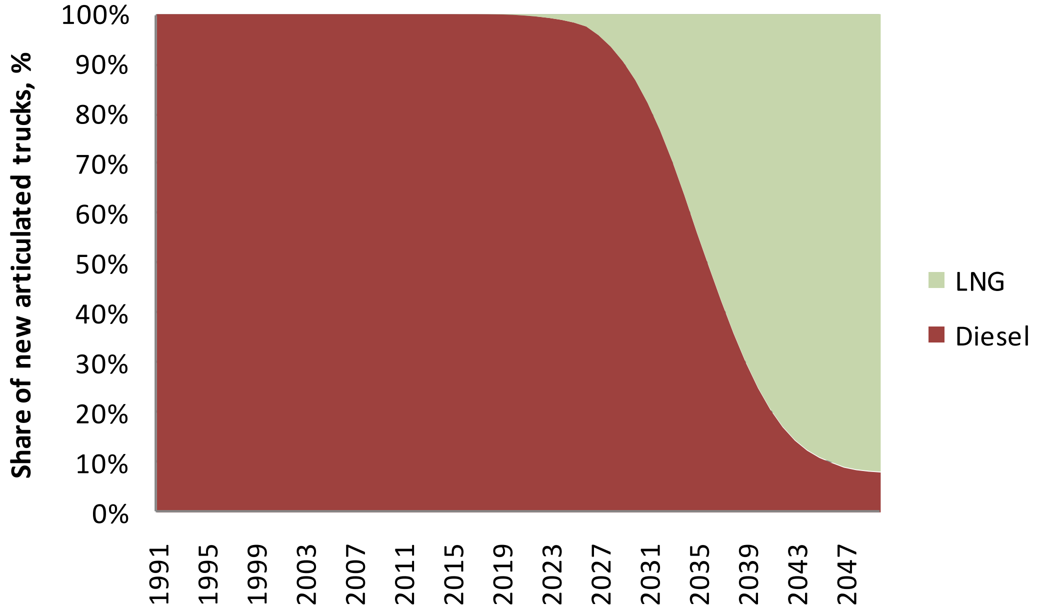
Source: SKM MMA analysis

- **Figure 6-15 Technology mix of rigid trucks**



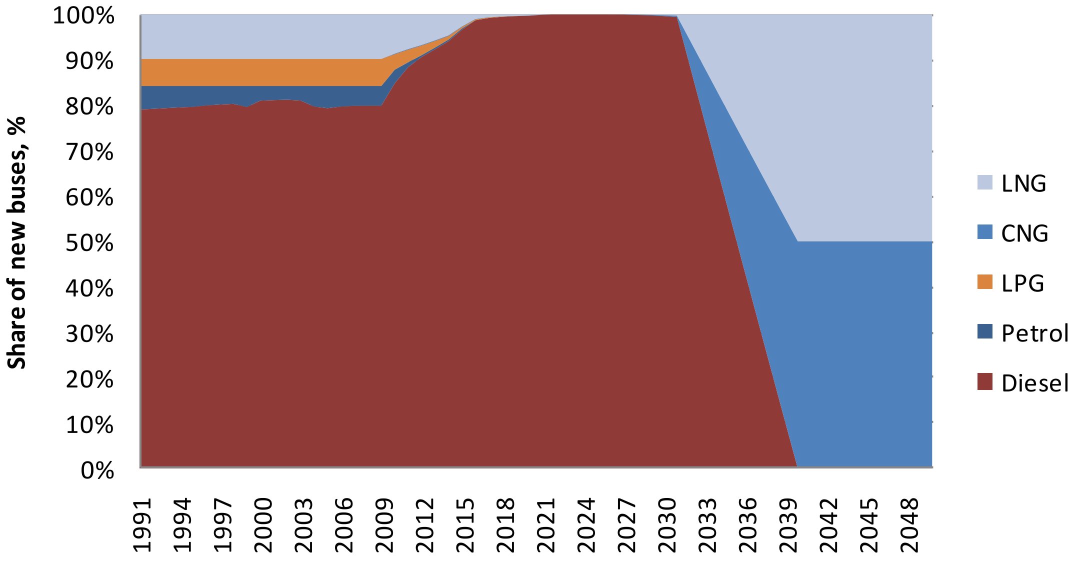
Source: SKM MMA analysis

- **Figure 6-16 Technology mix of articulated trucks**



Source: SKM MMA analysis

▪ **Figure 6-17 Technology mix of buses**



Source: SKM MMA analysis

6.1.3. Air transport

Domestic air transport emissions are projected to continue escalating through to 2050, peaking at 13.2 Mt CO_2e in that year, growing by 1.8-2% p.a. to 2030 and 3.6% p.a. after 2030. Similarly international air transport emissions are also projected to continue escalating through to 2050, peaking at 26.8 Mt CO_2e in that year, growing by 2-2.6% p.a. to 2030 and 5.3% p.a. after 2030. See Table 6-5 and Table 6-6.

In the case of domestic air emissions, emissions growth is broadly consistent with that seen in the last 8 years, and future emissions reductions are limited by the potential for future gains in fuel and operational efficiency[23]. At the same time, softening growth in GDP means that seat kilometres do not grow as fast as was the case historically.

[23] Since jet engines are a mature technology it is generally recognised that technology gains will not be large. Even though many projections fall in the range of 1-2.5% p.a., it is more than likely that future gains will themselves be below these levels. See Peeters PM, Middel J, Hoolhorst A (2005) *Fuel efficiency of commercial aircraft. An overview of historical and future trends*. NLR-CR-2005-669. (Amsterdam: Peeters Advies/ National Aerospace Laboratory NLR).

■ **Table 6-5 Domestic air emissions projection summary**

Category	Sub-category	1990	2000	2008	2020	2030	2050
Domestic Air travel							
Domestic seat-km, billions		14.8	42.7	71.1	108.3	164.4	335.5
Domestic pass-km, billions		10.5	32.2	56.2	86.4	132.1	271.4
Domestic fuel intensity (MJ/skm)		2.6	1.6	1.2	1.0	0.9	0.7
Domestic fuel use, PJ		42.2	72.2	85.7	113.8	149.0	237.3
Domestic air emissions, Mt CO2e		2.9	5.0	6.0	7.9	10.4	16.5
			Annual % change (1990-2000)	Annual % change (2000-2008)	Annual % change (2008-2020)	Annual % change (2020-2030)	Annual % change (2030-2050)
Seat-km			*11.1%*	*6.6%*	*3.6%*	*4.3%*	*3.6%*
Passenger-km			*11.9%*	*7.2%*	*3.6%*	*4.3%*	*3.7%*
Fuel intensity			*-4.5%*	*-4.0%*	*-1.1%*	*-1.4%*	*-1.2%*
Fuel Use			*5.5%*	*2.2%*	*2.4%*	*2.7%*	*2.4%*
Emissions			*5.5%*	*2.2%*	*2.4%*	*2.7%*	*2.4%*

Source: SKM MMA analysis

In the case of international air emissions, emissions growth is again broadly consistent with that seen in the past, and again reductions in emissions are limited by potential future gains in fuel and operational efficiency. Similarly softening growth in GDP leads to softened future growth in international seat kilometres.

■ **Table 6-6 International air emissions projection summary**

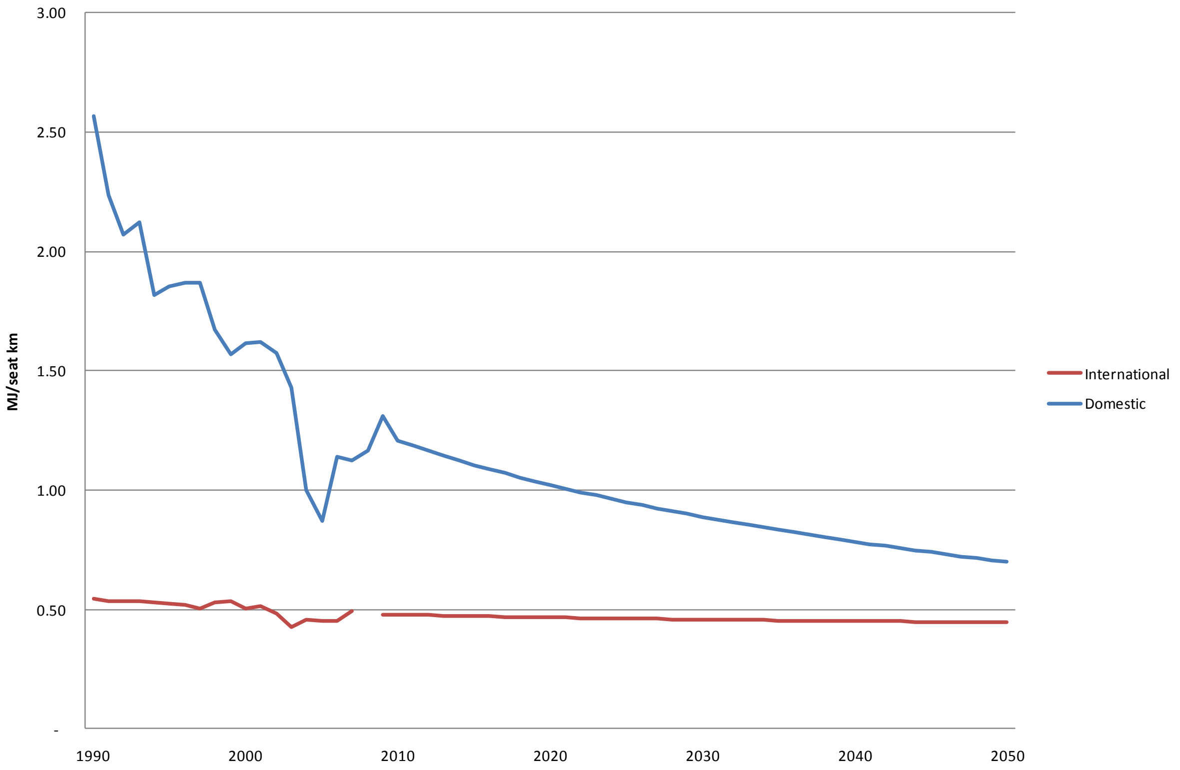
Category	Sub-category	1990	2000	2007	2020	2030	2050
International air travel							
International seat-km, billions		115.8	211.5	271.7	371.4	516.9	888.6
International pass-km, billions		78.0	146.6	205.4	279.8	393.5	682.8
International fuel intensity (MJ/skm)		0.5	0.5	0.5	0.5	0.5	0.4
International fuel use, PJ		63.0	106.2	133.3	173.0	236.4	395.2
International air emissions, Mt CO2e		4.4	7.4	9.3	12.0	16.5	27.5
			Annual % change (1990-2000)	Annual % change (2000-2007)	Annual % change (2007-2020)	Annual % change (2020-2030)	Annual % change (2030-2050)
Seat-km			*6.2%*	*3.6%*	*2.4%*	*3.4%*	*2.7%*
Passenger-km			*6.5%*	*4.9%*	*2.4%*	*3.5%*	*2.8%*
Fuel intensity			*-0.8%*	*-0.2%*	*-0.5%*	*-0.2%*	*-0.1%*
Fuel use			*5.4%*	*3.3%*	*2.0%*	*3.2%*	*2.6%*
Emissions			*5.4%*	*3.3%*	*2.0%*	*3.2%*	*2.6%*

Source: SKM MMA analysis

Air transport emissions are a product of seat kilometres and fuel intensity (in this report measured as MJ/seat km). Seat kilometres are in turn a product of passenger kilometres and load factor, where load factor is a measure of the proportion of filled seats in any journey. Passenger kilometres are driven by economic factors such as wealth and the oil price, while load factor is indicative of operational efficiency. Fuel intensity describes how fuel efficiency can be improved from technical innovation in aircraft design.

In the analysis undertaken, fuel intensity was noted to be steadily dropping (refer to Figure 6-18). It was also noted that fuel intensity for international travel is substantially lower than that for domestic travel, and SKM MMA understand that is due to greater fuel efficiency associated with longer flights, since substantially more energy is used in take-off and landing than cruising. To project this series forward, SKM MMA used a logistic trend function. Use of this method assumes that most improvement to aircraft efficiency has been realised and that future gains in efficiency will be more difficult to come by.

- **Figure 6-18 Fuel intensity projections of domestic and international aircraft**



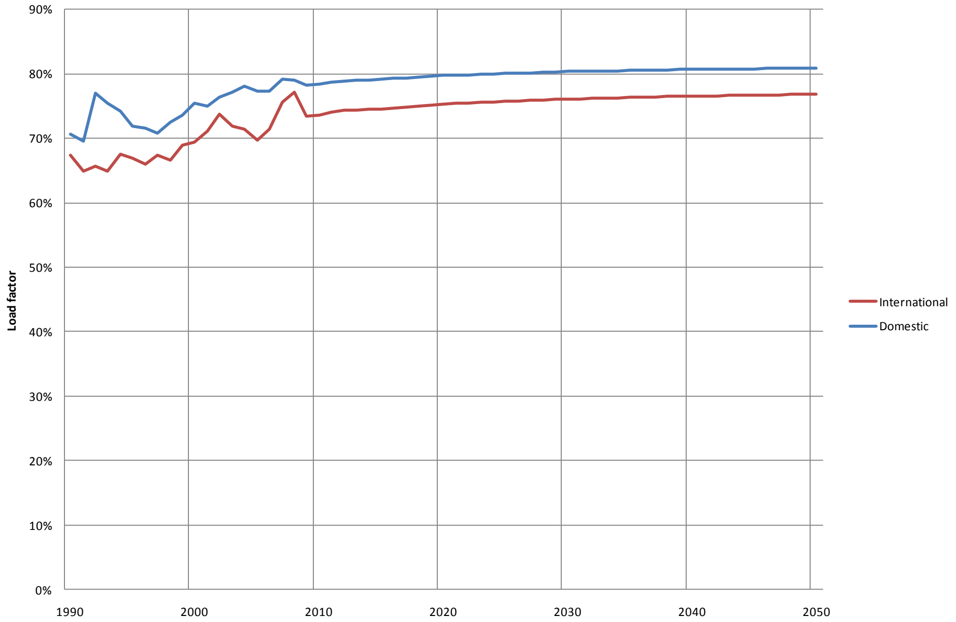
Source: SKM MMA analysis

Load factors were also considered, and again a log trend was applied to project this series forward. It was assumed that future gains in operational efficiency would not be as large as seen recently. See Figure 6-19.

Passenger kilometres was modelled by reviewing trends in passenger numbers as well as passenger kilometres, and reflecting the fact that the average trip length has been increasing historically.

SKM MMA note that there has been increasing air activity near mining towns[24] and that this may be impacting on this trend. Average air distance was therefore modelled using GDP/person and oil price as independent variables, and projected forward (see Figure-6-20). This assumes to some extent that continued mining activity is linked to GDP.

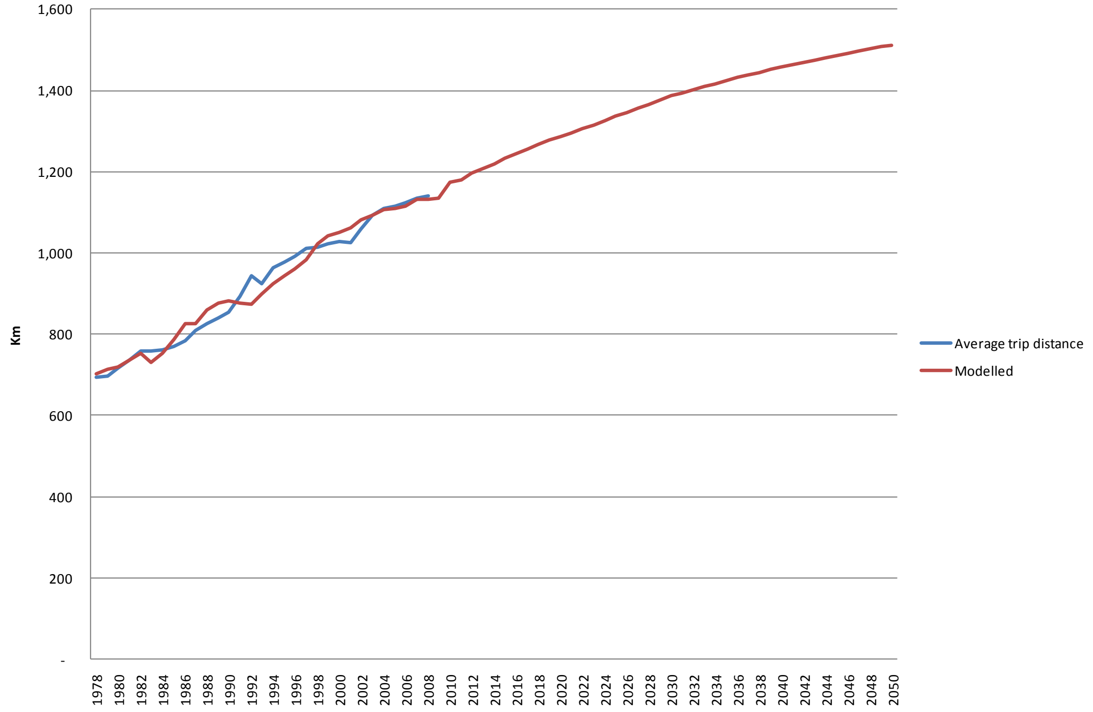
- **Figure 6-19 Load factor projections of domestic and international aircraft**



Source: SKM MMA analysis

24 SKM MMA reviewed detailed air travel data available on the BITRE website. See http://www.bitre.gov.au/Info.aspx?NodeId=96

- **Figure-6-20 Average domestic air trip length (km)**

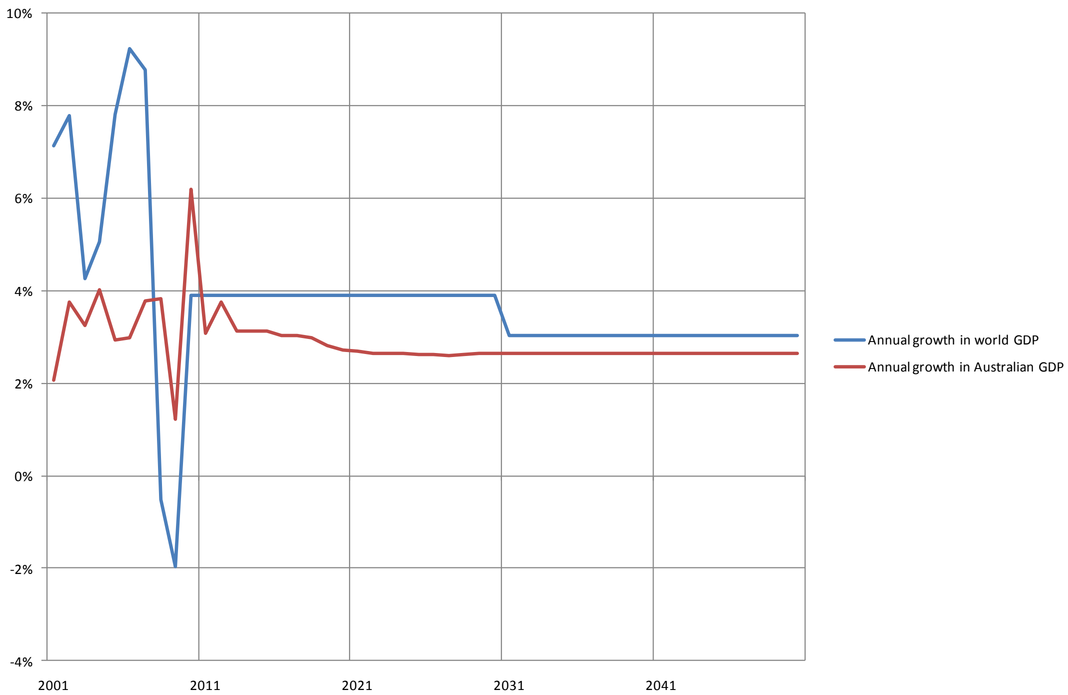


Source: SKM MMA analysis

Domestic passenger numbers were modelled by using GDP/person and international passenger numbers as independent variables. See Figure 6-22. Passenger numbers were multiplied by the average trip length to obtain passenger kilometres.

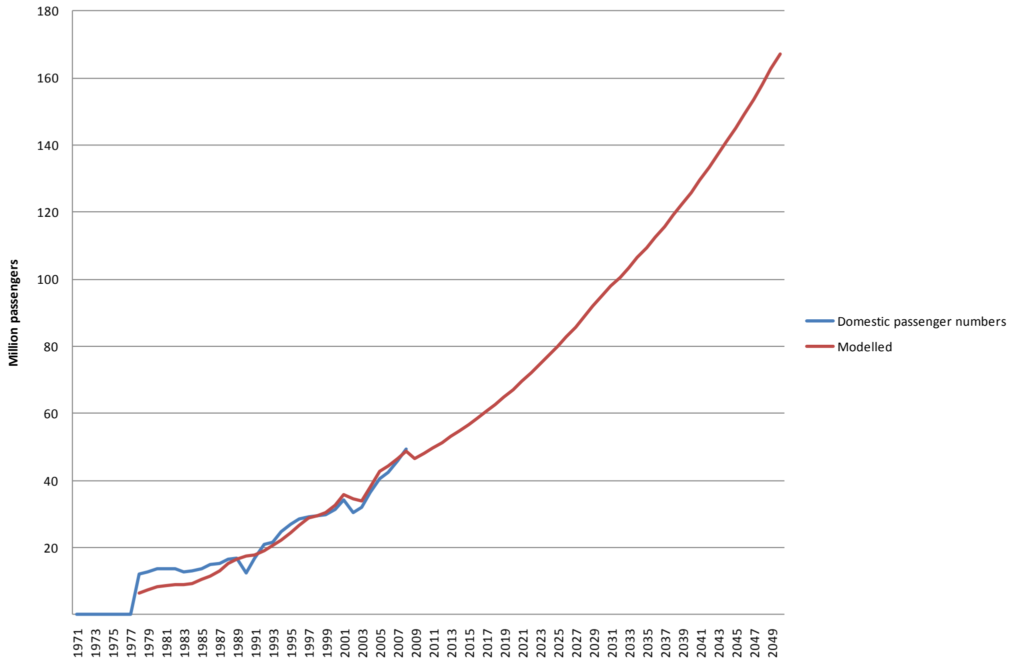
For international modelling, the same model formulation was employed, except world GDP was used to project seat kilometres. The rate of growth is therefore higher for international travel, because international GDP estimates generally assume higher growth rates. See Figure 6-21. Results are displayed in Figure 6-23.

Figure 6-21 Comparison of annual growth in World and Australian GDP



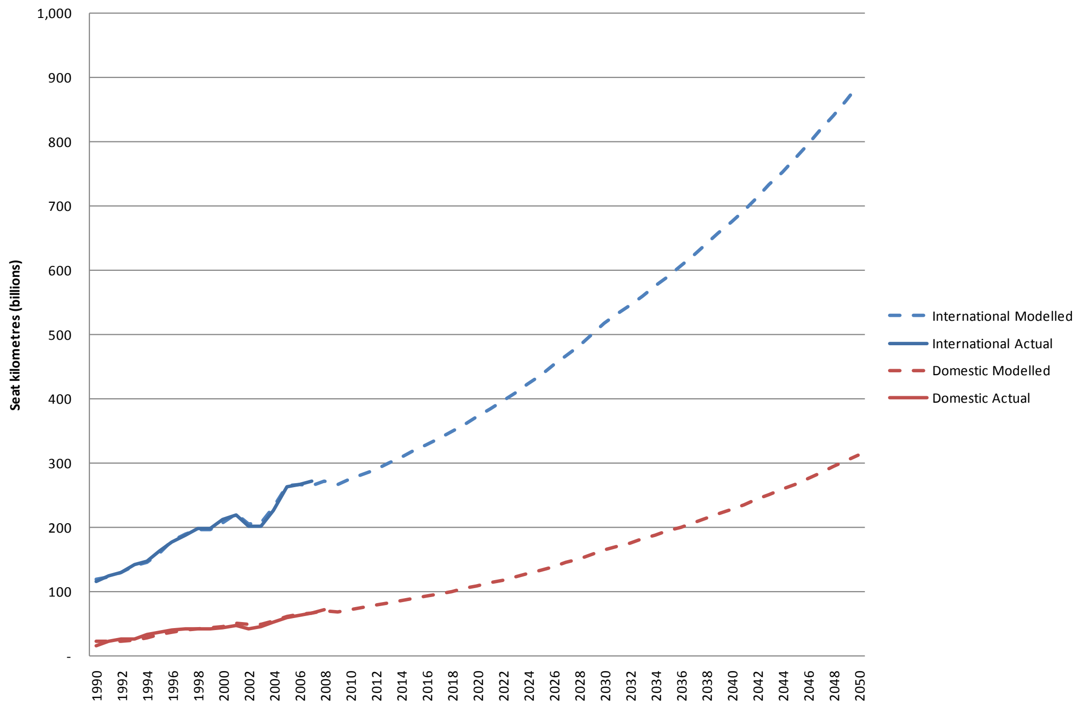
Source: SKM MMA analysis

Figure 6-22 Domestic passenger numbers



Source: SKM MMA analysis

■ **Figure 6-23 Seat kilometres projections**



Source: SKM MMA analysis

6.1.4. Rail transport

Rail Transport Emissions are projected to continue escalating through to 2050, peaking at 75.7 Mt CO_2e in that year, growing by 1.5% p.a. to 2030 and 2.4% p.a. after 2030. Freight related emissions dominate overall railway emissions, and freight rail emissions are expected to make up around 85% of all rail emissions by 2050. Freight related emissions are also expected to grow more quickly than for passenger rail emissions, with growth approximately 0.4-0.5% higher for the freight sector than for passenger travel.

Growth in passenger rail emissions is expected to be relatively low as a significant portion of the energy used in this sector is from electrified rail. See Table 6-7. Fuel intensity was assumed to stay constant for this sector, mainly because rolling stock and infrastructure is expected to have long lifetimes and therefore there is little scope for significant efficiency improvement. Passenger kilometres per person were trended against GDP/person to develop projections of passenger kilometres. It was also assumed that the same fuel intensity would apply to either electricity or diesel use, although SKM MMA understand there may be further efficiency gains from the use of electricity, particularly from regenerative braking.

Government freight rail emissions are expected to fall as a result of increased electrification. Currently private rail is all diesel powered; however it is likely that some electrification will occur in the future. Similarly government freight rail currently includes only around 8% electrification and some allowance has been made to increase this share. The modelling has assumed that electrification of private rail will occur increasing this energy share at 1% p.a. until 2028. After this time electrification of private rail will occur at a faster rate, increasing electricity's energy share by 1.5% p.a. For government rail, the modelling has assumed that the electricity share of government rail will increase by 1% p.a. to 2037 and this will ramp up to 1.5% p.a. after this time.

Freight rail tonne-kilometres were projected by first estimating the freight task that should be allocated to rail based on a multinomial logit model formulation. This was used to estimate mode share between road, rail and sea. The independent variables included investment in infrastructure and freight rates, which in turn were projected using oil price. Private freight projections and non bulk freight projections were projected using a trend with GDP and an indicator variable differentiating pre-1991 data where the underlying data seemed to contain a break that may have been caused by a change in data collection methods or similar. Government bulk rail tonne-kilometres were projected by taking the difference between total freight tonne-kilometres and private freight and non-bulk freight tonne-kilometres.

All fuel data was sourced from ABARE. However, for this work other statistics such as tonne-kilometres and associated fuel use was also available from ARA. Based on the ARA information, it was determined that the freight share of fuel use is roughly 80%, with 65% allocated to government freight, and therefore these proportions were used to split the ABARE fuel use data to freight task (government and non-government), and passenger task.

▪ Table 6-7 Passenger rail projections[25]

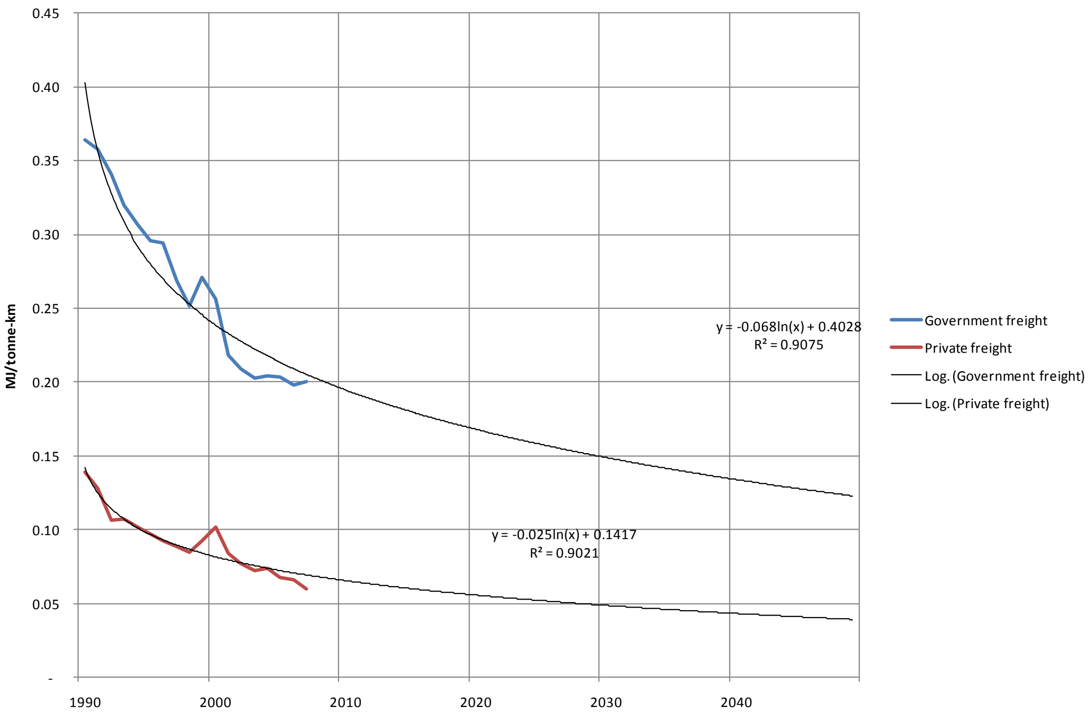
Category		1991	1998	2006	2020	2030	2050
Rail - Passenger journeys							
i. Non urban passenger							
Passenger		8.65	7.91	9.35	13.61	15.41	19.00
Passenger kilometres (billion)		1.88	2.04	1.74	2.54	2.87	3.54
Average trip kilometres		217.0	257.8	186.5	186.5	186.5	186.5
MJ/ passenger km		1.16	1.21	1.40	1.19	1.19	1.19
Fuel use, PJ		2.18	2.46	2.45	3.01	3.41	4.21
	Diesel				*1.21*	*1.37*	*1.69*
	Electricity				*1.80*	*2.04*	*2.51*
Emissions, kt CO2e					84.27	95.40	117.64
ii. Urban passenger heavy							
Passenger		405.81	438.40	501.34	589.83	667.77	823.44
Passenger kilometres (billion)		6.76	7.52	9.06	10.66	12.07	14.89
Average trip kilometres		16.7	17.1	18.1	18.1	18.1	18.1
MJ/ passenger km		0.53	0.53	0.48	0.48	0.48	0.48
Fuel use, PJ		3.58	3.96	4.34	5.10	5.77	7.11
	Diesel				*2.05*	*2.32*	*2.86*
	Electricity				*3.04*	*3.45*	*4.25*
Emissions, kt CO2e					142.46	161.28	198.88
iii. Urban passenger light							
Passenger		97.96	108.49	132.67	170.21	192.70	237.62
Passenger kilometres (billion)		0.66	0.51	0.55	0.70	0.80	0.98
Average trip kilometres		6.7	4.7	4.1	4.1	4.1	4.1
MJ/ passenger km		0.32	0.53	0.52	0.53	0.53	0.53
Fuel use, PJ (Electricity)		0.21	0.27	0.29	0.37	0.42	0.52
Emissions, kt CO2e					-	-	-
			Annual % change (1990-1998)	**Annual % change (1998-2006)**	**Annual % change (2006-2020)**	**Annual % change (2020-2030)**	**Annual % change (2030-2050)**
i. Non urban passenger							
Passenger			*-1.3%*	*2.1%*	*2.7%*	*1.2%*	*1.1%*
Passenger kilometres (billion)			*1.2%*	*-1.9%*	*2.7%*	*1.2%*	*1.1%*
Average trip kilometres			*2.5%*	*-4.0%*	*0.0%*	*0.0%*	*0.0%*
MJ/ passenger km			*0.6%*	*1.9%*	*-1.2%*	*0.0%*	*0.0%*
Fuel use, PJ			*1.8%*	*-0.1%*	*1.5%*	*1.2%*	*1.1%*
	Diesel					*1.2%*	*1.1%*
	Electricity					*1.2%*	*1.1%*
Emissions, kt CO2e						*1.2%*	*1.1%*
ii. Urban passenger heavy							
Passenger			*1.1%*	*1.7%*	*1.2%*	*1.2%*	*1.1%*
Passenger kilometres (billion)			*1.5%*	*2.4%*	*1.2%*	*1.2%*	*1.1%*
Average trip kilometres			*0.4%*	*0.7%*	*0.0%*	*0.0%*	*0.0%*
MJ/ passenger km			*-0.1%*	*-1.2%*	*0.0%*	*0.0%*	*0.0%*
Fuel use, PJ			*1.5%*	*1.2%*	*1.2%*	*1.2%*	*1.1%*
	Diesel					*1.2%*	*1.1%*
	Electricity					*1.2%*	*1.1%*
Emissions, kt CO2e						*1.2%*	*1.1%*
iii. Urban passenger light							
Passenger			*1.5%*	*2.5%*	*1.8%*	*1.2%*	*1.1%*
Passenger kilometres (billion)			*-3.6%*	*1.0%*	*1.8%*	*1.2%*	*1.1%*
Average trip kilometres			*-5.0%*	*-1.5%*	*0.0%*	*0.0%*	*0.0%*
MJ/ passenger km			*7.2%*	*-0.2%*	*0.1%*	*0.0%*	*0.0%*
Fuel use, PJ (Electricity)			*3.3%*	*0.8%*	*1.9%*	*1.2%*	*1.1%*

Source: SKM MMA analysis

[25] Note that historical emissions estimates are not available by rail classification (e.g. passenger or freight).

Energy intensity of freight rail has been declining. It is unclear whether this has occurred as a result of changes to operations (e.g. better load factors, fewer stops and starts, etc) or whether this has occurred as a result of changes to infrastructure (e.g. newer and more efficient rolling stock or putting in other infrastructure that increases efficiency). Advice from SKM indicates that longer and heavier trains, as well as improvement in locomotive technology is most likely to be the cause, as well as some limited improvement to track gradients and curves. SKM MMA have assumed that this will continue although the rate of improvement will occur at a slower pace. This was done using a logistic time trend. Projected energy use is then simply a product of energy intensity and tonne-kilometres for each sub-sector.

- **Figure 6-24 Projected energy intensity of freight rail**



Source: SKM MMA analysis

The combination of declining energy intensity and electrification counters to some extent any upward trends in freight carriage, but is insufficient to stop growth in emissions. The rail sector overall sees 1.5% p.a. growth to 2020, but this gradually reduces to 0.7% p.a. growth to 2030. After 2030, SKM MMA would expect rail emissions to grow at around 1.1% p.a. The freight sector's contribution to this slow down of growth in emissions is expected to be significant.

■ **Table 6-8 Freight rail projection summary[26]**

Category	1991	1998	2006	2009	2020	2030	2050
Rail - Freight							
i. Government nonbulk							
Million tonne-kms	19,170	25,510	41,230	41,230	44,717	54,814	64,875
MJ/ tonne-kilometre	0.36	0.25	0.20	0.20	0.20	0.17	0.15
Fuel use, PJ	6.86	6.42	8.16	8.16	8.90	9.28	9.75
Diesel	*6.20*	*5.74*	*7.49*	8.19	8.04	7.64	6.29
Electricity	*0.65*	*0.67*	*0.67*	0.71	1.24	2.11	4.19
Emissions, kt CO2e				573	562	534	439
ii. Government bulk							
Tonnes carried (millions)	189	248	368	280	519	748	1,487
Million tonne-kms	36,200	48,930	74,370	83,944	155,645	224,409	446,002
Average haul (kms)	192	197	202	300	300	300	300
MJ/ tonne-kilometre	0.36	0.25	0.20	0.20	0.17	0.15	0.12
Fuel use, PJ	12.96	12.30	14.72	16.71	26.35	33.72	54.97
Diesel	*11.70*	*11.00*	*13.51*	*15.38*	*22.82*	*26.42*	*32.98*
Electricity	*1.23*	*1.29*	*1.21*	*1.34*	*3.53*	*7.31*	*22.00*
Emissions, kt CO2e				1,075	1,595	1,847	2,305
iii. Private Freight							
Tonnes carried (millions)	190	244	317	368	429	506	661
Million tonne-kms	35,760	51,150	80,420	92,006	107,140	126,487	165,246
Average haul (kms)	188	209	253	250	250	250	250
MJ/ tonne-kilometre	0.13	0.08	0.07	0.07	0.06	0.05	0.04
Fuel use, PJ	4.58	4.32	5.28	6.15	5.98	6.18	6.43
Diesel	*4.55*	*4.30*	*5.27*	*6.13*	*5.62*	*5.20*	*4.00*
Electricity	-	-	-	-	*0.35*	*0.97*	*2.42*
Emissions, kt CO2e				430	394	364	280

		Annual % change (1990-1998)	Annual % change (1998-2006)	Annual % change (2006-2009)	Annual % change (2009-2020)	Annual % change (2020-2030)	Annual % change (2030-2050)
i. Government nonbulk							
Million tonne-kms		*4.2%*	*6.2%*	*0.0%*	*0.7%*	*2.1%*	*0.8%*
MJ/ tonne-kilometre		*-4.9%*	*-2.9%*	*0.0%*	*0.1%*	*-1.6%*	*-0.6%*
Fuel use, PJ		*-1.0%*	*3.1%*	*0.0%*	*0.8%*	*0.4%*	*0.2%*
Diesel		*-1.1%*	*3.4%*	*3.0%*	*-0.2%*	*-0.5%*	*-1.0%*
Electricity		*0.5%*	*0.0%*	*1.9%*	*5.2%*	*5.5%*	*3.5%*
Emissions, kt CO2e					*-0.2%*	*-0.5%*	*-1.0%*
ii. Government bulk							
Tonnes carried (millions)		*4.0%*	*5.0%*	*-8.7%*	*5.8%*	*3.7%*	*3.5%*
Million tonne-kms		*4.4%*	*5.4%*	*4.1%*	*5.8%*	*3.7%*	*3.5%*
Average haul (kms)		*0.4%*	*0.3%*	*14.0%*	*0.0%*	*0.0%*	*0.0%*
MJ/ tonne-kilometre		*-4.9%*	*-2.9%*	*0.2%*	*-1.5%*	*-1.2%*	*-1.0%*
Fuel use, PJ		*-0.7%*	*2.3%*	*4.3%*	*4.2%*	*2.5%*	*2.5%*
Diesel		*-0.9%*	*2.6%*	*4.4%*	*3.7%*	*1.5%*	*1.1%*
Electricity		*0.7%*	*-0.8%*	*3.3%*	*9.2%*	*7.6%*	*5.7%*
Emissions, kt CO2e					*3.7%*	*1.5%*	*1.1%*
iii. Private Freight							
Tonnes carried (millions)		*3.7%*	*3.3%*	*5.1%*	*1.4%*	*1.7%*	*1.3%*
Million tonne-kms		*5.2%*	*5.8%*	*4.6%*	*1.4%*	*1.7%*	*1.3%*
Average haul (kms)		*1.5%*	*2.4%*	*-0.5%*	*0.0%*	*0.0%*	*0.0%*
MJ/ tonne-kilometre		*-5.8%*	*-3.1%*	*0.6%*	*-1.6%*	*-1.3%*	*-1.1%*
Fuel use, PJ		*-0.8%*	*2.5%*	*5.2%*	*-0.2%*	*0.3%*	*0.2%*
Diesel		*-0.8%*	*2.6%*	*5.2%*	*-0.8%*	*-0.8%*	*-1.3%*
Electricity						*10.7%*	*4.7%*
Emissions, kt CO2e					*-0.8%*	*-0.8%*	*-1.3%*

Source: SKM MMA analysis

26 The large increase in average haul for government bulk rail is most likely to be due to hunter coal increases from Ulan, Surat to Gladstone.

6.1.5. Sea transport

Domestic Sea Transport Emissions are projected to continue escalating through to 2050, peaking at 3.6 Mt CO2e in that year, growing by -0.2% p.a. to 2020, then 0.7% p.a. to 2030 and finally by 1.2% p.a. to 2050. International Sea Transport Emissions are also projected to continue escalating through to 2050, with growth occurring at 0.9% p.a. to 2030, softening to 0.4% p.a. after 2030 to 2050. Recent years have seen reduced use of black coal and fuel oil, and these proportions of fuel use have been brought forward in the projections. Fuel intensity has declined historically, and this fuel intensity has been projected forward using a declining logistic trend (see Figure 6-25).

- **Table 6-9 Summary of sea transport emissions projections**

Category		1990	2000	2007	2009	2020	2030	2050
Maritime sector								
i. Domestic water								
Million tonnes		45	51	56	61	66	75	108
Million tonne-kms		94,200	108,900	130,400	132,127	142,529	162,425	234,680
MJ/tonne-kms		0.41	0.27	0.26	0.28	0.26	0.25	0.22
Fuel use, PJ		38.8	29.8	34.5	36.8	37.6	40.6	51.0
	Automotive gasoline	*14.07*	*15.10*	*15.56*	*15.79*	*18.41*	*20.84*	*25.69*
	Black Coal	*3.50*	*4.40*	*5.20*	*4.43*	*4.05*	*4.16*	*5.35*
	ADO	*1.22*	*1.51*	*6.62*	*10.76*	*9.84*	*10.11*	*12.99*
	IDF	*1.30*	-	-	-	-	-	-
	Fuel Oil	*18.71*	*8.66*	*7.06*	*5.70*	*5.21*	*5.35*	*6.88*
	Natural Gas	-	*0.10*	*0.10*	*0.10*	*0.10*	*0.10*	*0.10*
Emissions, Mt CO2e		3.05	2.36	2.92	2.66	2.71	2.92	3.68
ii. International water								
Million tonnes		NA	519	734	726	923	1,102	1,381
MJ/tonne-kms		NA	74	48	55	48	43	38
Fuel use, PJ		28.5	38.2	35.1	39.7	43.9	47.8	52.2
	ADO	*2.70*	*4.50*	*3.30*	*2.99*	*3.30*	*3.60*	*3.93*
	IDF	*2.90*	-	-	-	-	-	-
	Fuel Oil	*22.90*	*33.70*	*31.80*	*36.73*	*40.58*	*44.22*	*48.32*
Emissions, Mt CO2e		2.08	2.80	2.55	2.91	3.21	3.50	3.83

			Annual % change (1990-1998)	Annual % change (1998-2006)	Annual % change (2006-2009)	Annual % change (2009-2020)	Annual % change (2020-2030)	Annual % change (2030-2050)
i. Domestic water								
Million tonne-kms			*1.5%*	*2.6%*	*0.7%*	*0.7%*	*1.3%*	*1.9%*
MJ/tonne-kms			*-4.0%*	*-0.4%*	*2.5%*	*-0.5%*	*-0.6%*	*-0.7%*
Fuel use, PJ			*-2.6%*	*2.1%*	*3.2%*	*0.2%*	*0.8%*	*1.2%*
	Automotive gasoline		*0.7%*	*0.4%*	*0.8%*	*1.4%*	*1.2%*	*1.1%*
	Black Coal		*2.3%*	*2.4%*	*-7.7%*	*-0.8%*	*0.3%*	*1.3%*
	ADO		*2.1%*	*23.5%*	*27.5%*	*-0.8%*	*0.3%*	*1.3%*
	Fuel Oil		*-7.4%*	*-2.9%*	*-10.2%*	*-0.8%*	*0.3%*	*1.3%*
Emissions, Mt CO2e			*-2.5%*	*3.1%*	*-4.5%*	*0.2%*	*0.7%*	*1.2%*
ii. International water								
Million tonnes				*5.1%*	*-0.5%*	*2.2%*	*1.8%*	*1.1%*
MJ/tonne-kms				*-6.0%*	*6.9%*	*-1.3%*	*-0.9%*	*-0.7%*
Fuel use, PJ			*3.0%*	*-1.2%*	*6.4%*	*0.9%*	*0.9%*	*0.4%*
	ADO		*5.2%*	*-4.3%*	*-4.9%*	*0.9%*	*0.9%*	*0.4%*
	Fuel Oil		*3.9%*	*-0.8%*	*7.5%*	*0.9%*	*0.9%*	*0.4%*
Emissions, Mt CO2e			*3.0%*	*-1.3%*	*6.8%*	*0.9%*	*0.9%*	*0.4%*

Source: SKM MMA analysis

■ **Figure 6-25 Fuel intensity of domestic sea transport**

Source: SKM MMA analysis

7. Emission reduction measures and development of the BAU

There have been several incentive programs aimed at reducing greenhouse emissions from transport. It is difficult to quantify the abatement effects of some of these programs. However, a summary table is provided below. The impact of these measures defines the difference between the baseline and business as usual scenarios.

- **Table 7-1 Impact of emissions reduction measures**

Category	Sub-category	2010	2020
Emissions saved, kt CO2-e			
	Mandatory bio-fuels	5.7	498.4
	EEO	208.8	509.4
	AFCP	- 10.7	- 9.4
	GGAP	486.5	344.9
	Total	**690.3**	**1,343.3**

Source: SKM MMA analysis

7.1.1. Alternative fuels conversion program (2000-2008)

This program aimed to encourage the uptake of non-diesel fuels (LPG, LNG, and CNG) by commercial heavy vehicles. Grants were awarded to operators of commercial fleets for using these fuels, and to manufacturers for developing suitable engine technologies. The abatement effect of the program was relatively small: only 1084 vehicles were involved, and moreover, it was found that converting diesel engines to use other fuels does not necessarily improve greenhouse gas emissions[27]. This was found to be the case in vehicles which had lower horsepower, as they had a tendency to leave high levels of unburned methane in the exhaust, as was generally the case in the earlier years of the scheme. In later years trials indicated that gas derived fuels could be used with more success in a vehicle conversion situation provided the operating characteristics of given vehicles were appropriately considered prior to conversion. In late 2006 engine variations were developed which enabled around 10% CO_2e saving over equivalent diesel fuelled technologies, though SKM MMA understand only around 4 vehicles of this nature were switched to dual fuel capability.

To calculate emissions savings from this measure, SKM MMA assumed average travel distances for trucks and buses as described in section 4.2.3, as well as fuel intensity for each fuel as described in section 5. Fuel intensity for LNG and CNG was assumed to be a little higher than what is presently available, and was derived by taking a trend back in time. Based on documented vehicle

[27] "Alternative Fuels Conversion Program – steering technology development down a road of recovery", DEWHA 2009

numbers[28], conversions were assumed to have taken place evenly over the period from 2000 to 2008, with lifetimes of vehicles expected to be around 25 years. Emissions savings were thus calculated by first estimating fuel use for each vehicle under the new fuel less fuel use for each vehicle under diesel technology, and applying appropriate emissions factors. For the Alternative Fuels Conversion Program, while it is acknowledged that the program has had many positive benefits in the form of gaining significant early learning benefits with regard to the technology, the emissions benefit itself is projected to be negligible, and negative.

7.1.2. State government TravelSmart programs (2001-current)

These programs aim to reduce car use, by providing information on alternative transport and financial incentives. Many of the specific initiatives are carried out by local councils. The assessment of the trial of this program produced mixed results: in general, car use decreased, and public transport use, walking, and cycling increased. However, the size of the change varied among regions. It is also difficult to predict how long-lasting the effects of the program would be. Also, some states' TravelSmart programs no longer use the individual marketing technique described in the pilot study. SKM MMA understand that benefits of the program to date are of the order of 500 kt CO2e in 2009 (based on information supplied by the DCCEE).

For the purpose of the current study, it has been assumed that the impact will diminish slowly over time, as there may also be an impact of patrons setting an example to future generations. The impact of the Greenhouse Gas Abatement Program has been estimated as 1.1% of passenger vehicle fuel use, reducing by 1% p.a. to 2015, 5% p.a. to 2020, and 10% p.a. thereafter.

7.1.3. Energy efficiency opportunities (2006-current)

This program aims to reduce energy use by companies using at least 0.5 PJ/year. Energy savings from this program are forecast to be around 3PJ in 2010, increasing to around 7PJ in 2030, based on data provided by the DCCEE.

7.1.4. NSW mandatory bio-fuel standards

While bio-fuels are not as energy intensive as petrol and diesel, they are a much less emission intensive alternative. Bio-fuels reduce reliance on petroleum imports and are generally similarly priced and sometimes cheaper than standard petroleum products.

On 1 October 2007, the NSW government mandated a minimum ethanol content requirement of 2% in respect of the total volume of petrol sales in the state at the primary wholesale level. It was not required that ethanol be added to all petrol sold in NSW however. Exactly two years later the

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28 http://www.environment.gov.au/settlements/transport/publications/pubs/afcp-summary.xls

Biofuels Act 2007 was amended to increase the volumetric ethanol mandate to 4% from 1 January 2010, and then to 6% from 1 January 2011. All regular grade unleaded petrol would then be converted to E10 from 1 July 2011, implying a near to 10% volumetric proportion of ethanol at this time. In addition, the amendments allowed for a 2% volumetric biodiesel mandate from 1 January 2010, increasing to 5% from 1 January 2012. Exemptions apply for marinas and small businesses suffering hardship.

Without a mandate in place, SKM MMA has assumed a conservative projection of bio-diesel production and take-up. It has been assumed that bio-fuels would have been limited by a number of factors, such as:

- The ability of Australian industry to sustainably produce bio-fuels in a manner that does not increase emissions in this sector relative to the emissions that might have been created at the tailpipe under a fossil fuel
- Issues surrounding the competition for crops in alternative markets, such as the availability of sufficient biomass that has not already been dedicated to electricity production, human or livestock food supply or other purpose
- The ability of Australia to mass produce and develop non-food, second generation feed-stocks
- Ability of all produced bio-fuels to meet reference fuel standards
- The ability of bio-fuel producers to remain viable under potential cost increases associated with competition for feed-stocks
- Availability of infrastructure for bio-fuel production, when the infrastructure for second generation technologies (expected to be available around 2020) are quite different to first generation technology

Baseline production levels (before application of the mandate) of both fuels have been assumed to be around 0.8% of all base fuels by volume in 2010, increasing gradually to 1.2% by 2020, after which time second generation fuels are likely to be more readily available and the proportion of the overall mix will increase to 3.5-5.5% of base fuels by volume, with rates of biodiesel take-up going higher as a result of lower fuel sales of diesel relative to petrol. This is relatively conservative compared to other studies.

To date, NSW has led the way in bio-fuel consumption, and sales made up 66% of all Australian ethanol blended fuel sales in August 2010[29] alone, with remaining sales occurring in Victoria and Queensland at much lower rates of around 4% and 30% of the total respectively. It is most likely that this dominance has occurred as a result of the impending bio-fuels mandate, and that the increased production of bio-fuels from NSW has boosted consumption in Victoria and Queensland above what it might have been otherwise. In order to estimate the impact of this measure, SKM

29 "Australian Petroleum Statistics", Table 3b, August 2010, DRET.

MMA have estimated the additional bio-fuel that would be required to achieve the mandated bio-fuel targets, relative to the bio-fuel that is assumed to enter the market without a mandate. It has also been assumed that this standard is applicable to the road sector only, and that NSW fuel consumption is 32% of all Australian consumption, based on recent data.

8. Sensitivity Analyses

SKM MMA was also requested to conduct sensitivity analyses using high and low values of the following variables:

- Population (Growth increasing +/- 0.1% p.a. above baseline population growth)
- GDP (Growth increasing +/- 0.5% p.a. above baseline GDP growth)
- Fuel intensity (Private vehicle fuel intensity 15% above and below baseline fuel intensity and trucks 0.1% above and below baseline fuel intensity)
- Oil Price (High and low cases supplied by DCCEE – high case around 22% above baseline in 2030 and low case around 25% below baseline in 2030)
- Congestion parameters (+/- 50% of baseline congestion parameter)

In addition, two further sensitivity analyses were requested – an overall high case, encompassing high levels of population, GDP, fuel intensity, congestion parameters and a low oil price, as well as an overall low case, encompassing low levels of population, GDP, congestion parameters and a high oil price. The results are summarised in Table 8-1 below. When taken in combination, the high case provides projections 4.6% higher than our baseline projection by 2020, and 7.6% higher than the baseline by 2030. Similarly the low case provides projections 3.2% lower than the baseline in 2020 and 4.9% lower than the baseline by 2030. When looked at individually, the parameter with the largest variation is fuel intensity, as unrealised improvements to fuel efficiency can add as much as 3.1% to the projections by 2030.

Descriptive charts are also provided in Figure 8-1 to Figure 8-6. Most charts provide easily understood results – parameters which increase fuel use – such as low oil prices, high GDP, high congestion - generally raise emission levels while parameters which reduce fuel use will usually reduce emission levels. This is evident in most of the charts except for oil prices and population.

With regard to population, raising population levels while keeping GDP constant was found to reduce GDP/person, which is a predictive variable in much of the modelling. For example, reducing GDP/person reduces VKT/person estimates in the passenger travel models. Countering this, vehicle stock levels rise with higher population and therefore the change to population levels alone was found to bring about negligible changes in emission projections between the low and the baseline scenarios. Under the high population case the increase in population was significant enough to bring about a positive change in emissions.

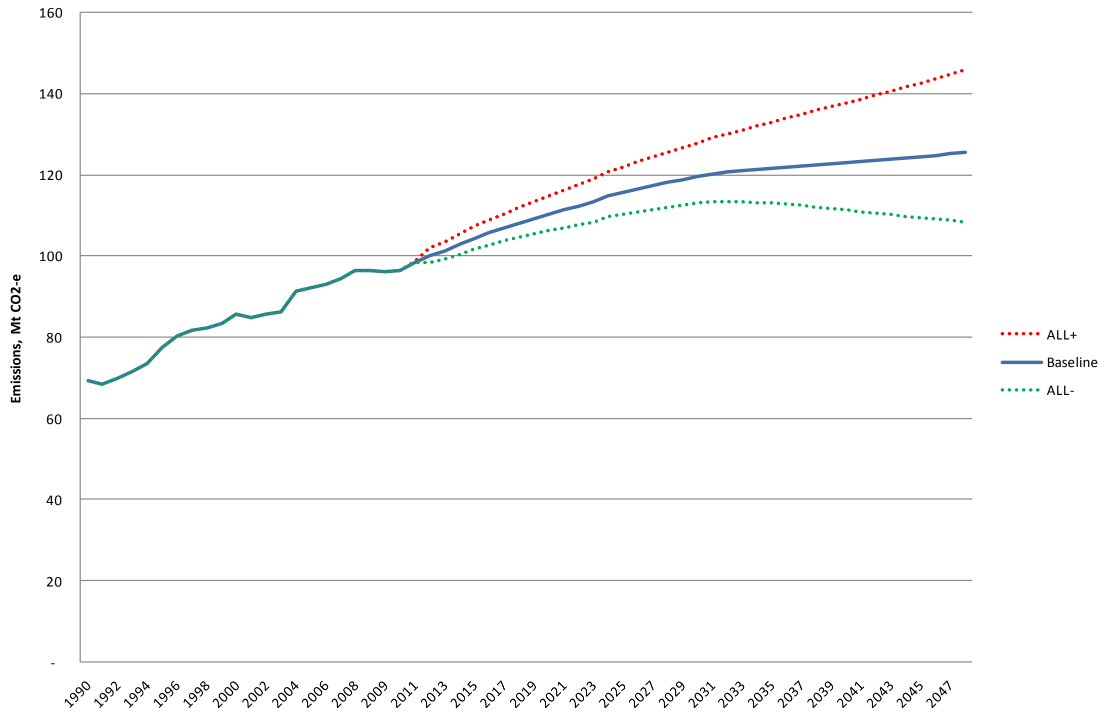
With regard to oil prices, low oil prices were found to bring about significant increases in emissions, as one would expect. However, high oil prices did not necessarily bring about a significant reduction in emissions until after 2040. There are a number of mitigating factors; these include increases in rail and sea freight emissions that occur as a result of reduced road freight emissions. Also, increased oil prices do have an effect on technology change and vehicle size, but these changes are restricted by the rate of vehicle turnover. In addition, the model assumes a relatively conservative outlook on technology change and thus there is some delay for consumers purchasing many alternative technologies.

Table 8-1 Summary of sensitivity analyses

Scenario	2008	2016	2020	2030	2050
Baseline (Mt CO2e)	96	106	110	120	126
ALL-	0.0%	-2.9%	-3.8%	-5.5%	-14.7%
ALL+	0.0%	3.0%	4.1%	7.0%	17.9%
Cong-	0.0%	-0.4%	-0.8%	-1.1%	-0.9%
Cong+	0.0%	0.4%	0.8%	1.1%	0.9%
Oil-	0.0%	0.1%	0.3%	0.9%	3.9%
Oil+	0.0%	-0.1%	-0.1%	0.1%	-3.6%
GDP-	0.0%	-0.8%	-1.5%	-3.3%	-5.2%
GDP+	0.0%	0.5%	0.8%	1.3%	3.8%
Pop-	0.0%	0.6%	0.5%	0.1%	-0.5%
Pop+	0.0%	1.0%	1.2%	1.6%	1.8%
FuelInt-	0.0%	-1.7%	-1.8%	-2.4%	-6.9%
FuelInt+	0.0%	1.7%	1.8%	2.4%	6.5%

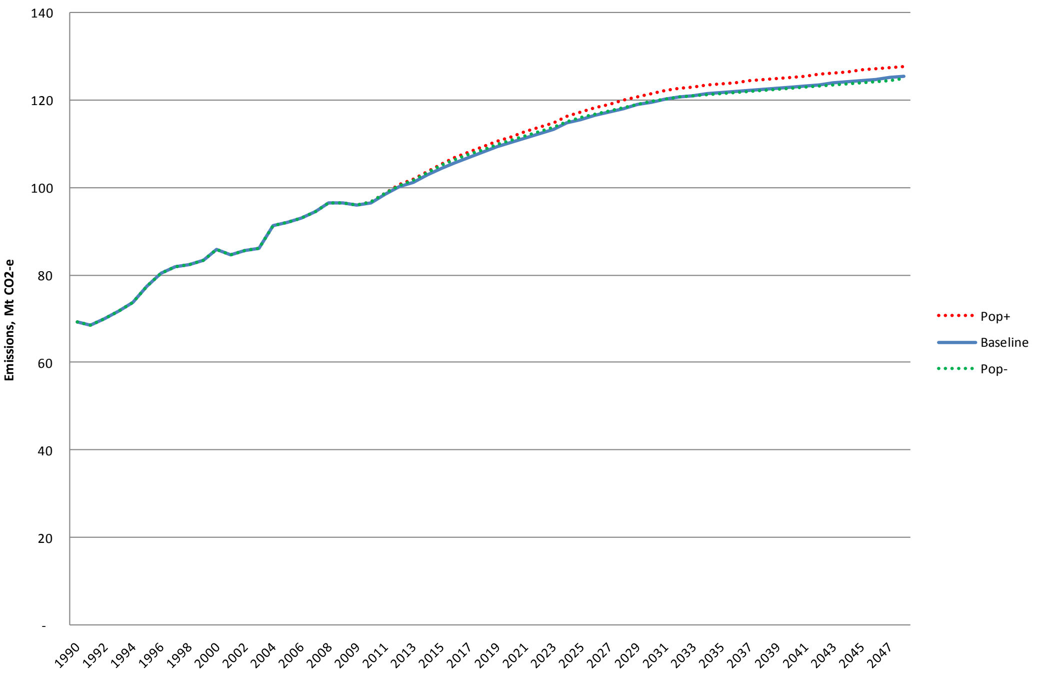
Source: SKM MMA analysis

Figure 8-1 Sensitivity analysis – overall high and low case



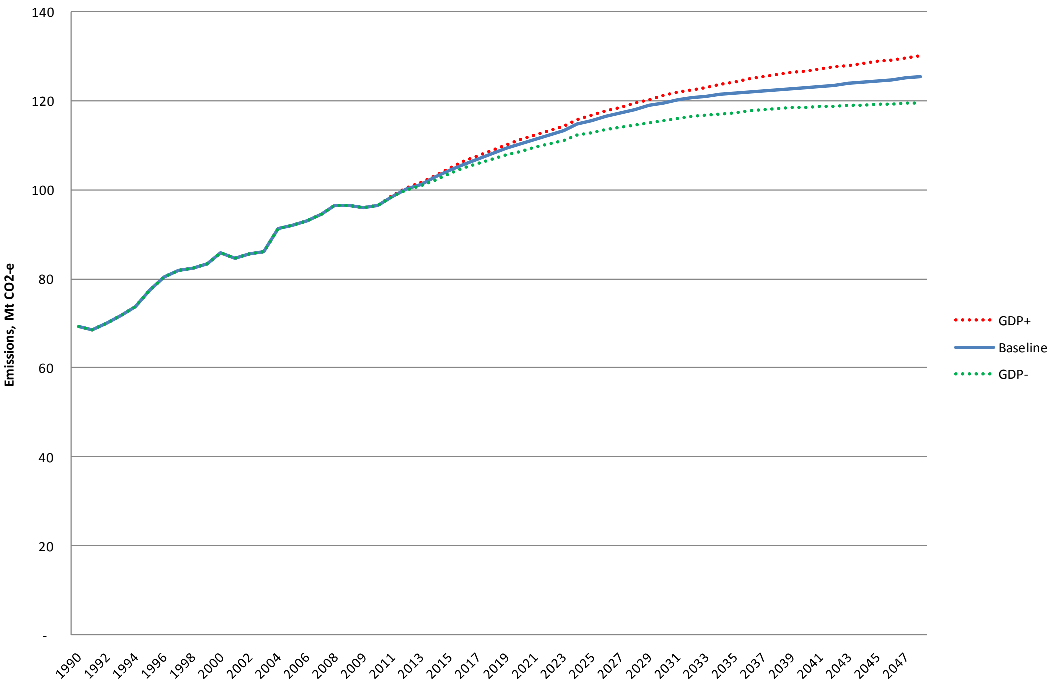
Source: SKM MMA analysis

Figure 8-2 Sensitivity analysis – population high and low case



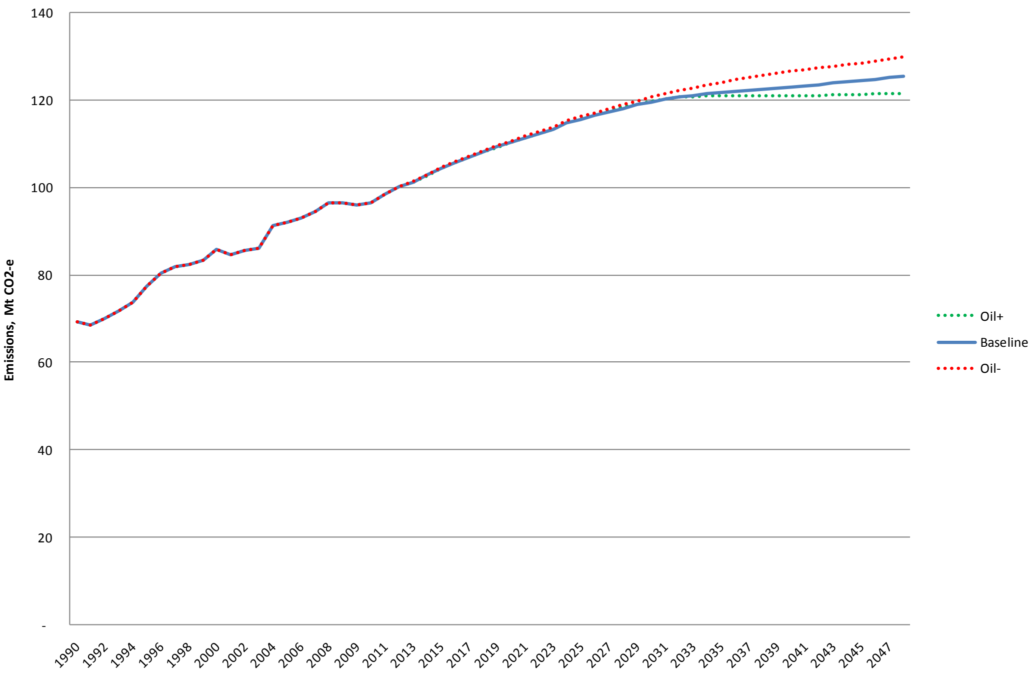
Source: SKM MMA analysis

Figure 8-3 Sensitivity analysis – GDP high and low case



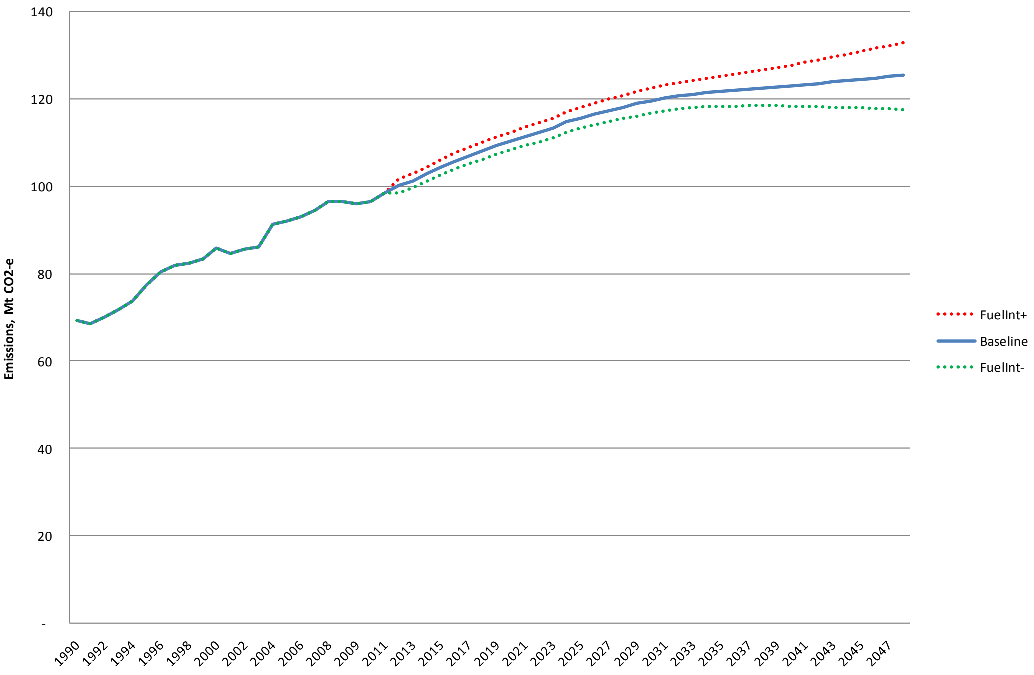
Source: SKM MMA analysis

- **Figure 8-4 Sensitivity analysis – oil price high and low case**



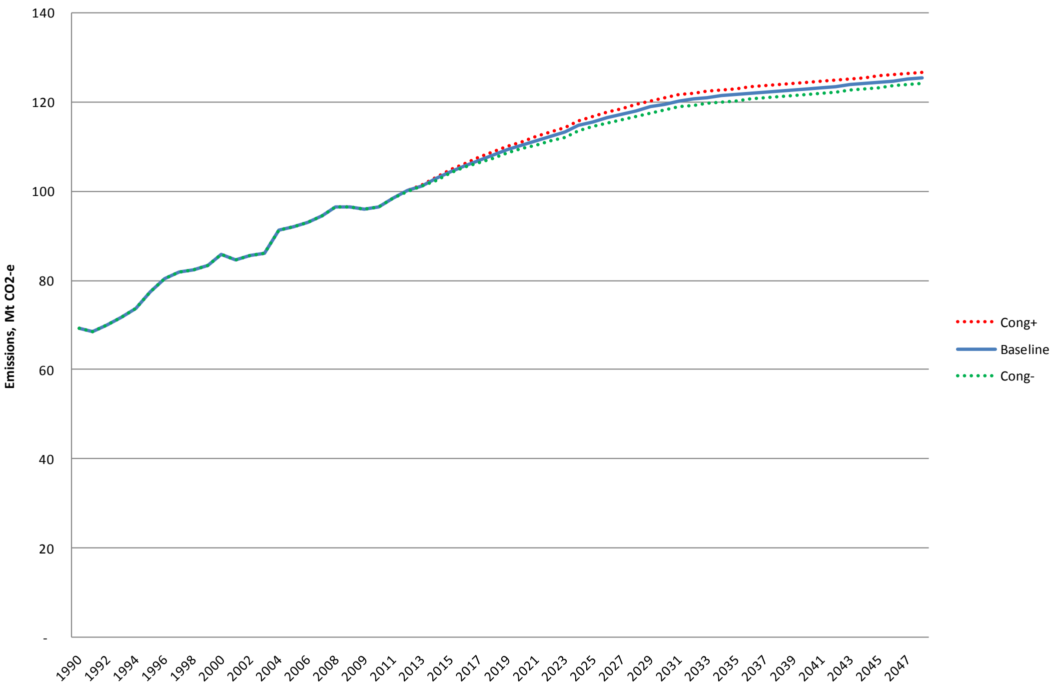
Source: SKM MMA analysis

- **Figure 8-5 Sensitivity analysis – fuel intensity high and low case**



Source: SKM MMA analysis

Figure 8-6 Sensitivity analysis – congestion parameter high and low case



Source: SKM MMA analysis

Appendix A Methodology

Our analysis of the transport sector uses an in-house Excel-based spreadsheet model called the Transport Emissions Model (TEM). The model operates in the following way:

- It divides the transport sector into a number of sub-sectors and activity types, based on the mode, type and size of transport task associated with each activity.
- For each activity, an estimate of activity task or demand is required. Typically activity task is measured in either vehicle kilometres travelled (VKT), tonne-kilometres (TKM), seat-kilometres (SKM), or passenger-kilometres (PKM).
- For each activity, a detailed model is built to estimate fuel intensity. Fuel intensity describes the amount of fuel required per unit of activity task. For example, in the private vehicle sector, a detailed stock and technology model is built to estimate litres of (petrol equivalent) fuel per 100 kilometres travelled.
- Task levels are multiplied by fuel intensity to obtain total fuel use. Only one form of task measure is appropriate for this calculation.
- Fuel use is multiplied by fuel emissions factors to derive total emissions.

An overview of the way the model is structured for the various sectors is provided in Figure A-1 through to Figure A-10 on the next few pages. Note that the models for passenger rail and freight rail are identical to the models for private vehicles and commercial vehicles, respectively.

Figure A-1 Private vehicle emissions model (duplicated for PVs, motorcycles, buses and rail passenger tasks[30])

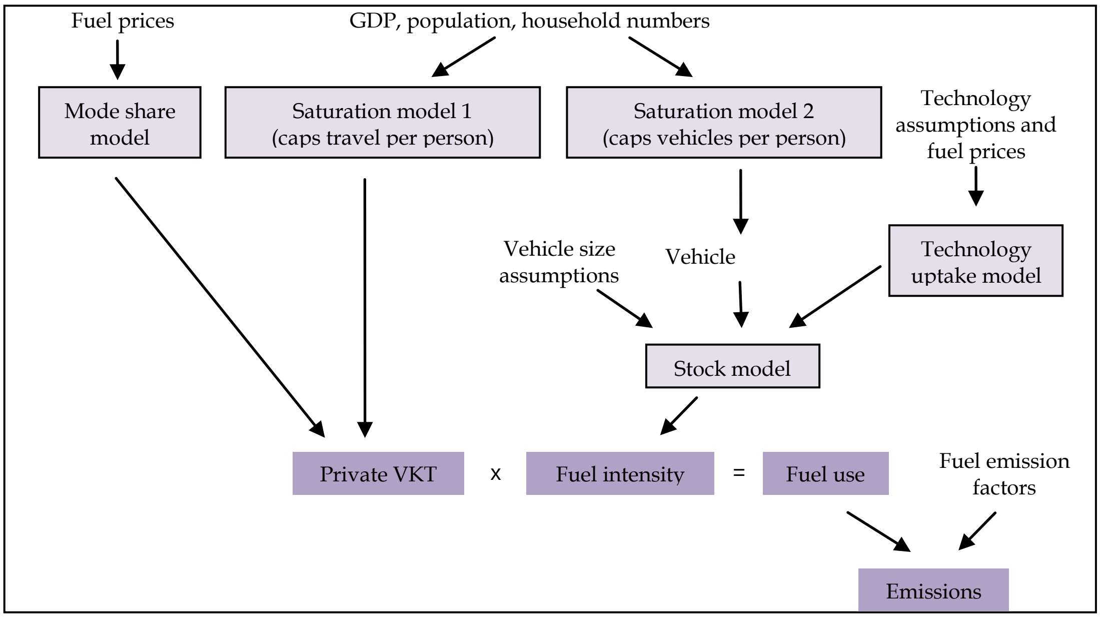
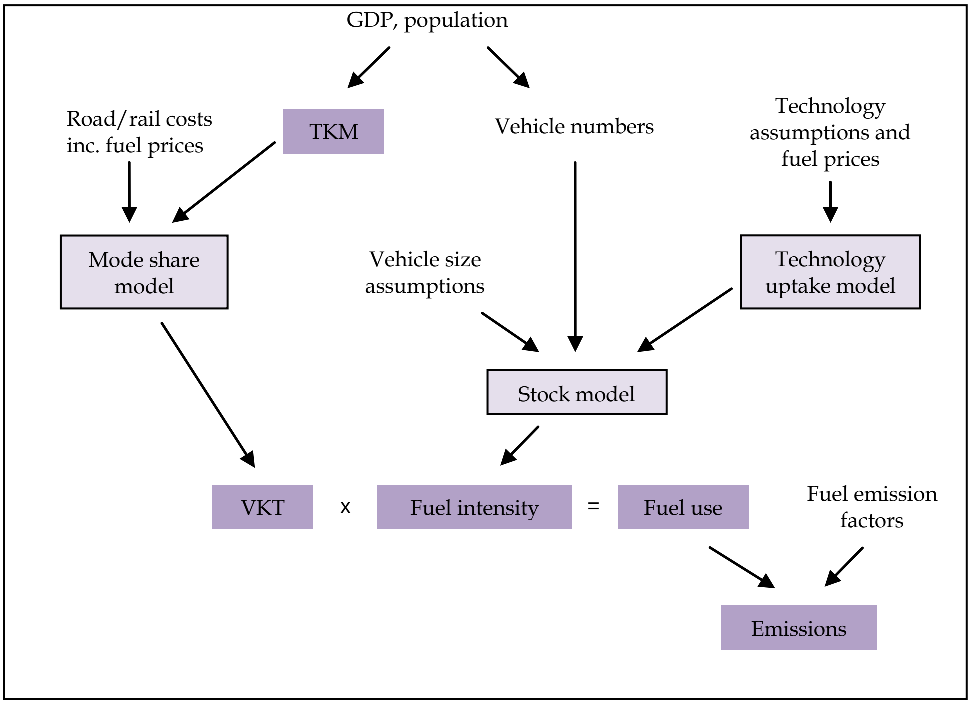


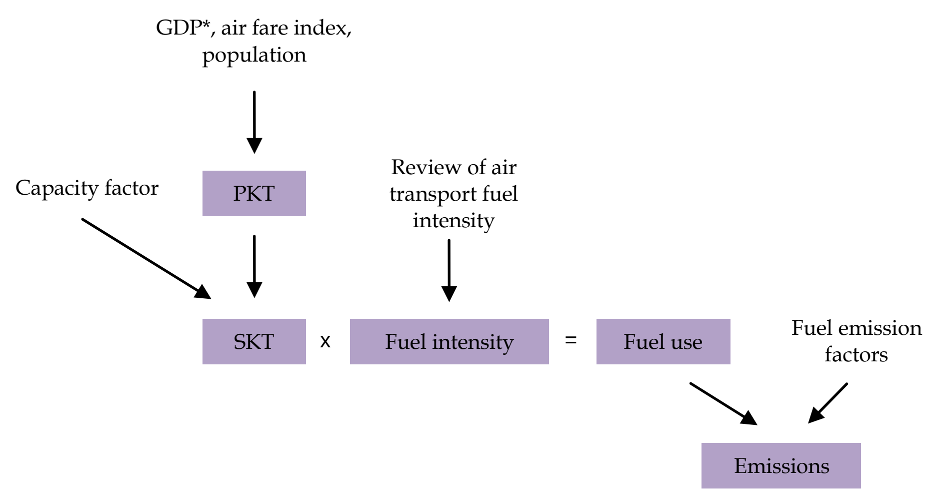
Figure A-2 Commercial vehicle emissions model (duplicated for LCVs, rigid and articulated trucks and rail freight tasks[31])



[30] Technology uptake models and stock models do not exist for rail passenger tasks. In these instances fuel intensity is estimated from historical values.

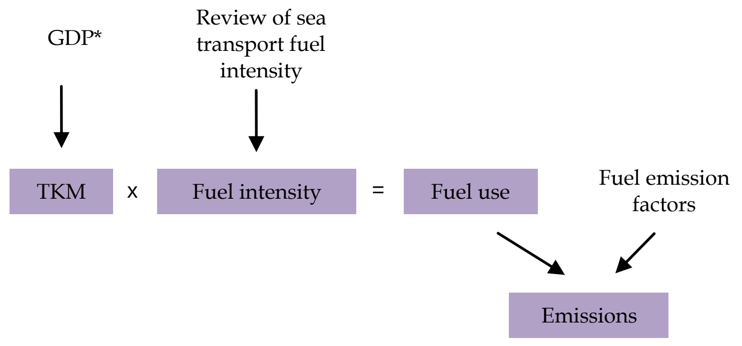
[31] Technology uptake models and stock models do not exist for rail freight tasks. In these instances fuel intensity is estimated from historical values.

- **Figure A-3 Air transport emissions model (applied for domestic and international transport, simple projection applied for general air transport)**



*World GDP for international model, Australian and world GDP for domestic model (since a portion of the domestic PKT arises from international tourism).

- **Figure A-4 Sea transport emissions model (applied for domestic and international transport)**



*World GDP for international model, Australian GDP for domestic model.

Table A-1 Transport sub-sectors

Sector	Activity type	Task measure (fuel intensity applied to measure with asterisk)
Road	Private vehicles (small, medium, large)	VKT*, VKT/person
	Light commercial vehicles	VKT*, TKM
	Buses	VKT*
	Motorcycles	VKT*
	Rigid Trucks	VKT*, TKM
	Articulated Trucks	VKT*, TKM
Rail	Non urban passenger	PKM*
	Urban Passenger heavy	PKM*
	Urban Passenger light	PKM*
	Government non-bulk	TKM*
	Government bulk	TKM*
	Private freight	TKM*
Air	Domestic	PKM, SKM*
	International	PKM, SKM*
Sea	Domestic	TKM*
	International	TKM*

Emissions estimates for international bunker fuels are also required. These are equivalent to international air transport emissions plus international sea transport emissions.

A.1 Activity task

Measures of activity task are important for a number of reasons, principally because they are also measures of transport demand. Passenger vehicle VKT is used to measure activity levels in the passenger vehicle fleet and is also applied to a fuel intensity estimate (that is, litres fuel used per 100 km travelled) to derive an overall estimate of fuel use from which emissions can be calculated. For commercial vehicles, the same holds true for VKT; however an alternative measure – TKM or tonne-kilometres - is typically also used to understand the impact of additional or lost tonnage on the system. For example, transference of some bulk tonnage to an alternative mode such as rail will not necessarily have a one-to-one effect on reducing VKT, and hence will not necessarily have a proportional reduction effect on emissions. In that instance, it is important to understand the impact of operational parameters such as average payload and efficiency of vehicles under different payloads. Average payload is influenced by a number of factors, including average vehicle size (for example, presence of B-doubles or B-triples, road trains, etc) and logistical ability to maximise vehicle capacity for each trip undertaken.

The activity level measures used for rail are passenger-kilometres and tonne-kilometres.

The activity level measures used in aviation (and requested by DCCEE) are passenger-kilometres and seat-kilometres. Passenger-kilometres are typically adjusted by a capacity factor to derive seat-kilometres, and seat-kilometres are typically a better estimate of transport activity that should be applied to fuel intensity. Higher airplane capacity factors are therefore indicative of lower fuel use per passenger-km and hence lower emissions per passenger-km.

Methods of projecting activity task for each sector are described in Table A-2.

Table A-2 Methods of projecting activity task

Sector	Task measure	Method used for projection
Road	Private VKT	Trend VKT/person with GDP (as a measure of income), utilising saturation functions.[32]
	Light commercial and rigid truck TKM	Trend TKM with GDP
	Articulated truck VKT	Estimate average payload based on history and apply to TKM forecast
	Articulated truck TKM	Trend TKM with GDP
Air	PKM	Trend PKM with GDP
	SKM	Divide PKM by capacity factor to obtain SKM
Rail	PKM	Trend PKM/person with GDP
	TKM	Trend with GDP
Sea	TKM	Trend with GDP

A.2 Fuel intensity estimates: road

Vehicle efficiency projections depend on vehicle technology and vary over the planning period. To better understand the changes occurring in vehicle efficiency over the entire fleet, a stock model has been built, which takes account of changeover of stock to newer models with improved efficiency, as well as changeover to different technologies with better efficiency. Vehicle attrition

32 It is also possible to use mode share projections as part of this work, though MMA have opted not to do this because of the difficulties associated with collected appropriate cost data for the public transport network. With regard to VKT/person (in the case of private VKT), it is possible to model mode share against travel cost and household income, assuming we had reasonable cost estimates for private travel versus public transport.

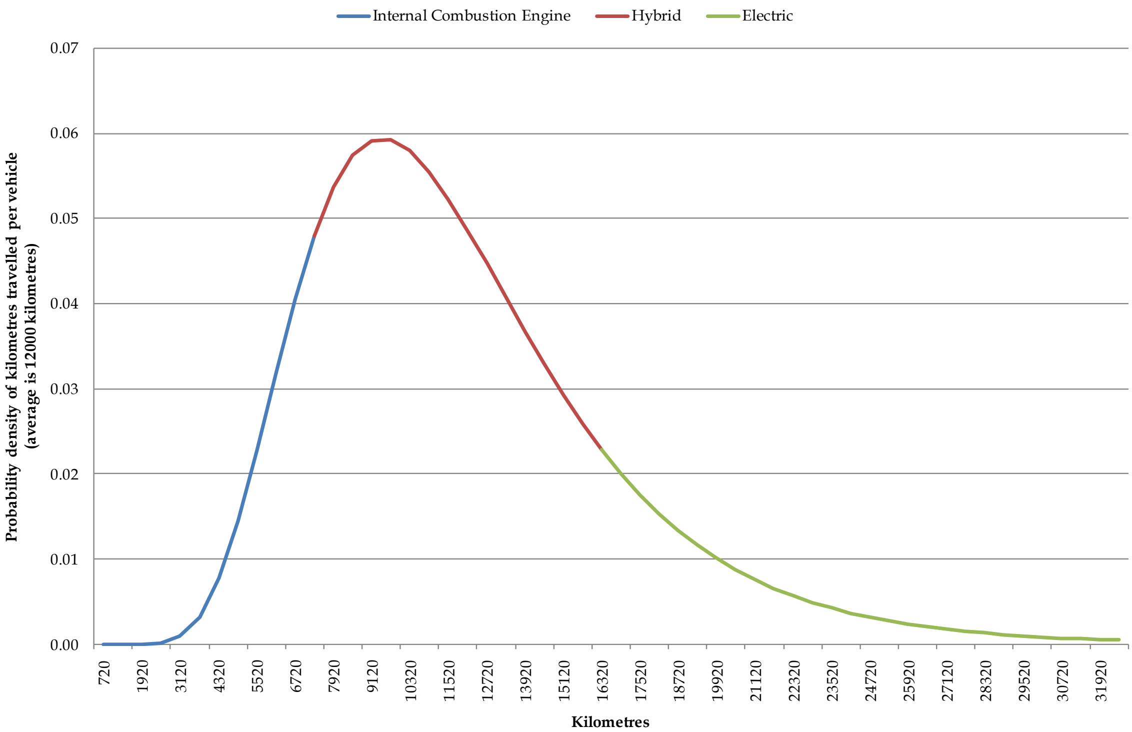
is modelled by retiring the oldest vehicles first and assuming a vehicle age distribution derived from ABS data.

Market shares for new vehicles are determined using a technology market share model. This model considers the following technologies:

- Internal combustion engine (ICE)
- Plug-in hybrid
- Mild hybrid (using regenerative braking to create power)
- Electric
- Hydrogen
- LPG
- Diesel

Under the technology market share model, technology costs are applied and the net present cost is calculated for each technology. A log-normal distribution of vehicle kilometres travelled is assumed for each vehicle purchased in a given year. The log-normal distribution was chosen in preference to the normal distribution because the series is naturally bounded at zero. The expected market share is determined by calculating the portion of the market for which a given technology would have the lowest cost. Figure A-5 illustrates this concept, showing a hypothetical example of a group of new vehicles where drivers travel a range of distances, represented on the x-axis of the chart. In the example, standard technology is still the cheapest form for those that drive relatively short distances, but hybrids or electric vehicles are economic for those in the fleet travelling longer distances.

Figure A-5 Technology market share example



The vehicle distance analysis described relies on assumptions made about book lives of vehicles, technology costs, and fuel efficiencies, and the discount rate.

Once technology market shares for new vehicles are established, an estimate of fuel intensity can be made for the stock of vehicles in use in each year in each class, including both existing and new vehicles (the model also assumes a decline in fuel efficiency for older vehicles). The fuel intensity is then multiplied by the transport task in each class to derive an estimate of fuel use.

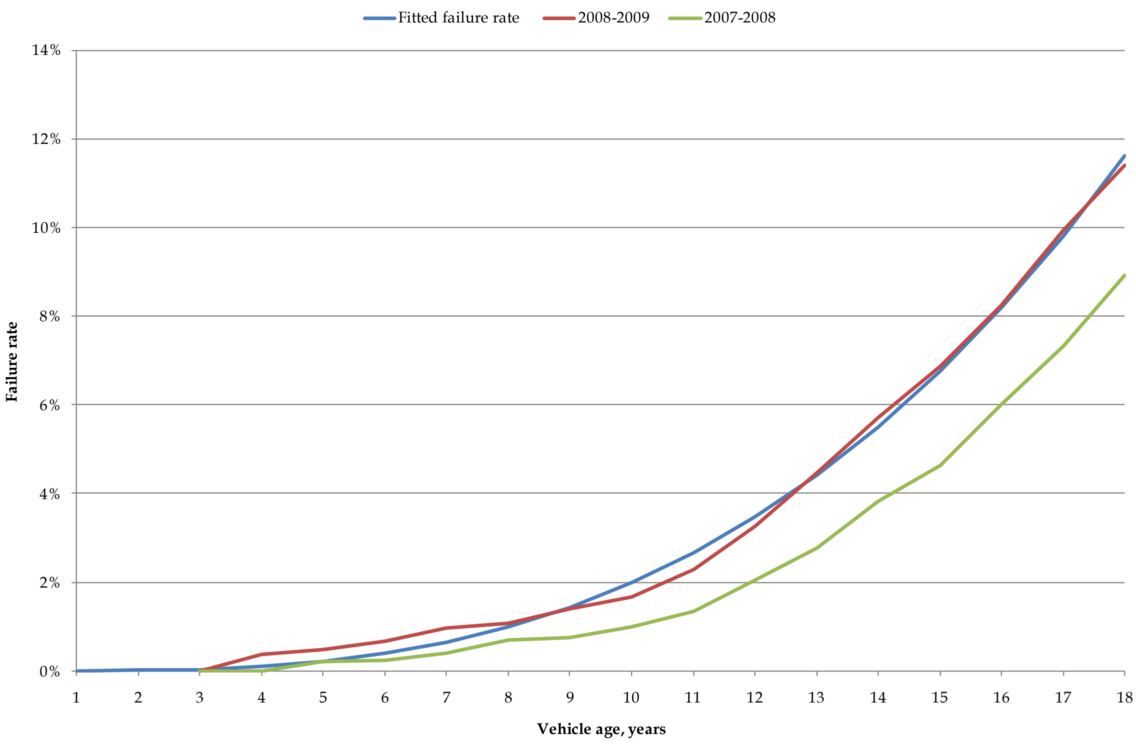
A.3 Vehicle ages and cohort analysis

The way vehicle age is distributed in a given vehicle fleet is important to the calculation of fuel intensity in that fleet. Each year a new cohort of vehicles will enter a given fleet, and that cohort is defined by fuel intensity and fuel mix. From this point on the relevant fuel intensity and fuel mix for that cohort remains in the fleet until a vehicle is deregistered, subject to a small amount of deterioration that may also occur with ageing.

To appropriately model the changing fuel intensity over time as is defined by new vehicle cohorts with changing fuel mix and intensity characteristics, it is necessary therefore to establish a means of estimating what proportion of a given vehicle cohort will still be in the fleet some years into the future, thereby enabling calculation of that cohort's relative contribution to fleet fuel/emission intensity in those future years.

As a means of understanding a cohort's relative contribution to fleet fuel intensity in some years in the future, some attention was paid to the drivers behind vehicle attrition. Vehicles can be de-registered as a result of damage in an accident, or, as a vehicle gets older, a vehicle may be retired for a mix of operational, cost or aesthetic reasons. This means that the probability of de-registration is likely to increase as a vehicle gets older. This effect is most obvious in the passenger vehicle market, where after the age of 8 years the probability of deregistering a vehicle will grow significantly compared to before that time. For supporting evidence of this, see Figure A-6, which shows de-registration rates by vehicle age, based on ABS Motor Vehicle census data for 2007, 2008 and 2009. The chart shown has been derived from counts of registered vehicles classified by year of manufacture. The green line shows the rate of de-registration between the 2007 and 2008 census, while the red line shows the rate of de-registration between the 2008 and 2009 census. The blue line displays a fitted model of the 2008 to 2009 de-registration pattern. It is also clear from the chart that de-registration of vehicles has increased from 2008 to 2009.

- **Figure A-6 Probability of vehicle de-registration by age – passenger vehicles**



Source: SKM MMA analysis of ABS Motor Vehicle Census data, 2008 and 2009

A body of study that links failure rates to distributions of product lifetimes is survival analysis. In this case, one can look at failure rates as being equivalent to de-registration rates. Use of survival analysis provides an appropriate vehicle lifetime distribution that may be employed to describe the probability of a vehicle remaining in the fleet after a given number of years. This probability defines that cohort's relative contribution to fleet fuel/emission intensity in the future.

The distribution applied for this study is the Weibull distribution; the Weibull distribution is a useful distribution to apply to survival analysis when the rate of failure – or in this case, de-registration – can vary over the life of a vehicle. To estimate failure rates and appropriate parameters for the Weibull distribution, SKM MMA have fitted models to ABS data for the years 2008 and 2009, and derived appropriate parameters that should realistically describe each cohort's contribution to fuel/emission intensity in the future.

The results of the model fit are described in Figure A-7, which describes any cohort's contribution to future fuel emission intensity after a number of years. Also, shown in Figure A-8 are modelled de-registration rates for each category of vehicle. These de-registration rates describe the probability of a vehicle in a given cohort remaining in the fleet after one year, given they started the year at a specific age.

- **Figure A-7 Probability of a vehicle remaining in fleet after x years – Australia**

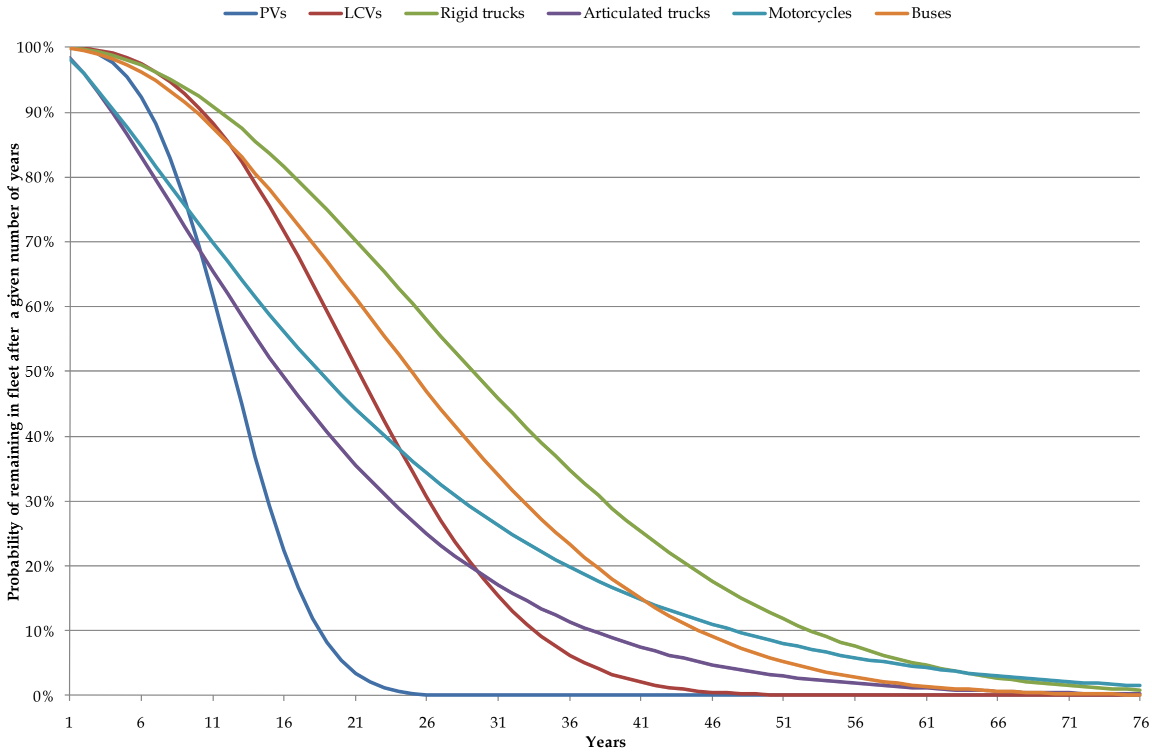
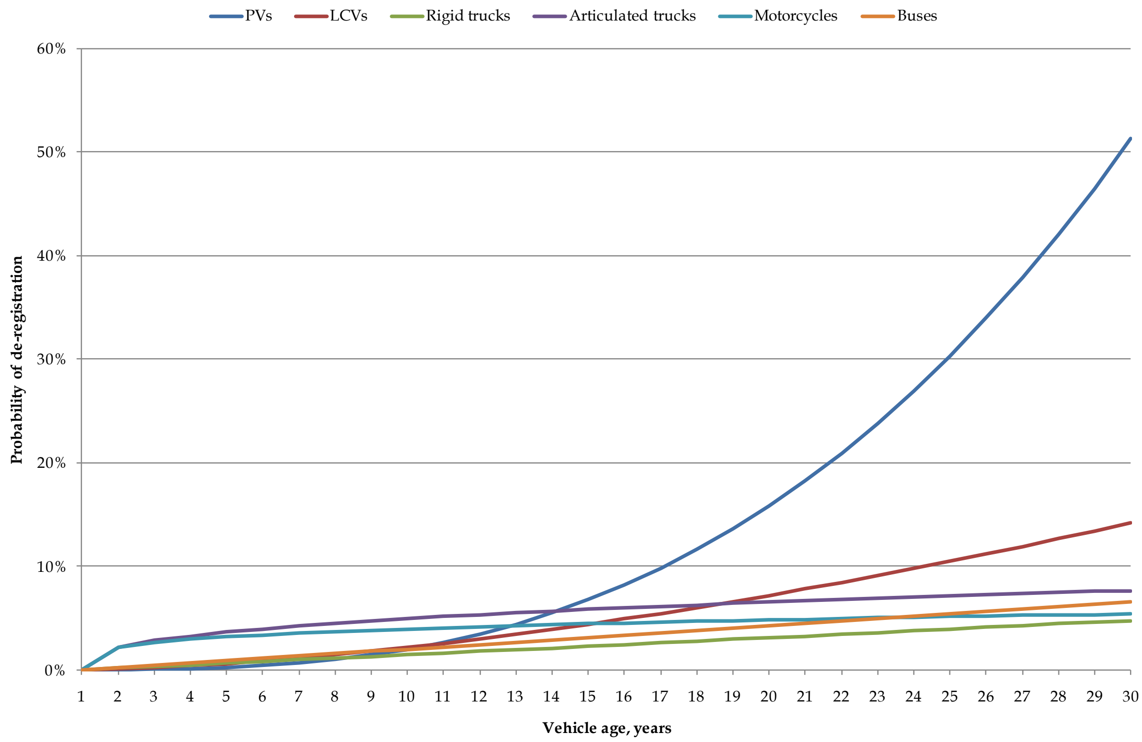


Figure A-8 Modelled vehicle de-registration rates - Australia



As an aside, the average lifetime of a given cohort using this approach will usually be larger than the estimated vehicle age in the overall fleet. This occurs because the stock of vehicles has been growing over time and therefore newer vehicles will make up a greater proportion of the market overall.

A.4 Fuel intensity estimates: air

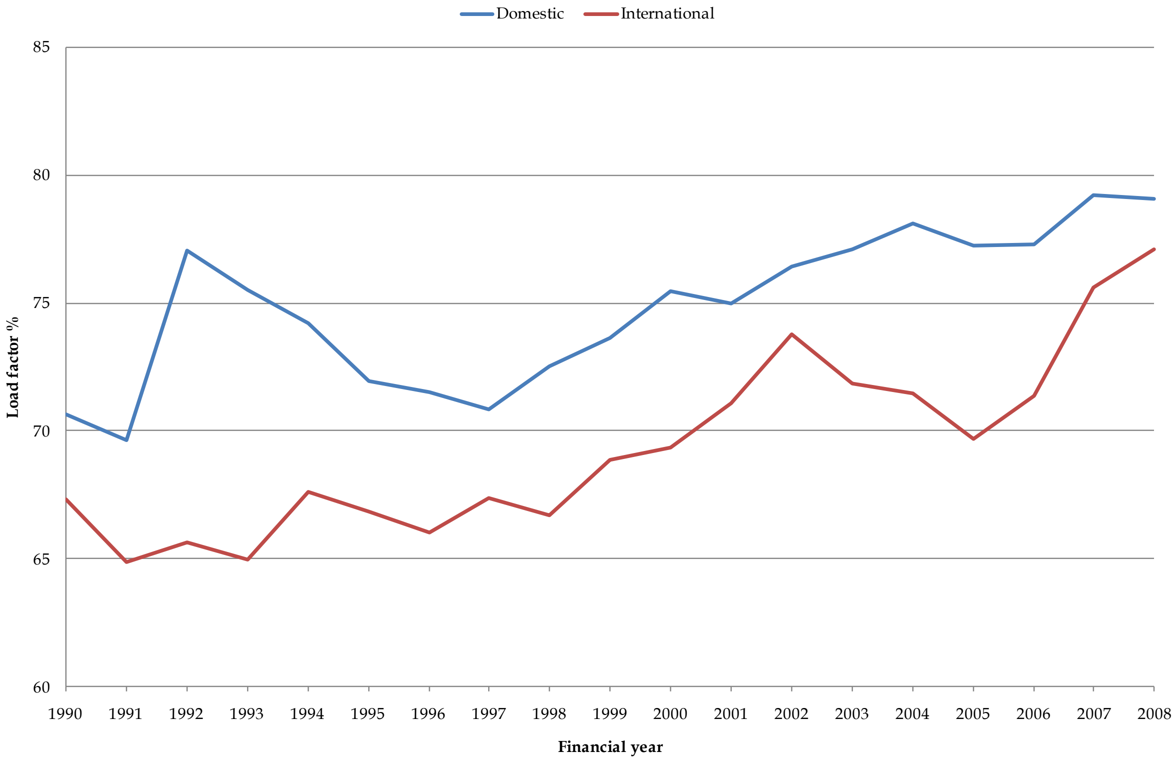
Since the fuel efficiency of international and domestic flights differ (due to the greater distances travelled for international flights and reduced number of take-offs and landings per km), international and domestic flights are modelled differently.

Also, since the economic drivers affecting international travel differ from the drivers affecting domestic travel, domestic air travel is split into two categories, as done by BITRE: flights where the passenger's entire journey is within Australia, and flights which are part of an overseas trip.

SKM MMA modelled the number of seat-km for domestic and international flights using Australian and world GDP respectively.

Since 1990, flight capacity factors have been increasing (refer to Figure A-9), implying that flights are closer to full capacity than in the past. This means that fewer planes are required to get each passenger to their destination, with the net effect that fuel use per passenger km has dropped.

- **Figure A-9 Historical aircraft capacity factors**



Source: SKM MMA analysis

During the same period, airplanes have also improved fuel efficiency[33]. Also, in spite of the greater weight on each plane due to the higher capacity factor, fuel use per seat-kilometre has dropped (refer to Figure A-10). For domestic air travel, the drop in fuel use per 100-seat km is larger than has been seen overseas, implying that Australia may have done some 'catching up'. For international air travel, the improvement in fuel efficiency approximately matches improvements seen overseas. In both cases, some levelling of efficiency appears to have occurred over the last 4-7 years. International trends have shown levelling of fuel efficiency since 2000, because of the increasing cost and difficulty in achieving further efficiency improvement, and it makes sense that Australia will follow a similar path. A projection of fuel efficiency that incorporates a flattened out fuel efficiency curve would therefore seem appropriate.

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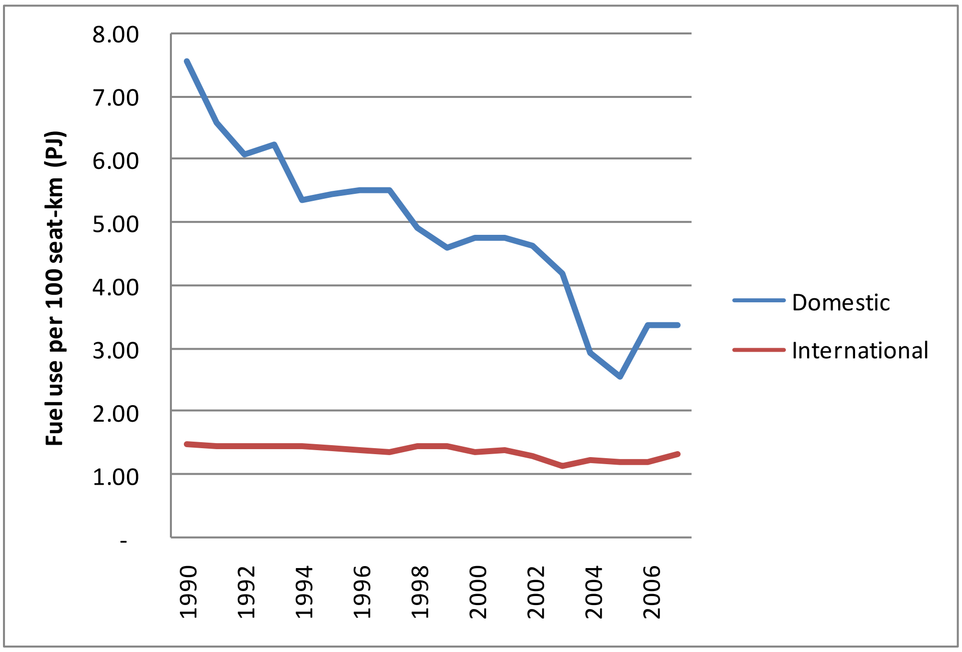
33 http://pre2010.theicct.org/documents/ICCT_Aircraft_Efficiency_final.pdf, "Efficiency Trends for New Commercial Jet aircraft: 1960 to 2008", ICCT, November 2009.

- **Figure A-10 Comparison of domestic and international fuel use per 100 seat-km (PJ)**



Source: SKM MMA analysis

A.5 Fuel intensity estimates: sea

Fuel intensity estimates are difficult for the maritime sector as the sector comprises a wide variety of activities, each with varied fuel sources. These activities include domestic and international shipping, coastal ferries, inland ferries, pleasure craft, cruise ships, fishing boats and military craft. Fuel sources may be domestic or overseas. This makes it difficult to determine the emissions factors for the fuel mix in use.

BITRE report that they have made estimates of fuel use and emissions, but that the data quality is poor because of fuel accounting problems resulting from the diverse uses of fuel in this sector. This means that they cannot guarantee that the data correctly excludes international bunker fuel use, military fuel use or fishing boat fuel use, and cannot guarantee that the data correctly includes automotive fuel sales for small craft. In the absence of other data, however, SKM MMA saw no feasible alternative dataset for use for this project. Therefore, SKM MMA calculated average fuel and emission intensity from the BITRE data, and this was used to project emissions through the study period. The forward projection uses GDP (Australian or world) as an input.

As with the aviation case, BITRE exclude fuel used by military vessels and SKM MMA assume this is also appropriate for the present task. Fuels in use in the maritime sector include automotive distillate, industrial diesel fuel, heavy fuel oil, coal, natural gas and automotive gasoline.

A.6 Fuel intensity estimates: rail

A detailed stock model is not as yet available for the rail transport sector. SKM MMA have extended historical fuel intensity data to form a projection. This is an appropriate method because upgrading the rail network with new technologies is limited by the long lifetimes of existing rail technologies.

With regard to electric rail, SKM MMA used emissions intensity outputs from the stationary energy model as a guide to future electrical emission intensity for the rail network.

A.7 Treatment of international bunker fuels

International bunker fuel emissions are emissions from international air and maritime fuel use. These are therefore covered in the air and sea models.

A.8 Emissions projections

Once fuel use is calculated for each sub-sector the appropriate emissions factor is applied to obtain emissions projections.

A.9 Modelling constraints

The solution provided for DCCEE must also be consistent with the stationary energy model: reserve margin and reliability constraints within the electricity system must be aligned should the transport model call for additional electricity consumption from either rail or electric vehicles. The transport model must also be consistent with fuel limits associated with fuels that are in short supply, such as bio-fuels, although the potential for import of these fuels should not be ignored.

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