CRC for Rail Innovation

Paper 10:
Modelling of Modal Shifts in the Transport Sector

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The Model

The modelling of costs and benefits of different policies is a standard practice in the discipline of economics for project evaluation. This procedure allows for the efficiency, defined, for example, by a benefit-cost ration (net benefits per unit of net cost), to be determined for a project, thereby allowing projects to be ranked in order of an efficiency criterion or rule. The model reported here starts from the type of base model used by the BTRE model for reporting greenhouse gas emissions to the Department of Climate Change. The reason why this model was chosen is that it is a bottom-up model that is transparent, with full details provided in reports from the department responsible for transport matters (BTRE 2002, 2006; BITRE 2008).

In simple form, the model derives activity in vehicle kilometres for different types of vehicle in different scenarios. These activity numbers are used to calculate estimates of operating costs and social costs that draw on parameters estimates developed in Papers 2 and 5. Three types of social cost are included, for each vehicle type: accidents, noise and air pollution. In addition, the emissions associated with a given scenario are calculated by applying fuel efficiency coefficients to estimates of the amount of fuel consumed, and then computing the greenhouse gas emissions by fuel using an emissions factor for that fuel.

Three Scenarios

Scenario 1 involves a significant shift of long-haul freight to rail and is broadly consistent with ARTC's medium-case scenario. It is modelled by fixing the quantum of road tonne-kms driven by articulated trucks at their base case 2010 level of 162.3 billion tkms for the 2010-20 period, and shifting the excess road task to the rail mode. It is assumed that there is no change in any other freight allocations or variables, such as average loads. The increased rail task is split according to the split of the rail freight task in the base case.

Scenario 2 is different from the first. The focus here is on passenger movements and freight movements remain since they are in the base case. In this scenario, a shift of motorists out of their cars and into public transport is assumed. Over 2010-20, the growth in passenger vehicle kilometres for cars is constrained to grow at 50% of the base case rate, with the other half of the base case growth shifted to public transport (70% to trains and 30% to buses). Standard occupancy rates are used to convert these assumptions into vehicle movements.

Scenario 3 is one in which both the freight and passenger changes occur and, in addition, there is increased electrification and increased use of renewable energy to provide electricity. To model this, two steps are undertaken. First, the renewable energy component would lessen the impact of coal, so the emission factor for electricity used in rail is reduced by 50% by 2020. Second, the increase in electrification sees urban passenger trains become totally electrified, and a significant portion of the freight network electrified, thereby resulting in a total of 60% of the total rail network being electrified (a change of 56%).

The Estimated Benefits

Table 10.1 below provides a summary of the estimated overall annual benefits from the three scenarios by 2020, expressed in constant price dollars in that year. Overall, the estimated benefits are very high, with a total annual benefit from all sources in Scenario 3 of about A$10 billion in 2020. The benefits from lower operating costs and the social benefits are of similar magnitude, while the benefits from emissions savings are smaller (about A$340 million by 2020).

Table 1 Summary of benefits: Annual benefits in 2015 and 2020 (A$ billion)

	Scenario 1	Scenario 2	Scenario 3
Total reduction in operating costs			
2015	0.94	1.34	2.28
2020	1.88	2.44	4.32
Total reduction in social costs (ex. climate change costs)			
2015	2.18	0.68	2.85
2020	4.06	1.23	5.30
Total reduction in climate change costs			
2015	0.08	0.05	0.14
2020	0.19	0.12	0.34
Total benefits			
2015	3.20	2.06	5.27
2020	6.14	3.79	9.96

The estimated benefits are expressed in net present value terms in 2008 in Table 2, using discount rates of 4%, 7% and 10% respectively. Again, the numbers are very large, with Scenario 3 having gross benefits with an NPV in 2010 of the total benefits over the decade to 2020 of A$27.4 billion, even at a discount rate of 10%.

Table 2 Discounted Value in 2010 of total benefits over 2010-20, relative to the base case (A$ billion, constant prices)

Rate	Scenario 1	Scenario 2	Scenario 3
		(A$ billion)	
4%	25.6	16.1	41.7
7%	20.6	13.0	33.7
10%	16.8	10.6	27.4

Investment to Achieve the Benefits

The investments that need to be undertaken if these benefits are to be achieved are many and varied. They cover both public and private participants in the industry and involve investment in track and equipment, in locomotives and many business service activities, and in renewal energy generation. It has been not been possible in this study to quantify the costs of these investments, although one important component (the rail freight track component) has been costed by ARTC. However, Table 3 shows the results of calculating the constant, real level of investment outlay per annum over the period 2010-20 that would be justified by these benefits, at different discount rates. It is clear that, even at 10%, the justified annual level of investment is well above that that would be necessary in practice to achieve the benefits. The issues involved in achieving these benefits are discussed in the Final Report of this project.

Table 3 Annual justified investment to achieve total benefits, for different discount rates (A$ billion per annum over 2010-20)

Rate	Scenario 1	Scenario 2	Scenario 3
4	2.9	1.8	4.8
7	2.7	1.8	4.5
10	2.6	1.8	4.2

Another way of approaching these figures is to calculate the implied social rate of return in 2010 to an upper bound of the likely constant annual level of investment during the decade to achieve these benefits. Taking that upper bound as A$20 billion, or A$2 billion per annum, the implied social rate of return on this investment is 50%.

Reduction in Transport Emissions

Most of Australia's transport emissions come from road transport, while emissions from air transport are a small but rapidly growing component. Road and air emissions are held at the base case in the scenario simulations, except for the reduction in road emissions that takes place as a result of the modal shift from road to rail. When Scenario 3 effects are taken into account, total transport emissions are about 11% lower than in the base case by 2030. If account is also taken of further action to reduce emissions intensity levels in road and air transport, relative to the base case, by 10% by 2030, total transport emissions are about 19% lower than the base case by 2030. Total transport emissions peak in 2024, and are less than 5% above their 2010 level in 2030. These results show that aggressive action can indeed reduce transport emissions significantly relative to unchanged policy trends, and can lead them to fall in absolute terms in due course.

1. Introduction

The modelling of costs and benefits of different policies is a standard practice in the discipline of economics for project evaluation. This procedure allows for the efficiency, defined for example by a benefit-cost ratio (net benefits per unit of net cost), to be determined for a project. This, in turn, allows projects to be ranked in order of an efficiency criterion or rule. To assist in determining the benefits and costs and subsequent net benefit ratio, the authors have developed a model to provide an appropriate framework for such analyses. This paper sets out the methodology for modelling the base case, together with three scenarios in the transport sector over the next 12 years to 2020.

The model produced by CSES is similar to the base model used by the BTRE model for reporting greenhouse gas emissions to the Department of Climate Change (DCC) and, subsequently, the Intergovernmental Panel on Climate Change (IPCC). The reason why this model was chosen is that it is a bottom-up model that is transparent, with full details provided in reports from the department responsible for transport matters (BTRE 2002, 2006; BITRE 2008).

In simple form, the model can be explained as proceeding from a specified path of transport activity, in vehicle kilometres for different types of vehicles, and an assumed pattern of fuel efficiency by vehicle type to give the amount of different types of fuel that are consumed. The amount of fuel consumed then is used to compute the greenhouse gas emissions using an emissions factor. The emissions factor is taken from official documents from the Department of Climate Change and International Panel on Climate Change. The method for calculating CO_2 emissions corresponds to that of Tier 2 (using DCC estimates (AGO 2006)) while methane (CH_4) and nitrous dioxide ($N2_O$) use IPCC emission factors, a Tier 1 method. Although Tier 3 is desired, using Tier 1 or 2 estimates results in a less precise, yet acceptable estimate of greenhouse gas emissions (IPCC-NGGIP 2006).[1]

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[1] Each tier represents a greater level of detail and preciseness in estimation of greenhouse gas emissions. Tier 1 is the least accurate and easiest to compute while Tier 3 is the most data demanding and considered most accurate.

2. Scenarios and Results

2.1. Scenarios

The model has been used to compare three scenarios to a base case. The base case model produces results approximately equal to the results submitted as the base case presented to the Department of Climate Change for the reporting of greenhouse gases from the transport sector (BITRE 2008).

The first scenario (Scenario 1) has fixed the amount of road Tkms driven by articulated trucks at 162.3 billion after 2010. While keeping the overall freight load the same as in the base case, this results in a shift of the excess road task to the rail mode. It is assumed that there is no change in any other freight allocations or variables, such as average loads. The rail task is split according to the split of the rail freight task in the base case.

The growth rates for rail freight are assumed to be in accordance with the expected increases reported by the ARTC and are shown in Table 10.1. This report shows that these growth rates will be easily contained within the growth projections of the ARTC report and, as a result, the extra rail task will be able to be absorbed.[2]

Table 10.1 Expected rail freight growth rates (percent per annum)

Market forecast	North-South	East-West	Average
		(% pa)	
General freight	2	2	2
Steel	3.5	3.5	3.5
Minerals	2	2	2
Grain (Dom)	3	3	3
Grain (XPT)	1.5	1.5	1.5
Average freight			*2.4*

Source: ARTC (2008).

In the second scenario (Scenario 2), the focus is on passenger movements, and freight movements have remained as they are in the base case. This scenario moves motorists out of their cars and into public transport. Vehicle kilometres for cars grew at 50% of the base case rate, and all the remaining growth in the base case was split between rail and bus. Rail obtained 70% of that growth in Vkms, while bus obtained 30%. The occupancy rates of the vehicles are 1.5, 9 and 30 for car, bus and train respectively.

The last scenario (Scenario 3), builds on the previous two scenarios by assuming that electrification of the network occurs. This electrification, however, is not using traditional coal plants, but renewable energy. To model this, two steps were undertaken. First, the renewable energy component would lessen the impact of coal on the environment, so the model reduces the emission factor by 50% and changes it from 89 to about 45. Second, the increase in electrification sees urban passenger trains become totally electrified, and a significant portion of the freight network electrified resulting in a total of 60% of the total rail network being electrified (a change of 56%). Details are provided in the rail section of the model description.

Tables 10.2 and 10.3 provide details about the changes of activities in the different scenarios.

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[2] Tables 8 and 14 in ARTC (2008).

Table 10.2 Scenario summary: Rail passenger and freight sectors

Year	Non-urban passenger pkm	Urban (heavy pass. rail) pkm	Urban (light pass. rail) pkm	Hire & reward non-bulk freight tkm	Hire & reward bulk tkm	Ancillary freight tkm	Total freight rail tkm
1990	2.35	7.18	0.48	19.49	35.36	33.06	87.91
1995	2.22	7.51	0.50	21.69	40.71	43.79	106.19
2000	2.38	8.34	0.56	27.39	57.17	49.00	133.56
2005	2.20	9.40	0.58	39.28	72.24	77.73	189.25
2010	2.39	10.56	0.64	48.92	82.63	114.49	246.04
Growth rate 2000-2010	*0.1%*	*2.4%*	*1.4%*	*6.0%*	*3.8%*	*8.9%*	*6.3%*
Base case							
2015	2.56	11.57	0.71	55.36	94.34	143.29	292.99
2020	2.75	12.61	0.79	61.66	106.74	169.62	338.02
Growth rate 2010-2020	*1.4%*	*1.8%*	*2.1%*	*2.3%*	*2.6%*	*4.0%*	*3.2%*
Scenario 1: Increased rail freight							
2015	2.56	11.57	0.71	62.48	106.48	161.73	330.69
2020	2.75	12.61	0.79	75.41	130.55	207.46	413.42
Growth rate 2015-2020	*1.4%*	*1.8%*	*2.1%*	*4.4%*	*4.7%*	*6.1%*	*5.3%*
Scenario 2: Increased passenger traffic							
2015	3.12	14.08	0.86	55.36	94.34	143.29	292.99
2020	3.75	17.20	1.07	61.66	106.74	169.62	338.02
Growth rate 201-2020	*4.6%*	*5.0%*	*5.3%*	*2.3%*	*2.6%*	*4.0%*	*3.2%*
Scenario 3: Increased rail freight and passenger traffic with increased renewable electricity							
2015	3.12	14.08	0.86	62.48	106.48	161.73	330.69
2020	3.75	17.20	1.07	75.41	130.55	207.46	413.42
Growth rate 2015-2020	*4.6%*	*5.0%*	*5.3%*	*4.4%*	*4.7%*	*6.1%*	*5.3%*

Table 10.3 Scenario summary: Road passenger and freight sectors (Vkm)

Year	Cars	Light Commercial Vehicles	Rigid & other trucks	Articulated trucks	Buses	Motorcycles	Total Road Vkm
1990	124.01	23.90	6.84	4.14	1.48	1.80	162.17
1995	139.37	27.27	6.32	4.80	1.54	1.57	180.87
2000	151.17	31.33	7.29	5.70	1.68	1.42	198.59
2005	164.62	35.38	8.16	6.34	1.85	1.73	218.08
2010	177.92	39.85	9.60	7.34	2.02	2.11	238.84
2000-2010	*1.6%*	*2.4%*	*2.8%*	*2.6%*	*1.9%*	*4.0%*	*1.9%*
Base Case							
2015	190.20	46.64	10.04	8.57	2.21	2.35	260.01
2020	200.31	53.87	10.51	9.69	2.44	2.60	279.42
2010-2020	*1.2%*	*3.1%*	*0.9%*	*2.8%*	*1.9%*	*2.1%*	*1.6%*
Scenario 1: Increased rail freight							
2015	190.20	46.64	10.04	6.95	2.21	2.35	258.39
2020	200.31	53.87	10.51	6.62	2.44	2.60	276.35
2015–2020	*1.2%*	*3.1%*	*0.9%*	*-1.0%*	*1.9%*	*2.1%*	*1.5%*
Scenario 2: Increased passenger traffic							
2015	184.06	46.64	10.04	8.57	2.30	2.35	253.96
2020	189.12	53.87	10.51	9.69	2.61	2.60	268.40
2015–2020	*0.6%*	*3.1%*	*0.9%*	*2.8%*	*2.6%*	*2.1%*	*1.2%*
Scenario 3: Increased rail freight and passenger traffic with increased renewable electricity							
2015	184.06	46.64	10.04	6.95	2.21	2.35	252.25
2020	189.12	53.87	10.51	6.62	2.44	2.60	265.15
2015-2020	*0.6%*	*3.1%*	*0.9%*	*-1.0%*	*1.9%*	*2.1%*	*1.1%*

2.2. Benefits

By investing in the future of rail, benefits accrue for Australia. This section presents our estimates of those benefits. It is divided into four sections: overall summary, operating costs, social costs, and greenhouse gases.

2.3. Summary of Overall Results

Table 10.4 shows a snapshot of the overall benefits. In all scenarios, there is a reduction in operating costs by 2020 of at least A$1.8 billion per annum compared to the base case, with this benefit reaching $4.3 billion in Scenario 3. Social costs, such as noise and air pollution, are reduced by at least A$1.5 billion compared to the base case, with a total of $5.3 billion in Scenario 3. Climate change costs when compared to the base case are reduced by A$0.12 billion to A$ 0.34 billion. The overall benefit for the year 2020 ranges from $3.8 billion in Scenario 2 to A$10.0 billion in Scenario 3.

Table 10.4 Summary of benefits ($A billion)

	Scenario 1	Scenario 2	Scenario 3
Total reduction in operating costs			
2015	0.94	1.34	2.28
2020	1.88	2.44	4.32
Total reduction in social costs (ex. climate change costs)			
2015	2.18	0.68	2.85
2020	4.06	1.23	5.30
Total reduction in climate change costs			
2015	0.08	0.05	0.14
2020	0.19	0.12	0.34
Total benefits			
2015	3.20	2.06	5.27
2020	6.14	3.79	9.96

The non-financial benefits are shown in Table 10.5, with the timeliness benefits drawn not from the model but from the ARTC (2008) report. These values suggest that, on the North-South corridor, 23 hours would be saved in journeys and reliability will increase by 36%. The East-West corridor will have a saving of 26.1 hours and a 30% increase in reliability.

Table 10.5 Non-financial benefits from investing in rail infrastructure

Non-financial	Scenario 1	Scenario 2	Scenario 3
Year	**Greenhouse gas emissions (Gg CO_2 eq)**		
2015	1958	1289	3429
2020	3814	2314	6753
	Timeliness (2005 to 2024)		
North-South corridor			
Hours saved from upgrades	23	23	23
Reliability increase (%)	35	35	35
East-West corridor			
Hours saved from upgrades	26.1	26.1	26.1
Reliability increase (%)	30	30	30

Source: The Timeliness data is from the ARTC (2008).

When an increase in rail passenger traffic alone is achieved (Scenario 2), about 2300 Gg of CO_2 equivalent gas is not emitted into the atmosphere per annum by 2020. When freight tasks are modified as in Scenario 1, the emissions savings are estimated at about 3800 Gg per annum, and when increased electrification and greater use of renewable energy is added to the passenger and freight changes (Scenario 3), there is about 6750 Gg per annum less greenhouse gas emitted in the atmosphere by 2020.

2.4. Operating Costs

These are the estimated total operating costs incurred by the community in meeting the transport tasks, and are derived in the model using the assumptions outlined in Paper 5. In all scenarios, overall operating costs are less than the base case (see Figure 10.1). When the freight load is shifted to rail, Figure 10.2 shows that there are significant savings. Figure 10.3 shows that, when increasing the passenger load, overall operating costs are likely to decrease compared to the base case. The specific estimates are provided in Table 10.6a.

It is also noteworthy that the overall savings in operating costs are the net effect of a shift in operating costs from road to rail. As shown in Table 10.6b, in Scenario 3, road sector operating costs are $12.9 billion less by 2020 than in the base case, because of lower freight and passenger traffic by road, while rail operating costs are up by $8.6 billion, thus giving a net saving of $4.3 billion.

Figure 10.1 Total operating costs

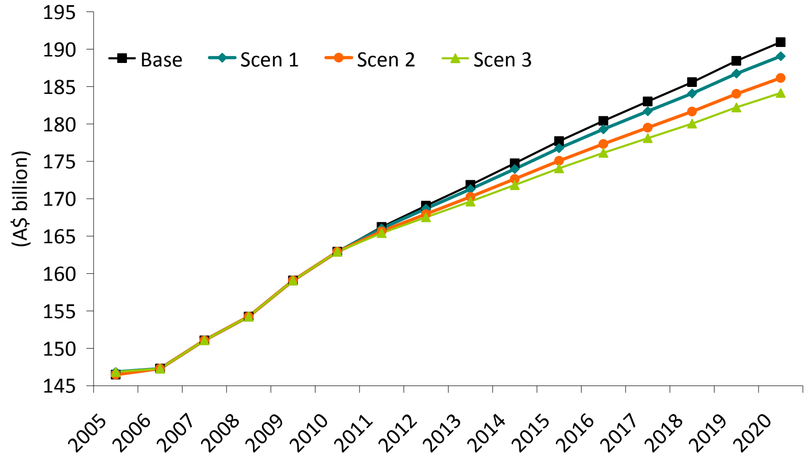


Figure 10.2 Operating costs for freight tasks

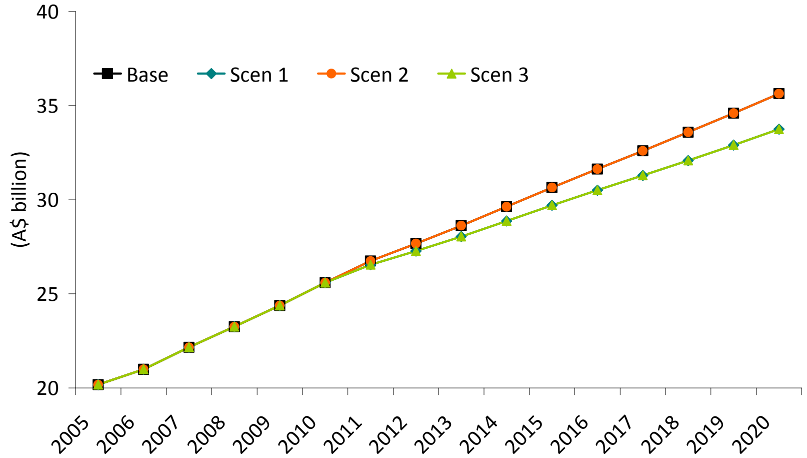


Figure 10.3 Operating costs for passenger tasks

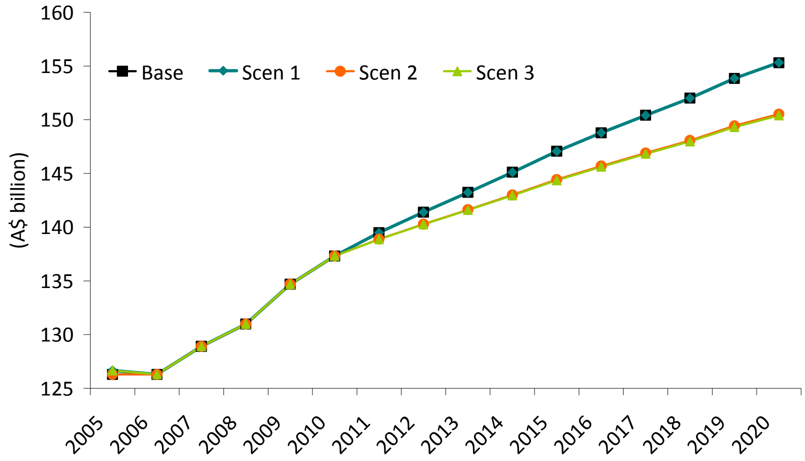


Table 10.6a Reductions in operating costs, by freight and passenger transport

Operating costs	Scenario 1	Scenario 2	Scenario 3
		($billion per annum)	
Year		Freight	
2015	0.94	0.00	0.94
2020	1.89	0.00	1.89
Year		Passenger	
2015	0.00	1.34	1.34
2020	0.00	2.44	2.44
Year		Total	
2015	0.94	1.34	2.28
2020	1.89	2.44	4.32

Table 10.7b Reductions in operating costs, by road and rail transport

Operating Costs	Scenario 1	Scenario 2	Scenario 3
		($billion per annum)	
Year		Road	
2015	2.64	4.19	6.82
2020	5.28	7.63	12.91
Year		Rail	
2015	-1.70	-2.85	-4.55
2020	-3.39	-5.19	-8.59
Year		Total	
2015	0.94	1.34	2.28
2020	1.89	2.44	4.32

Note: These tables shows reductions in operating costs, so that increases are shown as negative values.

2.5. Social Costs

Social costs include costs associated with transport mode such as noise, accidents, and air pollution costs not factored into normal operating costs and are thus external to the transaction. In the scenarios, overall social costs are made up of accident, noise, and air pollution costs (Figure 10.5 and Figure 10.6). Congestion costs are not included in the analysis. Overall, the net position is reduced social costs in all scenarios (Figure 10.4).

Figure 10.4 Total road (including petroleum refining) and rail externality costs

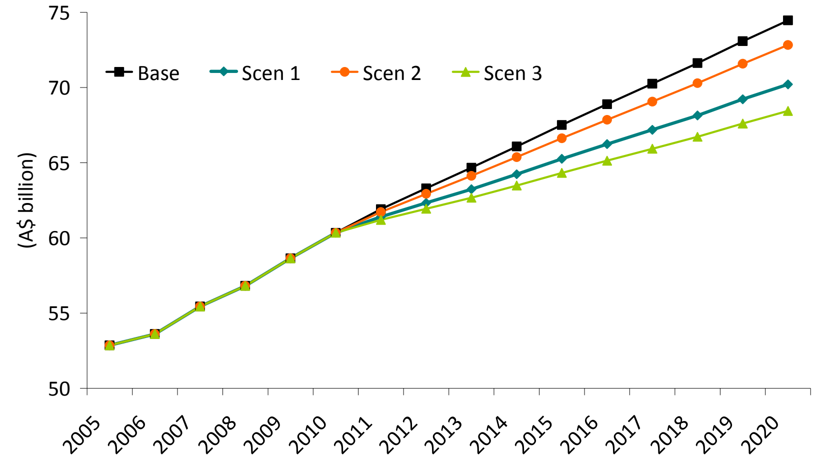


Figure 10.5 Road and petroleum refining externality costs

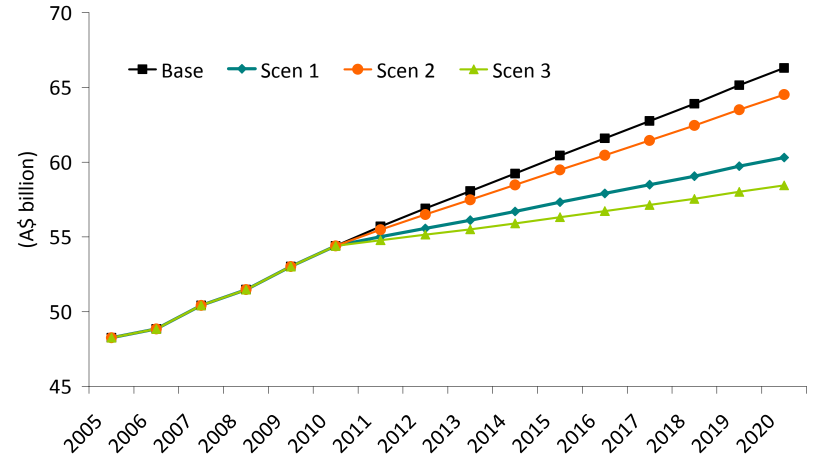


Figure 10.6 Rail externality costs

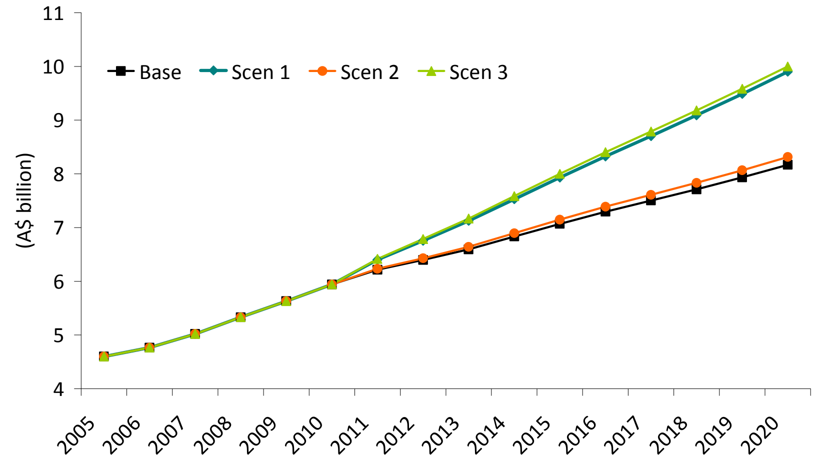


Table 10.8 shows that shifting more long-haul freight by train (Scenario 1) will have an effect of reducing about one-half billion dollars for accidents, one-tenth of a billion less noise related costs, and cleaner air costed at just over A$3.3 billion. In Scenario 3 the figure triples for accidents, is

relatively stable for air pollution and doubles for noise. Total costs range from A$1.2 billion in increased passenger task, A$4 billion for increased freight task, and A$5.3 billion for combined increase in passenger and freight tasks.

Table 10.8 Reduction in social costs (A$ billion)

Social costs	Scenario 1	Scenario 2	Scenario 3
Year		**Accidents**	
2015	0.30	0.57	0.87
2020	0.58	1.04	1.62
Year		**Noise**	
2015	0.07	0.05	0.12
2020	0.12	0.09	0.20
Year		**Air pollution**	
2015	1.80	0.06	1.86
2020	3.37	0.11	3.48
Year		**Total**	
2015	2.18	0.68	2.85
2020	4.06	1.23	5.30

2.6. Greenhouse Gas Emissions

Figure 10.7, Figure 10.8 and Figure 10.9 present CO_2 equivalent emissions from the three scenarios and the base case. All scenarios reduce greenhouse gases with the most significant reduction from Scenario 3.

Figure 10.7 Total CO_2 eq emissions

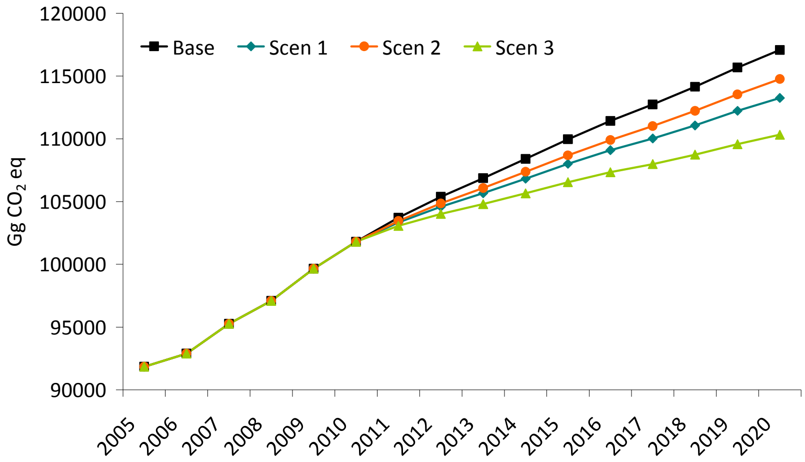


Figure 10.8 Road CO_2 eq emissions (no refining)

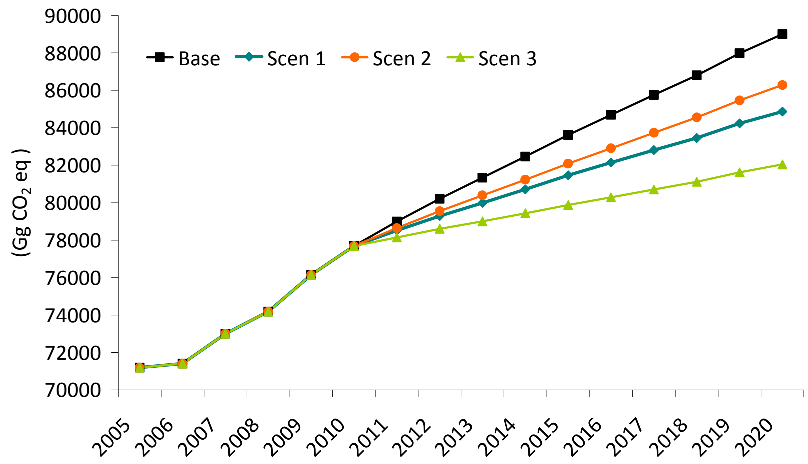
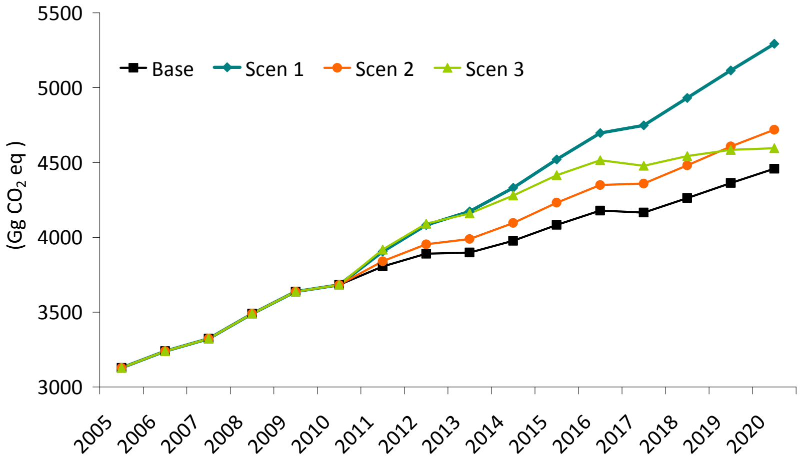


Figure 10.9 Rail CO_2 eq emissions (includes electricity)



The net changes in greenhouse gases are shown in Table 10.9. As noted above, all gases are reduced in the scenarios. Increased passenger tasks offer a reduction of 2300 Gg of greenhouse gas emissions, while increased freight task provides a 3800 Gg reduction. By doing both and increasing renewable energy and electrification, a 6750 Gg reduction occurs in 2020.

Table 10.9 Net changes in greenhouse gases

Climate change	Scenario 1	Scenario 2	Scenario 3
		($billion per annum)	
Year		**Climate change costs**	
2015	0.08	0.05	0.14
2020	0.19	0.12	0.34
Year		**GHG emission CO_2 e.q. savings**	
2015	1958	1289	3429
2020	3814	2314	6753

Table 10.10 Total climate change costs (A$ billions)

	Base case	Scenario 1	Scenario 2	Scenario 3
1990	0.83	0.83	0.83	0.83
1991	0.85	0.85	0.85	0.85
1992	0.91	0.91	0.91	0.91
1993	0.98	0.98	0.98	0.98
1994	1.05	1.05	1.05	1.05
1995	1.13	1.13	1.13	1.13
1996	1.19	1.19	1.19	1.19
1997	1.27	1.27	1.27	1.27
1998	1.35	1.35	1.35	1.35
1999	1.43	1.43	1.43	1.43
2000	1.54	1.54	1.54	1.54
2001	1.60	1.60	1.60	1.60
2002	1.72	1.72	1.72	1.72
2003	1.88	1.88	1.88	1.88
2004	2.08	2.08	2.08	2.08
2005	2.15	2.15	2.15	2.15
2006	2.26	2.26	2.26	2.26
2007	2.41	2.41	2.41	2.41
2008	2.57	2.57	2.57	2.57
2009	2.76	2.76	2.76	2.76
2010	2.94	2.94	2.94	2.94
2011	3.13	3.12	3.12	3.11
2012	3.33	3.30	3.31	3.28
2013	3.52	3.48	3.50	3.45
2014	3.74	3.68	3.70	3.63
2015	3.97	3.89	3.91	3.83
2016	4.20	4.10	4.14	4.03
2017	4.45	4.33	4.37	4.24
2018	4.71	4.57	4.62	4.46
2019	4.99	4.83	4.89	4.70
2020	5.28	5.09	5.17	4.94

2.7. Net Present Value

All scenarios result in favourable outcomes for society. When discounted, the savings streams provide an overall benefit for all three discount rates used (4, 7, and 10%), as shown in Table 10.11. In terms of financial results, the range of savings in the year 2020 from the expected base outcome range from A$16.8 billion to A$27.4 billion at a 10% discount rate.

Table 10.11 Discounted values for financial benefits above the base case (2008-2020)

Discount Rate	Scenario 1	Scenario 2	Scenario 3
4%	25.6	16.1	41.7
7%	20.6	13.0	33.7
10%	16.8	10.6	27.4

Note: Scenario value less base value = savings. For 2008-2011 there are no benefits accrued as the scenarios mimic the base case.

3. Investing in the Future

The electricity supply industry has projected an estimate of the need for A$30 billion of new investment over the next 10 years – some A$10 billion for electricity generation, and A$20 billion for distribution. It is suggested that, over the next 10 or more years, substantial investment will also be required for the upgrade of existing rail tracks and their extension, and for improved rail locomotives, network systems and coordination centres, such as modal interchanges.

The Australian Rail Track Corporation (ARTC) has produced a Rail Infrastructure Strategy 2008-2024 submission for Infrastructure Australia. These proposals are for rail freight improvements. ARTC does not own or lease any of the urban networks and it does not assume that any growth will occur in the intercity rail passenger market. ARTC already has an investment program in the Hunter Valley and North-South corridors in excess of A$3 billion. The proposed scopes of works include work on the North-South corridor between Melbourne and Brisbane, and the East-West Corridor between Melbourne, Sydney, Brisbane and Perth. The total investment is A$5.595 billion over 10 years, with the majority invested in the North-South corridor (A$4.9 billion).

In addition, ARTC propose a scope of works for the Hunter Valley totalling A$1,791 million. This gives A$7,398 million, in addition to network-wide improvements of A$563 million: a total of A$7,961 million.

4. The Model

The transport sectors used in this model are road, rail, maritime, and air. This section breaks down the model into modal sectors and explains their details. More detail can be found in (BTRE 2002, 2006; AGO 2006). The next section provides some details about the parameter values used in calculating the costs.

4.1. Operation Cost Data

Operating costs have been computed by CSES to allow a rough comparison about the ongoing costs and revenues of a modal shift (CRC for Rail Innovation 2008). These costs have been subsequently used in the model. Table 10.12 provides a summary of the costs used to calculate operating costs and rail revenue.

Table 10.12 Approximate revenue for road and rail

	Road	Rail	Air	Shipping
Freight (non-bulk)	0.070	0.045	1.270	0.020
Unit	$/Tkm	$/Tkm	$/Tkm	$/Tkm
Passenger				
System cost	0.72	0.53	0.00	0.00
Revenue	0.00	0.14	0.00	0.00
Unit	$/Vkm	$/Pkm	#N/A	#N/A

Note: Freight costs are for years 2006-2007, Passenger costs are for 2008.
Source: (Rasmussen 2008).

The model uses the cost of non-bulk freight rates for estimating bulk costs however in reality these costs are lower. Air and shipping costs for passengers and freight are not reported, and do not affect the overall results since changes do not occur in these industries when altered from the base case. The model has adjusted the rail non-bulk cost upwards by 50% from those reported in Paper 5 to reflect door-to-door costs.

Passenger costs for road consist of car, motorbike, and bus modes. In the model, they have been all equated, though this is not likely in reality. Likewise, rail passenger costs have been regarded as equal regardless of whether a passenger kilometre was used on the light urban rail network, urban network, or an interstate journey. Only rail passenger revenue is calculated, and rail revenue is considered to be equal among urban heavy, urban light rail, and non-urban classes.

4.2. Social Cost Data

CSES has computed costs on the externalities associated with road and rail sectors and used them in the model. These costs are derived from Schreyer, Schneider et al. 2004 and are reported in Table 10.13.

Table 10.13 Externality Cts (A$/Vkm)

	Road						Rail	
	Car	**LCV**	**Medium (rigid)**	**Heavy**	**Bus**	**Motorcycle**	**Passenger**	**Freight**
Accidents	0.10	0.01	0.14	0.19	0.04	0.37	0.00	0.00
Noise	0.02	0.01	0.13	0.19	0.02	0.03	0.01	0.01
Air pollution	0.04	0.03	0.43	1.49	0.36	0.01	0.01	0.02

Source: Schreyer, Schneider et al. 2004.

The externality figures from Schreyer, Schneider et al. (2004) were converted to Australian dollars using an exchange rate of 1 Euro = A$1.7 and adjusted for inflation from 2000 to 2004 using data from the Australian Bureau of Statistics (ABS 2008).

The externality costs for climate change are based on those reported by treasury in their recent analysis of climate change (Treasury 2008).

Table 10.14 Climate change costs based on Treasury estimates

Year	CPRS 15	Year	CPRS 15
1990	13	2006	27
1991	14	2007	28
1992	14	2008	29
1993	15	2009	31
1994	16	2010	32
1995	16	2011	33
1996	17	2012	35
1997	18	2013	37
1998	19	2014	38
1999	20	2015	40
2000	20	2016	42
2001	21	2017	44
2002	22	2018	46
2003	23	2019	48
2004	24	2020	50
2005	26		

Source: (Treasury (2008, Table 6.1) Calculated as $C_t = C_{t-1} \times 1.046$ after 2010 and $C_t = \frac{C_{t-1}}{1.046}$ before 2010 and 2010 set to 32 as tabled in Table 6.1 (Treasury 2008).

4.3. Road

This section is the first section explaining the calculation engine in the model. The road sector comprises of six vehicle types: cars, light commercial vehicle (LCV), rigid trucks, heavy trucks, buses, and motorbikes. Cars and motorbikes represent the private passenger loads, buses public passenger loads, while LCV, rigid, and heavy represent freight loads.

The amount of fuel road vehicles used in petajoules (PJ) can be described by the following equation:

$$PJ = Billion\ Vkm \times Fuel\ Intensity_{L/100km} \tag{1}$$

where:
Vkm is vehicle kilometres.

The amount of fuel is adjusted based on historical estimates of the proportion of fuel type per total amount of fuel. The amounts are shown below. These estimates are approximately equivalent to those reported by ABARE adjusted for military use.

Table 10.15 Proportion of road vehicle fuel type (*Q*)

	Autogas	ADO[3]	LPG	GAS	Total
Actual PJ	600.60	256.15	57.38	0.92	915.05
Proportion	0.66	0.28	0.06	0.00	1.00

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[3] ADO is estimated to be higher; however, all residual fuels and ADO reported by ABARE add up to this amount. ABARE's estimates adjusted for military use are 600, 256, 66 and 1 totalling 923 (BTRE 2002, 2006; AGO 2006).

Emissions are computed as:

$$E_k^{gas} = PJ_k \times Q_k \times EF_k^{gas} \qquad (2)$$

where:
E is the emission of *gas* type from combusting fuel *k*,
PJ is the amount of fuel *k* in *PJ*,
Q is the proportion of road vehicle fuel type,
EF is the emission factor for *gas* type from combusting fuel *k.*

All the emission coefficients that are not related to refining are shown in Table 10.20 for CO_2 emission factors (with their respective effective emission factor) and Table 10.22 for non-CO_2 emissions factors.

Freight costs for road transport are found by equation (3):

$$Op\ costs_i\left(\$A\right) = Billion\ Tkm \times Cost_i \qquad (3)$$

and passenger costs use equation (4):

$$Op\ costs_i\left(\$A\right) = Billion\ Vkm \times Cost_i\,. \qquad (4)$$

Except climate change costs, all other externality costs *i* are shown in Table 10.13 and are used to compute externality costs with equation (5):

$$Ext\ costs_i\left(\$A\right) = Billion\ Vkm \times Cost_i \qquad (5)$$

Climate change costs are based on emissions and costs shown in Equation (6), which shows how to compute these costs.

$$Ext\ costs_{Climate\ Change} = E^{CO2eq} \times CC\ cost \qquad (6)$$

where:

$Ext\ Costs_i$ are externality costs for cost *i*,
E^{co2eq} are emissions converted to CO_2 equivalents (CH_4=21, N_2O=310),
CC Cost are the Treasury reported climate change costs of mitigation reported in

Associated emissions to road transport are those from oil and gas refining. These are included in this model, although they are not included in the BTRE model. The procedure to calculate these emissions is obtained from the AGO (BTRE 2002, 2006; AGO 2006). Equation (7) shows how the model forecasts future needs of natural gas refining:

$$Gas_t^{refining} = Gas_{t-1}^{refining} \times \left(1 + \left(\frac{Gas_t^{road} - Gas_{t-1}^{road}}{Gas_{t-1}^{road}}\right)\right) \qquad (7)$$

where:
$Gas^{refining}$ is natural gas refined at time *t* in PJ,
Gas^{road} is natural gas consumed by road transportation at time *t* in PJ.

Petroleum product refining forecasts, mostly automotive gasoline, are computed based on equation (8):

$$Autogas_t^{refining} = Autogas_{t-1}^{refining} \times \left(1 + \left(\frac{Autogas_t^{road} - Autogas_{t-1}^{road}}{Autogas_{t-1}^{road}} \right) \right) \qquad (8)$$

where:
$Autogas^{refining}$ is automotive gasoline refined at time *t* in PJ,
$Autogas^{road}$ is automotive gasoline consumed by road transportation at time *t* in PJ.

The activity variables are then used to compute the amount of greenhouse gases. The emission factors are shown in Table 10.16. Equation (9) shows the emissions calculation algorithm.

$$E_{refining}^{gas} = Act_{refining} \times EF_{refining}^{gas} \qquad (9)$$

where:
E is the emissions from refining for a specified *gas* (CO_2, CH_4, *and* N_2O),
Act is the amount of product refined in *PJ*,
EF is the effective emission factor for *gas* for refining activities.

Table 10.16 Emission factors for refining

		Oxidation	F	Effective EF
CO_2	Petroleum products ned	0.99	68.6	67.914
	Natural gas	0.995	51.4	51.143
CH_4	Petroleum products nec	0.001	0.8	0.0008
	0.01Natural gas	0.001	1.1	0.0011
N_2O	Petroleum products ned	0.001	0.6	0.0006
	Natural gas	0.001	0.1	0.0001

Source: (AGO 2006).

4.4. Rail

The rail sector is made up of four major categories, urban light passenger rail (trams), heavy passenger, privately owned freight, and hire and reward freight. Heavy passenger is split between urban and non-urban rail transport, while hire and reward is split between bulk and non-bulk freight.

For passenger categories, the amount of fuel consumed in PJ is computed according equation (10) to:

$$PJ = Billion\ Pkm \times Fuel\ Intensity_{MJ/km} \qquad (10)$$

where:
Pkm is passenger kilometres.

Freight fuel use in PJ is computed using equation (11):

$$PJ = Billion\ Tkm \times Fuel\ Intensity_{MJ/km} \qquad (11)$$

where:
Tkm is tonne kilometres.

Unlike the IPCC/AGO methodology, this model computes and reports the emissions from the production of electricity. Electrification is based on the following equation, which is the same as used in the BTRE reports (AGO 2006, p. 26, Table 8 and p. 27, Table 9):

$$\begin{aligned} PJ_{Elect} &= \alpha \times urban\ pass + \beta \times hnr\ bulk + \\ &\quad \chi\left(Non-urban\ pass + hnr\ non-bulk + private\right) \\ PJ_{Non-Elect} &= (1-\alpha)\times urban\ pass + (1-\beta)\times hnr\ bulk + \\ &\quad (1-\chi)\left(Non-urban\ pass + hnr\ non-bulk + private\right) \\ \alpha &= 0.95 \\ \beta &= 0.2 \\ \chi &= 0 \end{aligned} \tag{12}$$

where:
urban pass is urban light PJ and heavy rail PJ,
hnr stands for hire and reward PJ,
while the parameters *α*, *β*, and *χ* represent the percentage of electrification.

Emissions are computed as:

$$E_k^{gas} = PJ_k \times EF_k^{gas} \tag{13}$$

where:
E is the emission of *gas* type from combusting fuel *k* (coal or ADO),
PJ is the amount of fuel *k* in *PJ*,
EF is the emission factor for *gas* type from combusting fuel *k.*

Consistent with the method used to report transport's contribution to the greenhouse gas total, electricity for rail use is usually omitted. However, in this model it has been included. The emissions coefficient used is that of coal, which is similar to the procedure used by BTRE (2002, p. 202).

In Scenario 3, however, the emission factor for coal has been reduced to represent the influx of renewable energy into the rail network. The emissions factor has decreased from 89 in 2010 to 40 by 2020. The increased electrification adjusts the parameters in equation (12). The parameter changes are *α* changes from 0.95 to 1, *β* changes from 0.2 to 0.342 (5% per year), and lastly *χ* changes from 0 to 0.26. In other words, this means that the urban network is completely electrified, while, of the freight network that is currently electrified, *hire and reward* bulk freight increases to 35% over 10 years of operation, and the remaining freight tracks are electrified by 1% per year.

Freight costs for rail are computed in the same way as road (equation (3)) while equation (14) is used for passengers:

$$Op\ costs_i\left(\$A\right) = Billion\ Pkm \times Cost_i \tag{14}$$

Equation (15) shows how the rail passenger revenue was calculated:

$$Op\ revenue_i\left(\$A\right) = Billion\ urban\ Pkm \times revenue_i \tag{15}$$

Externality costs for passengers are computed from equation (16):

$$Ext\ costs_i^{pass}\left(\$A\right) = Billion\ Pkm \times Cost_i^{pass} \qquad (16)$$

and freight from Equation(17):

$$Ext\ costs_i^{freight}\left(\$A\right) = Billion\ Tkm \times Cost_i^{freight} \qquad (17)$$

where:
pass refers to passenger costs,
freight refers to freight costs.

Climate change costs are computed from emissions as in equation (6).

4.5. Maritime

The maritime sector was only computed in PJ and has no drivers. The fuel was split according to the average consumption of fuel *k* in the navigation sector over the last 4 years (see Table 10.13).

Table 10.17 Amount of fuel consumed (in PJ) by the maritime sector (2003-2007)

	2003-04	2004-05	2005-06	2006-07	Average %
Black coal	4.00	5.60	4.80	5.20	0.31
ADO	1.98	1.98	2.4	11.04	0.23
Fuel oil	7.7961	7.7961	6.3968	7.09645	0.46
Natural gas	0.1	0.1	0.1	0.1	0.01
Total PJ	13.88	15.48	13.70	23.44	

Source: BTRE (2002).

Emissions from this sector are computed as those in equation (13). No costs for this transport sector were computed. In the final model, when emissions from navigation are used, they are based on those presented by BITRE (2008, Table 2.5).

4.6. Aviation

The drivers in the aviation sector are domestic passengers and international visitors on the domestic network. These drivers give us the number of passenger kilometres, which are used to calculate fuel use. Equation (18) is the algorithm used:

$$PJ_k = Pkm \times fint \times Load \times fuelpro_k \qquad (18)$$

where:
PJ is amount of fuel *k* consumed in *PJ*,
fint is the fuel intensity of domestic aircraft,
load is the percentage of fullness of a domestic aircraft,
fuelpro is the proportion fuel *k* per total fuel.

The assumptions include a passenger loading moving from 0.75 to 1 in 2020 and fuel intensity decreases (aircraft become more efficient in use of fuel) to 22% of the year 2000 value, which amounts to about 1% per year. The fuel proportions are taken from BTRE along with the assumptions above (BTRE 2006, Table 2.7). More details can be recovered from the BTRE submissions to the Australian Greenhouse Office (BTRE 2002, Appendix 3; BTRE 2006). As for navigation, aviation does not change in the model and, in the most recent form of the model, emissions from BITRE have been used (when required for aviation in the model) (BITRE 2008, Table 2.8).

5. References

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6. Appendix

6.1. Computation of GHG

Following the method of the AGO (now DCC), estimation of data on fuel use by mobile sector was obtained from ABARE. (ABARE Table F, Australian energy consumption, by industry and fuel type – energy units).[4] The data in this table was modified as per Table A.1 (BTRE 2006), reproduced in Table 10.19.

Table 10.18 shows the data categories calculated. The data were also adjusted according to equations (8) to (26)from the AGO guidelines. For *h* = 3 (mobile sector = railway) the emission (*E*) from activity data was calculated as:

$$E^{gas}_{3,k} = A_{3,k} \times EF^{gas}_{3,k}$$

where:
A is rail fuel consumption of type *k,*
EF is emissions factor for gas CO_2, CH_4, or N_2O, from fuel *k*.

Similarly for *h* = 1 or 4 we have:

$$E^{gas}_{h,1,k} = A_{h,1,k} \times \left(1 - MU_{h,k}\right) \times EF^{gas}_{h,1,k}$$

where:
MU is military usage of fuel *k*, for *h* = 1 or 4, sourced from Table 10.18.

For *h* = 2, emissions are calculated as:

$$E^{CO2}_{2,i,k} = A_{2,k} \times \left(1 - MU_{2,k}\right) \times Q_i \times EF^{CO2}_{k} \times P_k$$

And:

$$E^{gas}_{2,k} = A_{2,k} \times \left(1 - MU_{2,k}\right) \times Q_i \times EF^{gas}_{2,k}$$ for non CO_2 gases,

where:
P is the proportion of oxidised fuel,
Q is the proportion of vehicles in class *i* reported in Table 10.21 (AGO 2006).

The proportion of category *i* vehicles before 2006 and was estimated to be that of 2003.

Unlike, the AGO however, we have used Tier 1 to calculate non-CO_2 gases, using the coefficients in Table 10.22. For rail, LPG uses the road value and fuel oil uses the navigation's EF, even though the IPCC default is very general. For aviation, all emission factors are the same regardless of gas. For navigation, coal and IDF used rail's EF, and LPG and ADO use road's EF. EFs for natural gas were not provided.

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[4] http://www.abareconomics.com/interactive/energyUPDATE08/excel/table_F_08.xls

Table 10.18 Data categories calculated

Mobile source sector = h	Category = i	Fuel type = k
1 = Civil aviation	1 = Domestic aviation	4 = Avgas 5 = Avtur 6 = IDF
2 = Road transportation	1 = Passenger vehicle 2 = LCV 3 = Medium duty trucks 4 = Heavy duty trucks 5 = Buses 6 = Motorcycles	1 = Autogas 2 = ADO 3 = LPG 8 = (Nat) gas
3 = Railway transportation		2 = ADO 3 = LPG 6 = IDF 7 = Fuel oil 8 = (Nat) gas 9 = Coal
4 = Navigation	1 = Domestic marine	2 = ADO 3 = LPG 6 = IDF 7 = Fuel oil 8 = (Nat) gas 9 = Coal

Table 10.19 Factors used to allocate ABARE fuel consumption

	General	Military
Road gas	96.81%	0.06%
Road ADO	99.50%	0.50%
Water ADO	60.00%	40.00%
Water fuel oil	99.95%	0.05%
Air avgas	96.50%	3.50%
Air avtur	92.00%	8.00%

Table 10.20 Effective CO_2 emission factors by *k* for *h* = 2 (road) and energy densities

k =	Fuel type	p_k	F_k	Effective EF	NRG Density
1	Autogas	0.99	67.4	66.73	34.2
2	ADO	0.99	69.9	69.20	38.6
3	LPG	0.99	60.2	59.60	26.2
4	Avgas	0.99	67	66.33	33.1
5	Avtur	0.99	69.6	68.90	36.8
6	IDF	0.99	69.9	69.20	39.6
7	Fuel Oil	0.99	73.6	72.86	39.7
8	Gas	1	51.4	51.40	39.3
9	Black Coal	0.99	90	89.10	0

Table 10.21 Proportion of vehicles in category *i*

		2003	2006	2007
i =	Vehicle type			
1	Passenger	10365941	11188880	11462400
2	Camper	38337	41520	43266
2	LCV	1879755	2114333	2189559
3	Rigid	348673	383546	394491
4	Articulate	64261	71680	74444
2	Non-freight	18599	20293	21247
5	Bus	70122	75375	77548
6	Motorbike	377271	463057	511966
	Total motor	13162959	14358684	14774921
		2003	**2006**	**2007**
i =	Vehicle type			
1	Passenger	0.79	0.78	0.78
2	LCV	0.15	0.15	0.15
3	Medium duty trucks	0.03	0.03	0.03
4	Heavy duty trucks	0.00	0.00	0.01
5	Buses	0.01	0.01	0.01
6	Motorcycles	0.03	0.03	0.03

Note: LCV = light commercial vehicles includes campers, non-freight trucks (ambulances, etc.) and LCVs.
Source: Table: Type of Vehicle – Census years 2003, 2006, and 2007 (ABS 2007).

Table 10.22 Non-CO_2 emission factors

IPCC Table	k =	Fuel type	CH_4	N_2O
3.2.2	1	Autogas	33	3.20
3.2.2	2	ADO	3.9	1.30
3.2.2	3	LPG	62	0.20
3.6.5	4	Avgas	0.5	21.00
3.6.5	5	Avtur	0.5	2.00
3.4.1	6	IDF	4.15	28.60
3.5.3	7	Fuel oil	7	2.00
Not found*	8	Gas	0	0.00
3.4.1	9	Black coal	2	1.50

Note: * this fuel source not found in literature.

6.2. Glossary and Terms

Many of the terms are found in the reference documents and have been adopted. Fuller versions of the definitions can be found in these sources (ABS 2007).

Fuel types

Autogas	Automotive gasoline
ADO	Automotive diesel oil
LPG	Liquefied petroleum gas
Avgas	Aviation gasoline
Avtur	Aviation turbine fuel
IDF	Industrial diesel fuel
Fuel oil	Residual (heavy) fuel oils including those obtained by blending
Gas	Natural gas (methane CH_4)

Black coal	bituminous and sub-bituminous coals

Truck types

Articulated trucks are vehicles constructed primarily for the carriage of goods, consisting of a prime mover (having no significant load-carrying area) but linked, with a turntable device, to a trailer.

Light Commercial Vehicles includes rigid trucks less than 3.5 tonnes, utilities, panel vans and vans without rear seats.

Rigid trucks are motor vehicles exceeding 3.5 tonnes, constructed with a load carrying area.

Kilometre types

Passenger-kilometre (pkm) is the product of the distance a vehicle travels times the number of occupants travelling that distance.

Tonne- kilometre (tkm) is the product of the weight of freight transported (tonnes) and the distance of its transportation (kilometres).

Vehicle-kilometre (vkm) is the movement of a road motor vehicle over one kilometre.

Units and numbers

Table 10.23 Notes on terms used

Prefix	Number	Scientific notation	Common name
kilo	1000	1E+03	Thousand
mega	1000000	1E+06	Million
giga	1000000000	1E+09	Billion
tera	1000000000000	1E+12	
peta	1000000000000000	1E+15	

6.3. Specific Method for Computing Projections

Cars

$$Fuel\_car = vehicles \times km\_car \times fint\_car$$

$$L = V \times km \times L / km$$

Heavy truck

$$Fuel\_truck = freight\ task \times fint\_truck / load$$

$$L = Btkm \times L / km$$

LCV

$$Fuel\_LCV = vehicles \times km\_LCV \times fint\_LCV$$

$$L = V \times km \times L / km$$

Rigid truck

$$Fuel\_Rigid = vehicles \times km\_Rigid \times fint\_Rigid$$

$$L = V \times km \times L / km$$

Bus

$$Fuel\_bus = vehicles \times km\_bus \times fint\_bus$$

$$L = V \times km \times L / km$$

Bike

$$Fuel\_Bike = vehicles \times km\_Bike \times fint\_Bike$$

$$L = V \times km \times L / km$$

Rail

$$Fuel\_rail = km\_rail_g \times fint\_rail_g$$

(Equation IV.1 in BTRE 2002, p. 189).