Greenhouse Gas Emissions from Australian Transport: Long Term Projections

Report

This Report provides a 'business as usual' scenario for the emission of greenhouse gases from the Australian transport sector for the period 1993-94 to 2014-15. Models for emissions from cars, trucks, rail, sea and air transport reflect sectoral activity, fuel intensity and emission intensity factors. The models indicate that emissions from the Australian car fleet over the next two decades will decline while emissions from trucks and aircraft are likely to grow quite strongly. Background information and historical data series are also provided.

Bureau of Transport and Communications Economics

Report 88

GREENHOUSE GAS EMISSIONS FROM AUSTRALIAN TRANSPORT
LONG-TERM PROJECTIONS

Australian Government Publishing Service, Canberra

ISSN 1034–4152
ISBN 0 644 43016 8

Printed by the Australian Government Publishing Service

FOREWORD

In his 21 December 1992 Statement on the Environment, the Prime Minister announced that the Bureau of Transport and Communications Economics (BTCE) would be commissioned to provide a comprehensive analysis of the range of possible measures for reducing greenhouse gas emissions in the transport sector.

This Report contributes to the BTCE study by providing a 'base case' or 'business as usual' scenario for the emission of greenhouse gases from Australian transport. That is, the base case is an estimate of expected future emission levels assuming that Australian governments take no action to reduce greenhouse gas emissions from the transport sector. Any measures proposed to reduce greenhouse gas emissions should be assessed against this 'base case' scenario.

The BTCE is frequently approached for advice on matters such as the task performed by the various transport modes or fuel usage rates. To assist other researchers and to help inform public debate about greenhouse gas emissions, historical data and commonly requested information such as urban/rural shares of the transport task have also been included as part of the study.

Substantial contributions to the research, analysis, figures and report writing were made by David Cosgrove (research leader), Trisha Dermody, Dr David Gargett, Lynton Higgs, Anita Scott-Murphy and Karen Subasic. Additional assistance was provided by Damien Eldridge. Valuable input was also provided by other members of the Transport Externalities branch of the BTCE.

The research team received valuable assistance from a number of people. In particular, the BTCE would like to thank Professor Harry Watson for reviewing the report. In addition, special thanks are expressed to Shane Bush and Luan Ho Trieu of the Australian Bureau of Agricultural and Resource Economics (ABARE), Bill Bourke from Qantas, Neil Chambers from the Australian National Maritime Association (ANMA) and Marcus Wigan, Visiting Professor at the Institute of Transport Studies, Sydney.

Dr Leo Dobes
Research Manager

Bureau of Transport and Communications Economics
Canberra
March 1995.

CONTENTS

Page

TABLES

Page

FIGURES

Page

Page

UNITS

The basic units used in the Report are joules (J), grams (g), metres (m) and litres (L). Standard metric prefixes are:

kilo (k)	=	10^3 (thousand)
mega (M)	=	10^6 (million)
giga (G)	=	10^9 (billion)
tera (T)	=	10^{12}
peta (P)	=	10^{15}

The main prefix and unit combinations found in this Report are petajoules (PJ) and gigagrams (Gg). Gigagrams are equivalent to the commonly used unit of kilotonnes (kt). Another unit occasionally used is terametres (Tm). A terametre is equivalent to one billion kilometres. In tables, 0.0 is used to denote an amount that is assumed negligible, n.a. denotes not available and .. denotes not applicable.

ABSTRACT

This Report provides a 'business as usual' scenario for the emission of greenhouse gases from the Australian transport sector for the period 1993–94 to 2014–15. Models for emissions from cars, trucks, rail, sea and air transport reflect sectoral activity, fuel intensity and emission intensity factors. The models indicate that emissions from the Australian car fleet over the next two decades will *decline* while emissions from trucks and aircraft are likely to grow quite strongly. Background information and historical data series are also provided.

SUMMARY

Considerable attention has been devoted in recent years to the problem of global warming and the associated increase in greenhouse gas emissions as a result of human activity. In 1991, Australia ranked about sixteenth among major greenhouse gas producing countries.

The National Greenhouse Response Strategy (endorsed by Australian governments in December 1992) aims to reduce greenhouse gas emissions in Australia to 1988 levels and below within a decade. The BTCE has been commissioned to estimate the costs of potential abatement measures in the Australian transport sector.

Australian transport accounts for about 12 per cent of all Australian greenhouse gas emissions due to human activity (from energy use, industrial processes, agriculture, land-use changes, forestry, and waste disposal). Transport accounts for about 25 per cent of emissions from Australian energy use. The transport sector is therefore important in any overall Australian strategy to reduce greenhouse gas emissions. If the cost to the Australian community of reducing emissions is to be minimised, however, it is essential that policy decisions be based on comparisons of the marginal costs of any potential measures in the transport sector with similar costs in other sectors.

In order to evaluate abatement measures in a specific sector, it is necessary to establish a *base case* (or 'business as usual' scenario) of greenhouse gas emissions, to provide a point of reference into the future. Estimates can then be made of the effect (and the associated cost) of each measure. This Report provides the first step by developing base case projections separately for road passenger vehicles, road freight vehicles, rail transport, shipping and aviation.

Because the atmospheric effect of greenhouse emissions poses a long-term problem, long-term abatement measures need to be considered, as well as more immediate policies. Equally, the longer-term effects of short-term policies need to be assessed. The BTCE has chosen to analyse measures and emissions to the year 2015, even though projections over such a long period are obviously subject to a great deal of uncertainty and reliance on underlying assumptions.

Long-term projections should ideally be based on simple models that capture only major underlying forces or trends. Variables that explain variation solely in the shorter term are often not suitable for modelling long-term behaviour. Because the structure of the models used in this Report has been kept as simple as possible, the results obtained should match qualitative expectations. The models reflect forces that affect sectoral activity, fuel intensity (for example, litres per 100 kilometres for road vehicles) and emission intensity (that is, grams of greenhouse gases emitted per unit of fuel consumption).

Future passenger vehicle travel is likely to be influenced by a marked slowing in the growth of Australian car ownership (cars per person). Slow expected population growth for Australia will slow the growth in numbers of passenger cars even further. New car fuel and emission intensities are likely to be reduced by the scheduled implementation of automobile industry product plans. The net result of these forces is a projected *decline* in greenhouse gas emissions (of about 10 per cent) from the Australian car fleet over the next two decades.

Emissions from trucks, on the other hand, are likely to continue to grow quite strongly, in line with expected growth in the Australian economy. Expected growth in road freight activity over the next two decades is of the order of 4 per cent per annum. The limited potential for reductions in the fuel intensities of truck engines restricts the scope for achieving reductions in emissions through the introduction of new vehicles. Emissions from road freight vehicles are projected to be one of the two fastest growing emission categories in the Australian transport sector to the year 2015, approximately doubling over the period.

The other fast-growing area is likely to be air transport. BTCE projections suggest that annual growth in domestic air passenger travel of 4 per cent is likely. Some decline in fuel intensities is possible over the period to 2015, but the low densities of many of the domestic routes somewhat limits the potential effectiveness of measures such as encouraging increased aircraft size. Overall, it is likely that the rapid growth in projected aviation activity will translate fairly directly into rapid growth of greenhouse emissions. The BTCE projects emissions from domestic aviation to double by 2015.

Projected growth in total emissions from domestic transport is expected to be of the order of 1.2 per cent per year between 1993 to 2015; an increase in emissions of about a third over the period. Figure 7.1 illustrates the expected long-term decline in the relative importance of emissions from cars, and the rapid increase from trucks. By about the year 2015, road freight vehicles could account for as much annual greenhouse emissions as cars. Although emissions from international aviation have not been attributed to Australia, the BTCE has estimated the emissions resulting from the use of Australian bunker fuel by international aircraft (figure 7.2). If international aviation emissions are included, BTCE projections have cars, trucks and aircraft accounting for roughly equal shares of total transport emissions in 2015 (with about 34, 37 and 22 per cent respectively). The BTCE projects the contribution of rail transport and shipping to total emissions to remain small (with shares of about 2 and 4 per cent respectively).

Emission levels presented in this Report are generally those resulting directly from the combustion of fuel within transport engines; so-called 'end-use' estimates. However, electric vehicles themselves emit no greenhouse gases, although power stations using fossil fuels to generate the electricity would do so. It is therefore important to use 'full fuel cycle' estimates that include energy used to extract, process and distribute the fuel to the end-user. Full fuel cycle estimates permit comparisons between petrol-driven road vehicles and transport modes such as electric trains. On a full fuel cycle basis, the greenhouse gas emissions attributable to the transport sector were about 13 per cent higher than on an end-use basis in 1992–93.

Further refinements are possible, taking into account the energy use associated with manufacture of vehicles and the construction and maintenance of transport infrastructure. Estimates of the additional emissions associated with these activities are also presented in the Report.

Background information that is often sought by researchers and policy-makers is provided in appendices to this Report, which include historical data on transport tasks, a detailed 1992–93 greenhouse gas emission inventory, and details of the emission projections.

On the basis of the methods of analysis and the projections developed in this Report, the BTCE will conduct work on costing greenhouse gas abatement measures over the course of the coming year, with the aim of identifying a least-cost set of measures for the transport sector.

CHAPTER 1 INTRODUCTION AND BACKGROUND

Emissions from the transport sector, and particularly from road vehicles, can have detrimental effects on both human wellbeing and the natural environment.

The primary adverse impacts on the environment due to emissions from the transport sector relate to:

- local air quality,
  - through the emission of noxious gases such as carbon monoxide and nitrogen dioxide, causing increased susceptibility to respiratory infections;
  - by the formation of low-level ozone (the main component of smog);
  - from increases in urban levels of toxic substances such as lead, benzene and cadmium;
  - by the formation of highly reactive compounds (called atmospheric oxidants) capable of damaging crops and buildings;
  - through the emission of sulfur dioxide, the main cause of acid rain; and
  - by the generation of suspended particle hazes (called aerosols), which reduce visibility and influence cloud formation; and
- global atmospheric change,
  - through the depletion of stratospheric ozone, due to the release of chlorofluorocarbons (CFCs) from air-conditioners and refrigeration; and
  - from the warming effect of certain gaseous emissions (commonly called the *greenhouse effect*).

The gaseous pollutants generated by transport activities vary considerably in their chemistry, rates of emission, atmospheric concentrations and environmental effects. Considerable attention has been devoted in recent years to the *anthropogenic* (that is, of human origin) greenhouse effect. However, many studies on greenhouse gas emissions focus solely on the major contributor, carbon dioxide (CO_2). Most noxious emissions contribute both to local air pollution and to the greenhouse effect and are often easier to reduce than CO_2 emissions. Any debate concerning transport emissions should therefore be based on an analysis of *all* the major gases emitted and their effects, not on CO_2 alone.

A full assessment of transport emissions and measures to reduce them needs to consider all costs and benefits involved (including an examination of resource use, environmental effects and social aspects).

Analysis of the benefits to Australia of reducing greenhouse gas emissions is complicated by the fact that greenhouse emissions have a global effect: in this sense they are analogous to a joint product. Uncertainty regarding the global climatological, social and economic effects of reduced emissions means that any estimate of benefits could be only indicative. The current work program of the BTCE does not envisage estimates of the benefits to Australia of a reduction in greenhouse emissions from the transport sector.

Working Paper 10 (BTCE 1993a) outlines the BTCE approach to identifying a least-cost combination of measures for reducing greenhouse emissions in the transport sector.

A necessary first step in assessing the effect of any measure is the estimation of a base case ('business as usual') level of emissions from the transport sector. Comparison of the social costs of implementing each measure against a common reference level permits assessment of the relative cost-effectiveness of different measures. This Report provides base case projections for the period 1993–94 to 2014–15.

BACKGROUND

The greenhouse effect

The *natural greenhouse effect* maintains the earth's temperature at a level suitable for sustaining life (a summary of the process is contained in NGAC 1992).

Some of the solar radiation received by the earth is reflected back into space by the planetary surface and atmosphere, including clouds. The remainder is mostly absorbed by the earth's surface, thereby warming it. The infra-red radiation subsequently emitted upwards from the heated ground is absorbed by a number of atmospheric constituents, the so-*called greenhouse gases*. Greenhouse gases re-emit infra-red radiation both upwards and downwards (and are said to be *radiatively active*), serving to maintain the global surface temperature at around 33 degrees Celsius warmer than it would otherwise be (IPCC 1994, p. 7).

The major greenhouse gases are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs) and ozone (O_3). With the exception of CFCs (which are man-made) all occur naturally. However, concentrations of some greenhouse gases are increasing substantially as a result of human activity, creating the *enhanced* or *anthropogenic* greenhouse effect.

The major contributor to the greenhouse effect is water vapour. However, water vapour is not normally considered in greenhouse gas inventories, because human output is negligible when compared to the day-to-day precipitation cycle. The next most significant greenhouse gas is carbon dioxide, which is the major gas associated with the anthropogenic greenhouse effect.

The transport sector generates both *direct* (radiatively active) and *indirect* greenhouse gases. The main direct greenhouse gases emitted from the transport sector (apart from water vapour) are carbon dioxide, methane, nitrous oxide and chlorofluorocarbons. Indirect greenhouse gases such as carbon monoxide (CO), oxides of nitrogen other than N_2O (NO_x) and non-methane volatile organic compounds (NMVOCs) do not have a strong radiative effect themselves, but influence atmospheric concentrations of the direct greenhouse gases. Sulphur oxide (SO_x) emissions are also known to influence climatic change. The negative radiative forcing due to sulphate aerosols show large regional variations with the largest effects in the Northern Hemisphere (IPCC 1994, p. 8). Because the exact nature and magnitude of the effects of atmospheric sulphur oxides are still very uncertain, SO_x emissions are excluded from the projections given in this Report. The physical and chemical aspects of transport-related emissions are described in appendix I.

Many studies on greenhouse gas emissions focus solely on the output of CO_2. However, such studies do not take sufficient account of the complex chemistry of transport emissions and the intricate relationships between local and global air quality. Results obtained may therefore be misleading. Wherever possible, BTCE analysis includes the estimated effects due to all the major greenhouse gases.

To represent the total greenhouse effect of the emissions of several different gases those emissions need to be expressed in terms of a common unit. It is standard to use CO_2 equivalent emissions, calculated on the basis of the *global warming potential* (GWP) for each gas (see appendix II). The GWP is an index, defined to be the warming effect over a given period due to an emission of a particular gas, relative to an equal mass of CO_2 (for example, if the GWP of methane is 24.5, then 1 kg of CH_4 emissions has the average global warming effect of 24.5 kg of CO_2 emissions).

Representative GWP values for the main greenhouse gases have been calculated by the Intergovernmental Panel on Climate Change (IPCC). Due to the varying atmospheric lifetimes of greenhouse gases, GWP figures depend on the assumed time period over which the effects of emissions are considered. The IPCC (1990, 1992, 1994) has estimated GWP values which range over various time horizons, including 20, 100 and 500 years. Reports dealing with greenhouse gas emissions (such as IEA 1993 and BTCE 1991a) have typically used the 100-year values derived by the IPCC. This Report is also based on a GWP horizon of 100 years.

Due to the presently incomplete understanding of the complex atmospheric processes involved in the indirect effects, GWP values for indirect greenhouse gases were not given in the latest IPCC revisions (IPCC 1992, 1994). Since there is considerable uncertainty about the indirect values (their refinement being a topic of current research), care must be exercised in applying GWPs. IPCC (1994, p.26) states that GWPs are difficult to apply to gases with short atmospheric lifetimes (such as NO_x and NMVOCs), and that the 'calculation of many indirect GWP components is not currently possible because of inadequate characterisation of many of the atmospheric processes involved'. The IPCC (1992, 1994) states that on current knowledge the scientific community is confident only that:

- the indirect GWP for methane is a positive number, possibly comparable in magnitude to its direct value; and
- CO, NMVOCs and NO_X emissions 'will affect the radiative balance of the atmosphere through changes in tropospheric ozone'. Limited data suggest that tropospheric ozone in the Northern Hemisphere may have doubled since pre-industrial times, resulting in a global radiative forcing of between 13 and 38 per cent of that for CO_2.

The GWPs used in the BTCE analysis, based on various IPCC results, are given in table 1.1. The IPCC (1994, p. 28) is reasonably confident that the GWP values for direct effects are of the right order with a typical uncertainty of plus or minus 35 per cent. However, the current uncertainty surrounding the indirect effects hampers quantitative analysis of transport emissions. The BTCE has included analysis of the indirect effects based on the GWP scenario in table 1.1, on the understanding that the results derived need to be suitably qualified.

The GWPs specified in table 1.1. allow total CO_2 equivalent emissions for Australian transport to be calculated. The BTCE estimates that Australian transport vehicles accounted for around 80.4 million tonnes of CO_2 equivalent

TABLE 1.1 OVERVIEW OF AUSTRALIAN GREENHOUSE GAS EMISSIONS, 1990

Gas[a]	*Global warming potential (GWP)*	*Contribution to Australian CO_2 equivalent emissions (per cent)*	*Australian human-sourced emissions (gigagrams of gas)*		*Contribution of transport vehicles to Australian emissions (per cent)*[b]	
			Energy use	*Total*[c]	*Energy use*	*Total*[c]
Direct						
Carbon dioxide	1	58.6	288 353	426 088	23.2	15.7
Methane	24.5	21.0	1 054	6 244	2.1	0.4
Nitrous oxide	320	2.7	3.7	60.3	61.4	3.8
CFCs	8 500[d]	9.5[e]	..	13	..	5[f]
Indirect[g]						
Carbon monoxide	1	3.6	4 470	26 082	85.4	14.6
Nitrogen oxides	8	2.1	1 276	1 949	39.0	25.5
Non-methane volatile Organic compounds	8	2.5	628	2 238	82.9	23.3
Total CO_2 equivalent	..	**100**	**335 100**	**727 000**[e]	**25.4**	**11.7**

.. not applicable

a The major contributor to the greenhouse effect is water vapour. However, water vapour is not normally considered in greenhouse gas inventories, because human output is negligible when compared to the day-to-day precipitation cycle.

b. Includes emissions from military transport and emissions due to Australian bunker fuel consumption by international transport.

c. Includes all man-made sources and sinks for emissions from energy use, industrial processes, agriculture, land use change and forestry, and waste disposal.

d. GWPs (100-year time horizon) for various CFCs range from 4 000 to 11 700. The value given here is for CFC-12, the main gas used in vehicle air-conditioners.

e. The net warming effect of CFCs is uncertain, since CFC-induced depletion of stratospheric ozone results in negative (global average) radiative forcing. Since the late 1970s, the negative indirect effect has been of a similar magnitude to the positive direct effect (IPCC 1994, p. 5). Estimated total CO_2 equivalent emissions less CFCs are 658 000 Gg for Australia in 1990, of which CO_2 accounts for 65 per cent.

f. Emissions during vehicle operation would account for around only 5 per cent of national CFC output. The share is considerably higher (up to 18 per cent) when allowance is made for CFC release due to vehicle servicing, accidents, manufacture and disposal.

g. Does not include indirect effects due to carbon emitted as CH_4, CO or NMVOCs (which are eventually converted to CO_2 in the atmosphere) since CO_2 estimates are made on the assumption of total conversion of fuel carbon content to CO_2. The GWP for methane includes both direct and indirect effects.

Notes 1. The figures provided in the table refer to 'end-use' emission estimates. That is, for transport, the emissions resulting solely from vehicle operation.

2. Gigagrams equals 10^9 grams, commonly called a kilotonne.

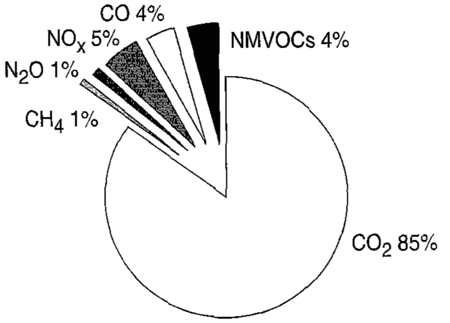
Sources NGGIC (1994c, pp. 12–13); DME (1990, pp. 22–23); IPCC (1990, pp. 11–13; 1992 pp. 19–21; 1994, p. 28); Cosgrove (1992, p. 7); BTCE estimates.

emissions in 1993, excluding CFCs (85.3 million tonnes including CFCs). The contribution of each greenhouse gas, both direct and indirect, to total CO_2 equivalent emissions from transport vehicles is displayed in figure 1.1.

The international greenhouse debate

Concern about the effects of global warming has prompted a number of international conferences in recent years. One of the most influential has been *The Changing Atmosphere: Implications For Global Security* Conference, held in Toronto in June 1988. This conference urged all governments to adopt action plans aimed at reducing annual CO_2 emissions to 20 per cent below 1988 levels by the year 2005. The outcome has since become known as the *Toronto target*.

The principal international body investigating greenhouse issues, the Intergovernmental Panel on Climate Change (IPCC), was established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP). Its three Working Groups (Science, Impacts, and Response Strategies) have been tasked with assessing the scientific basis of global climate change, evaluating the environmental and socioeconomic impacts, and formulating possible response strategies.



Total CO_2 Equivalent Emissions: 80.4 million tonnes

Note Emissions relate to energy end-use (excluding CFCs). In 1993 road sector CFC emissions are estimated to be around 4.9 million tonnes in CO_2 equivalent terms. Excludes emissions from military transport.
Includes international transport emissions. That is, emissions generated from bunker fuel uplifted in Australia and consumed by international sea and air carriers travelling to and from Australia.

Source BTCE estimates.

Figure 1.1 Share of greenhouse gases in Australian transport emissions, 1993

International negotiations commenced in January 1991 for a Framework Convention on Climate Change. The text of the Convention adopted at the United Nations Conference on Environment and Development (UNCED) held at Rio de Janeiro in June 1992 was signed by more than 150 countries.

The Framework Convention does not contain a binding target, but calls on developed countries and others identified in Annex 1 to the Convention to aim to return their greenhouse gas emissions to 1990 levels by the year 2000. The Convention requires participating countries to maintain inventories of greenhouse gas emissions, to co-operate in international research and to develop strategies for emission reduction.

The Convention includes a number of caveats, taking into account the individual circumstances of countries, their economic structures and their resource bases. Also recognised is the need to maintain strong and sustainable economic growth, as well as the need for an equitable contribution by each of the Parties to the Convention to the global effort to limit greenhouse gas concentrations in the atmosphere to a safe level (UNEP/WMO 1994).

The Convention entered into force on 21 March 1994, ninety days after the required fifty ratifications. The first 'Conference of the Parties'(CoP 1) to the Convention is scheduled to be held in Berlin from 28 March to 7 April 1995. Activities at CoP 1 will include decisions on implementation issues, review of the adequacy of commitments (contained in Article 4.2 (a, b)) of the Convention and a review of first National Communications submitted by the Parties. An Intergovernmental Negotiating Committee (INC) has been negotiating since December 1992 to prepare for CoP 1.

Yet even worldwide adoption of the targets currently being discussed in major international forums would probably not prevent the enhanced greenhouse effect. The IPCC has calculated that stabilisation of atmospheric concentrations of the main greenhouse gases at 1990 levels would require reductions in anthropogenic emissions of as much as 60 per cent for carbon dioxide, 20 per cent for methane, 80 per cent for nitrous oxide and 85 per cent for CFCs (IPCC 1990).

Australia's response to the international greenhouse debate

In October 1990, the Australian Government adopted an Interim Planning Target (IPT) for greenhouse gases based on the Toronto target. The aim of the Interim Planning Target is:

to stabilise greenhouse gas emissions (not controlled by the Montreal Protocol on Substances that Deplete the Ozone Layer) based on 1988 levels, by the year 2000 and to reduce these emissions by 20 per cent by the year 2005...subject to Australia not implementing response measures that would have net adverse economic impacts *nationally or on Australian trade competitiveness, in the absence of similar action by major greenhouse producing countries* (Commonwealth of Australia 1992).

Australia signed the United Nations Framework Convention on Climate Change at UNCED in June 1992 and ratified it in December 1992. Because the Convention requires a reduction by the year 2000 of greenhouse gases to 1990 levels, it is in fact less stringent than the Interim Planning Target because Australian greenhouse gas emissions in 1990 were greater than those in 1988.

Australian governments endorsed a National Greenhouse Response Strategy (NGRS) at the 7 December 1992 meeting of the Council of Australian Governments. The Interim Planning Target was used as a basis for development of the NGRS, which contains mainly 'no regrets' measures (that is, measures which have net benefits, or at least no net cost, in addition to addressing the enhanced greenhouse effect (Commonwealth of Australia 1992)).

The Ecologically Sustainable Development (ESD) Strategy, also endorsed by the Council of Australian Governments on 7 December 1992, sets out the broad strategic and policy framework under which governments are to make decisions co-operatively and to take actions to pursue ESD in Australia.

Both the NGRS and ESD strategies contain a number of response measures relating to the transport sector, including undertaking further research. In this context, the Prime Minister announced in his 21 December 1992 Statement on the Environment that the BTCE would be commissioned to provide a comprehensive analysis of the range of possible measures for reducing greenhouse gas emissions in the transport sector.

This Report contributes to the BTCE study by providing a 'base case' or 'business as usual' scenario for the emission of greenhouse gases from the Australian transport sector. That is, the base case is an estimate of expected future emission levels assuming that Australian governments take no action to reduce greenhouse gas emissions from the transport sector. Any measures proposed to reduce greenhouse gas emissions should be assessed against this base case scenario.

Chapters 2 to 5 detail models of transport activity levels derived by the BTCE to allow the projection of transport emissions. Each of the econometric models presented in the Report are based on the assumption that transport demand elasticities are constant over time. To express such models in linear form, all regression equations are stated in log-log terms (that is, the natural logarithm is taken of both the dependent and independent variables).

International greenhouse emissions

A report by the World Resources Institute (WRI 1994) has ranked the contribution to global greenhouse gas emissions by various countries. Estimates are based on anthropogenic sources of CO_2 (fossil fuel combustion, cement manufacture and deforestation), CH_4 (landfills, coal extraction, oil and gas production, wet rice agriculture, and livestock production), and the two main CFCs (CFC-11 and CFC-12).

Global emissions of greenhouse gases in 1991 were estimated to be about 34 billion tonnes of CO_2 equivalent. Australia accounted for around 1.13 per cent of global emissions, ranking sixteenth among countries that contribute to the greenhouse effect (table 1.2); and ninth in per capita terms (WRI 1994). Table

TABLE 1.2 MAJOR GREENHOUSE GAS-PRODUCING COUNTRIES, 1991[a]

Country	*Per cent of global emissions*	*World ranking*
United States	19.14	1
Former Soviet Union	13.63	2
China	9.92	3
Japan	5.05	4
Brazil	4.33	5
Germany[b]	3.75	6
India	3.68	7
United Kingdom	2.37	8
Indonesia	1.89	9
Italy	1.72	10
Iraq[c]	1.71	11
France	1.63	12
Canada	1.62	13
Mexico	1.43	14
Poland	1.16	15
Australia	1.13	16
South Africa	1.12	17
Spain	1.01	18
Venezuela	1.01	19
Republic of Korea	0.98	20

a. The World Resources Institute ranking of countries is based on the emissions of carbon dioxide, methane and chlorofluorocarbons. Other greenhouse gases such as nitrous oxide and ozone are excluded. Indirect greenhouse gases such as carbon monoxide and nitrogen oxides are also excluded from the analysis. Inclusion of these other gases could alter the rankings.

b. Data for Germany include both the former Federal Republic of Germany and the former German Democratic Republic.

c. Emissions from the oil well fires in Kuwait were assigned to Iraq, resulting in a temporarily high ranking for 1991.

Source WRI (1994, p.201).

1.2 provides an overview of emissions from the major greenhouse gas producing countries.

Average global CO_2 emissions per capita increased from around 2.7 tonnes in 1955 to 4.2 tonnes in 1991 (WRI 1994, p. 366). However, because of different levels of development, population growth and energy intensities of human activities (including transport systems), there is considerable variation in the contribution of the major regions to greenhouse gas emissions. Table 1.3 provides 1991 estimates of CO_2 emissions per capita for each major region of the world.

An example of differences in transport systems can be seen in car ownership rates. Globally, the number of passenger cars doubled between 1970 and 1987 (table 1.4). However, in 1987 car ownership ranged from one car per 1 075 people in the People's Republic of China to one car per 1.8 people in the United States (OTA 1991). In 1991, Australian car ownership was approximately one car per 2.2 persons.

TABLE 1.3 CARBON DIOXIDE EMISSIONS BY REGION, 1991

Region	*CO_2 emissions (tonnes per capita)*	*Share of global CO_2 emissions (per cent)*
North America	13.5	25.4
Former USSR	12.3	15.8
Oceania[a]	11.2	1.3
Europe	8.2	18.1
Asia	2.1	29.4
South America	2.0	2.6
Africa	1.0	3.0

a. Primarily Australia.

Source WRI (1994, pp. 362–363).

TABLE 1.4 PASSENGER CAR NUMBERS BY REGION

	Passenger cars ('000)		
Region	*1970*	*1987*	*Growth per year (per cent)*
North America	95 846	149 417	2.65
Australia–New Zealand	4 703	8 802	3.76
OECD—Europe	63 908	130 310	4.28
OECD—Total	173 236	318 007	3.64
World	193 516	395 048	4.29

Source ECMT (1990, p. 18).

TABLE 1.5 CARBON DIOXIDE EMISSIONS[a] FOR SELECTED COUNTRIES, 1990

Country	*Population 1990 (millions)*	*Energy use emissions (million tonnes)*	*Energy use emissions per capita (tonnes)*	*Transport emissions (million tonnes)*	*Transport emissions per capita (tonnes)*	*Contribution of transport to energy use emissions (per cent)*
Australia	17.1	288.4	16.88	67.0	3.87	23.2
Belgium	10.0	122.1	12.26	36.3	3.64	29.7
Bulgaria	8.8	81.5	9.24	11.8	1.34	14.5
Canada	26.5	452.7	17.07	144.9	5.46	32.0
Denmark	5.1	55.5	10.80	15	2.92	27.0
Finland	5.0	60.6	12.14	15	3.01	24.8
France	56.4	350.5	6.21	116.7	2.07	33.3
Hungary	10.6	75.2	7.13	10.4	0.99	13.8
India	850	563	0.66	66	0.08	11.7
Indonesia	178	118.2	0.66	30.7	0.17	26.0
Italy	57.7	371.8	6.45	101.6	1.76	27.3
Japan	124	1 074.7	8.67	214	1.73	19.9
New Zealand	3.4	26.2	7.68	10.3	3.02	39.3
Nigeria	115.5	71.6	0.62	6.2	0.05	8.7
Philippines	61.5	38.4	0.62	13.5	0.22	35.2
Poland	38.2	473.5	12.40	34.6	0.91	7.3
Sri Lanka	17.0	3.5	0.21	2.1	0.12	60.0
Sweden	8.6	56.3	6.58	24.3	2.84	43.2
Switzerland	6.7	45.9	6.84	16.9	2.52	36.8
Turkey	56.1	182.5	3.25	21.6	0.39	11.8
United Kingdom	57.4	564	9.83	120.7	2.10	21.4
United States	250	5224	20.90	1 527	6.11	29.2
OECD	839	10 300	12.12	2 800	3.34	27.2
World	5 292	22 700	4.29	4 370	0.83	19.3

a. CO_2 only, as distinct from CO_2 equivalent emissions (as in table 1.2).

Notes 1. Emissions include those due to bunker fuel consumption.
2. Many of the estimates in this table are based on limited or preliminary data and are therefore very approximate.

Sources World Bank (1992); ECMT (1994, pp. 4–12); BTCE estimates (based on OECD/IEA 1991; OECD 1994).

The contribution of transport to CO_2 emissions resulting from energy use will vary between countries, reflecting the different composition of their transport systems. For example, in 1990 India's transport sector accounted for only 12 per cent of national CO_2 emissions from fuel combustion, while Swedish transport accounted for about 43 per cent (table 1.5).

In 1990, Australian transport accounted for about 23 per cent of energy use CO_2 emissions, similar to the OECD average for transport of around 27 per cent. Though substantially lower than the United States (but close to the OECD average), Australia's transport emissions per capita are considerably higher (nearly 5 times greater) than the world average.

EMISSIONS FROM THE AUSTRALIAN TRANSPORT SECTOR

The various industry sectors of the Australian economy contribute differing amounts to total CO_2 emissions resulting from energy use (figure 1.2), ranging from only 2 per cent for agriculture to 38 per cent for manufacturing and construction. Domestic transport (including emissions due to the generation of electricity for electric rail and to the refining of petroleum for transport fuel) accounts for a quarter of total CO_2 emissions from Australian energy use.

In order to estimate the levels of current and future greenhouse gas emissions from transport, it is necessary to first estimate the Australian transport task and the amount of fuel consumed in performing this task.

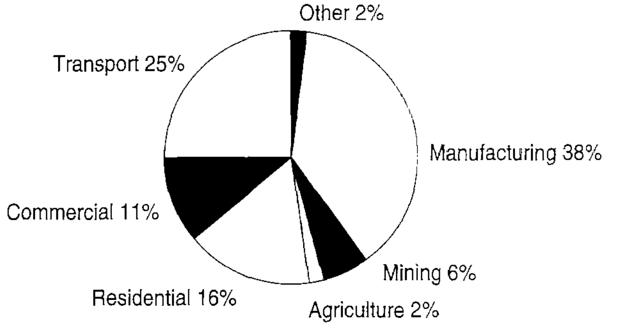
Appendix III provides time series estimates of aggregate transport activity for each of the main components of Australian transport. Time series estimates for transport fuel consumption are detailed in appendix IV. The methodology for estimating transport greenhouse gas emissions from both fuel combustion and fugitive releases (fuel evaporation and air-conditioner refrigerant leakage) is provided in appendix V.

The BTCE estimates that about 61.7 million tonnes of carbon dioxide were emitted by domestic civil transport (including oil and gas transport by major pipelines) energy end-use in Australia in 1993. Military transport emitted a further 1 million tonnes of CO_2 in 1993. In CO_2 equivalents, domestic civil transport emissions for 1993 are 73 million tonnes and military transport emissions are about 1.1 million tonnes.

Figures 1.3 and 1.4 show that road transport is the sector that contributes by far the largest proportion of domestic transport emissions (about 87 per cent). The road share falls slightly (to around 79 per cent of total transport emissions) if emissions due to Australian bunker fuel use by international sea and air transport are included (figure 1.5), but is still dominant. Passenger cars are the major contributor, at about 52 per cent of total transport emissions, followed by commercial vehicles (light commercial vehicles and trucks) with about 25 per cent.

However, the proportions of total CO_2 equivalent emissions given in figures 1.4 and 1.5 for aviation (5.5 and 11.3 per cent respectively) are lower bounds. Because the warming effects of substances emitted are dependent on the altitude at which they are released, the use of constant GWP values across modes would underestimate the contribution of air travel to total emissions.

Aircraft emissions (NO_x, NMVOCs and water vapour) contribute to the production of ozone and the formation of ice clouds in the upper troposphere. Although the magnitude of these effects is very uncertain, they could be as important to global warming as the carbon dioxide emissions from aircraft (RCEP 1994, p. 72). If further research validates the effects of non-CO_2 aircraft emissions having such a strong impact, then the contribution of aviation to total CO_2 equivalent emissions could roughly double.

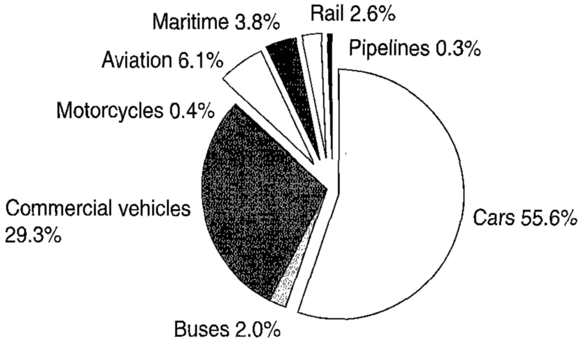


Total = 270 million tonnes CO_2

Notes 'Other' includes non-combustion activities such as direct emissions from coal mining and petroleum production, petrochemical feedstocks, lubricants, bitumen, solvents and waxes. Emissions due to electricity generation and other energy transformation (including petroleum refining, coke ovens, briquetting and gas industry own use and losses) have been apportioned amongst the industries in which the (secondary) energy was used.

Sources Bush S., Leonard M., Bowen B., Jones B., Donaldson K., and Ho Trieu L., (1993, p.18, 100); BTCE estimates.

Figure 1.2 Australian domestic CO_2 emissions by sector, 1990–91

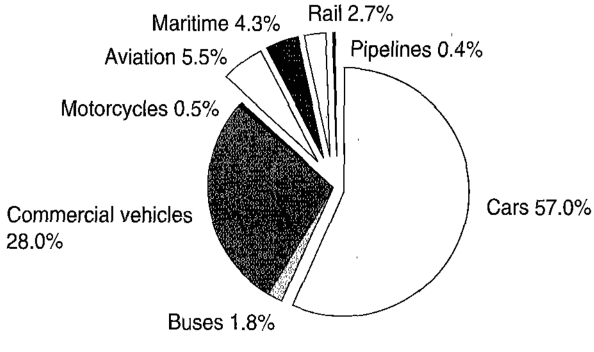


Total CO_2 Emissions: 61.7 Mt

Notes Emissions relate to energy end-use (excluding CFCs). Pipeline emissions are those due to major oil and gas transmission, and do not include the urban distribution of gas and water. Figures may not add to 100 per cent due to rounding.

Source BTCE estimates.

Figure 1.3 Carbon dioxide emissions from Australian domestic civil transport, 1993

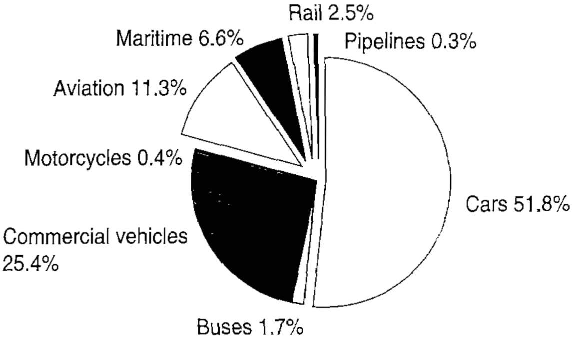


Total CO_2 Equivalent Emissions: 73.2 Mt

Notes Emissions relate to energy end-use (excluding CFCs). Pipeline emissions are those due to major oil and gas transmission, and do not include the urban distribution of gas and water. Figures may not add to 100 per cent due to rounding.

Source BTCE estimates.

Figure 1.4 Carbon dioxide equivalent emissions from Australian domestic civil transport, 1993



Total CO_2 Equivalent Emissions: 80.4 Mt

Notes Emissions relate to energy end-use (excluding CFCs). Pipeline emissions are those due to major oil and gas transmission, and do not include the urban distribution of gas and water. International transport emissions are those due to Australian bunker fuel consumption by international sea and air carriers travelling to and from Australia.

Source BTCE estimates.

Figure 1.5 Carbon dioxide equivalent emissions from Australian domestic and international transport, 1993

CHAPTER 2 ROAD TRANSPORT

PASSENGER VEHICLES

Road passenger transport currently accounts for about 60 per cent of the total carbon dioxide equivalent emissions from the Australian transport sector. Most of this comes from cars, with only 1.8 per cent of transport emissions due to buses and 0.5 per cent to motorcycles.

There has been an increasingly obvious trend toward saturation of the market for personal automobiles in the last 10 years in terms of ownership per person. Growth in total use of fuel has been restrained by this trend. The average rate of fuel use has also been influenced by two other opposing factors: the move to larger average engine sizes and the decreasing fuel intensity (litres per 100 kilometres) of newer engines *per unit of power output* (that is, per kilowatt or horsepower). Average vehicle kilometres driven each year have been relatively constant over the last 20 years. The net result of all these factors has been for total passenger car fuel use (and hence CO_2 emissions, which are related directly to the quantity of fuel use) to grow quite slowly in recent years.

Cars also produce *non*-CO_2 greenhouse gases; and their emission rates vary with factors such as weather conditions, the presence of catalytic converters and smoothness of traffic flow. Overall greenhouse emissions (CO_2 and non-CO_2) from cars are therefore a function not only of fuel use, but also of the emission intensity (grams emitted per litre of fuel consumed) of the fleet. Though non-CO_2 gases are emitted in much smaller quantities than CO_2, their contribution to total CO_2 equivalent emissions is significant (around 18 per cent) when GWPs are taken into account.

Over the last 10 years, there has been both a slowing in the growth of total fuel use by cars and a reduction in the emission intensity of newer Australian cars. Emission intensity has declined due primarily to the increasing proportion of cars fitted with catalytic converters, which dramatically lower non-CO_2 emissions, after the introduction of unleaded petrol in 1986. The growth in total greenhouse gas emissions has therefore been relatively slow (about 1.7 per cent per annum).

On the basis of long-term historical data, BTCE projections have motor vehicle ownership in Australian starting to level out at about 500 cars per thousand persons by the beginning of the next century. Because Australia's population will continue to grow, overall car numbers will also continue to grow, but at a decreasing rate. Continued technological developments are likely to result in significant decreases in fuel intensity and reductions in emissions of non-CO_2 gases from new cars, an effect that will become increasingly apparent as older cars are scrapped. Even in the absence of specific abatement measures, therefore, greenhouse gas emissions from cars are likely to decline during this decade and well into the next century.

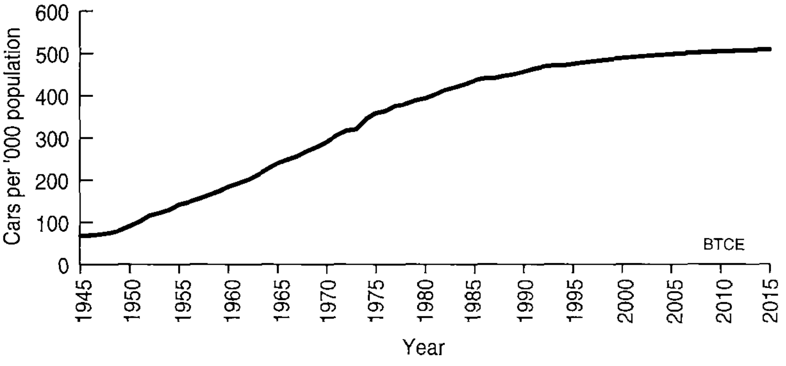
The first section of this chapter sets out the evidence for a declining trend in car emission levels. Past studies of car numbers and car fuel use are reviewed, and the nature of the BTCE projections is set out in terms of disaggregated elements. Subsequent sections present the modelling and reasoning behind the individual elements of the forecasting process. Overall projections of emissions from road passenger transport are then presented, together with some analysis of the sensitivity of the results to changes in forecasting assumptions.

Previous studies of cars, car fuel use and emissions

In 1964, the then Commonwealth Department of Shipping and Transport (1964, p. 15) used a logistic (S-shaped) curve to predict the growth in the number of cars per 1000 population in Australia. It concluded that the number of cars per 1000 population was likely to reach a saturation level of about 500 to 550 early in the next century. This now appears prescient, since during the 1990s the number of cars per 1000 persons seems to be slowing toward a saturation level of the order of 500 (figure 2.1).

Gruebler and Nakicenovic (1991, p. 58) present data on automobile stocks in twelve developed countries. All were found to follow logistic growth curves for the number of cars per 1000 of their population. The Australian saturation level was estimated to occur early next century at between 440 and 550 cars per 1000 population (a range given a 90 per cent probability of covering the 'true' value). Gruebler and Nakicenovic estimated growth in total car numbers from 1995 to 2000 to be 1.6 per cent per annum (table 2.1).

A study by the National Institute of Economic and Industry Research in Melbourne (NIEIR 1994 , pp. 3.31–3.38) modelled vehicle scrappage and new car registrations separately in order to project the vehicle stock from 1995 to 2000. NIEIR assumed a 1.1 per cent per year increase in *average* vehicle kilometres travelled (VKT) for the Australian car fleet, resulting in a projected



Sources ABS (1994b, 1992b); BTCE estimates.

Figure 2.1 The number of cars per thousand population in Australia

TABLE 2.1 HISTORICAL AND PROJECTED GROWTH IN FUEL CONSUMPTION BY AUSTRALIAN CARS

(per cent per annum)

Component	*Historic*	*Gruebler and Nakicenovic (1991)*	*NIEIR (1994)*	*ABARE (1991)*	*AIP (1994)*	*BTCE (1995)*	*FORS (1991)*
Period	1984–1994	1995–2000	1995–2000	1995–2000	1995–2000	1995–2000	1995–2000
Number of cars	1.9	1.6	1.8	0.9	..	1.6	2.0
Average VKT per car	0.3	..	1.1	2.0	..	0	–0.4
Total VKT	2.2	..	2.9	2.9	..	1.6	1.6
Fuel intensity	–0.2	..	–1.0	–1.0	..	–1.1	–1.0
Total car fuel use	2.0	..	1.9	1.9	1.5	0.5	0.6

.. not applicable

Notes 1. VKT is vehicle kilometres travelled.
2. Fuel intensity is typically measured in litres per 100 kilometres.

Sources Gruebler & Nakicenovic (1991, p. 58); NIEIR (1994, pp. 3.31–3.38); ABARE (1991); Bush et al. (1993); AIP(1994, p. 7); FORS (1991b, p. 33); BTCE (1991c); BTCE estimates.

annual growth in *total* VKT of about 2.9 per cent. NIEIR also assumed a 1 per cent annual drop in fuel intensity, resulting in an annual growth rate in car fuel consumption of about 1.9 per cent. Because NIEIR did not assume a logistic pattern in the total car stock, its projected growth rate for car numbers and total VKT is at the high end of the range of studies considered here.

Car fuel use projections derived by the Australian Bureau of Agricultural and Resource Economics (ABARE) (Bush et al. 1993, pp. 63, 112; Donaldson, Gillan and Jones 1990), are based on a logistic curve for motor vehicle ownership. Hensher and Young (BTCE 1991c) report disaggregated elements of ABARE projections done in 1989 for the period 1990 to 2000. The model yielded a projected growth of 0.9 per cent per year in the total number of cars. ABARE assumed an increase in average VKT of 2.0 per cent per year, giving total VKT growth of about 2.9 per cent per annum over the period 1995 to 2000. This high growth rate, which is due to the fairly large assumed increase in average VKT, puts ABARE's forecast of total VKT at the high end of the range of studies considered. An annual decrease of 1.0 per cent in the fuel intensity of cars was assumed by ABARE, giving a projected annual increase in total car fuel use to 2000 of 1.9 per cent.

The Australian Institute of Petroleum (AIP 1994, p. 7) presented forecasts of the growth in total car fuel use (petrol and LPG) of 1.5 per cent per year from 1995 to 2000. No details of the assumptions that went into this forecast were available.

The Federal Office of Road Safety (FORS 1991b, p. 33) modelled new registrations and scrappage separately to arrive at the vehicle stock in the year 2000. The assumed growth in car numbers was about 2 per cent per year for the period 1995 to 2000. With an assumed decrease of 0.4 per cent per year in average VKT, growth in total VKT was about 1.6 per cent per year for the period. FORS also modelled a 1 per cent fall in fuel intensity, with the result that projected fuel use rose by 0.6 per cent per year.

The current BTCE study projects the number of cars to grow on average by 1.6 per cent annually from 1995 to 2000. The BTCE also assumes that average annual VKT per car will remain constant (since average VKT has varied by only around 5 per cent over the last 20 years). The BTCE projects annual growth in total VKT from 1995 to 2000 to be 1.6 per cent, somewhat below the historic growth rate of 1.9 per cent.

The BTCE has assumed that the fuel intensity of cars will decrease by 1.1 per cent a year in the period from 1995 to 2000, which is similar to the assumptions by NIEIR, ABARE and FORS. The historical record for the period 1984 to 1994 shows that the fuel intensity of the fleet decreased by a much smaller amount than the 1 per cent common among the forecasts to 2000. Should the trend to larger engine sizes not cease (as assumed by most forecasters) but rather continue to offset decreases in fuel intensity *per unit of power output,* then the models of NIEIR, ABARE, BTCE and FORS will underestimate the projected annual growth in car fuel consumption by about 1 per cent. In this case, the BTCE projection of 0.5 per cent annual growth in fuel consumption would become 1.5 per cent. However, the BTCE considers that the assumed decreases in fuel intensity are likely under the industry product plans adopted or currently being proposed in Australia and overseas, and that 0.5 per cent per annum is a realistic projection of the growth in car fuel consumption to the year 2000. The BTCE has included the effect of industry plans in the base case because these plans were announced as early as 1991, and are predicated on levels of technology readily achievable in the early 1990s. Any further reductions negotiated between government and the motor vehicle industry in the future should be treated as part of emission abatement measures.

Car emissions — the framework of the BTCE projections

A general framework was developed by the BTCE to project emissions from cars to the year 2015.

A model of fuel consumption is the main component of the framework. The model decomposes fuel consumption into four components:

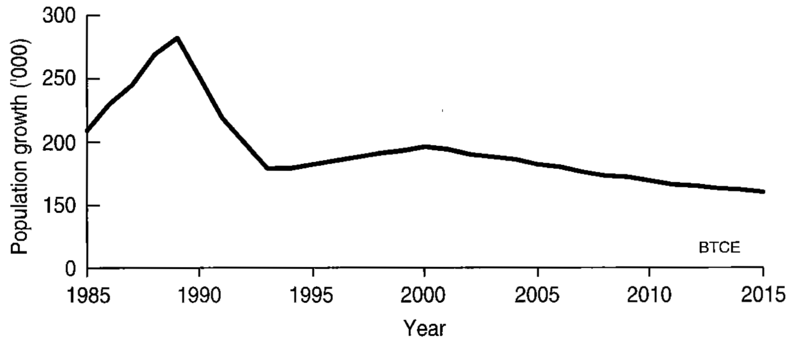
Fuel Consumption	=	Vehicles / Population	x	Population	x	VKT per vehicle	x	Average fuel intensity
(litres)		(cars per thousand persons)		(thousand persons)		(annual kilometres per car)		(litres per kilometre)

Figures 2.1 to 2.6 show graphically the results of this process.

Figure 2.1 shows the logistic shape assumed for the number of cars per 1000 people, which is currently about 450 and is projected to level off at between 500 and 520 by early next century. Figure 2.2, based on recent ABS projections (ABS 1994b), shows the assumptions about population growth over the period. Multiplying the two components together results in the projection of total vehicle numbers (figure 2.3).

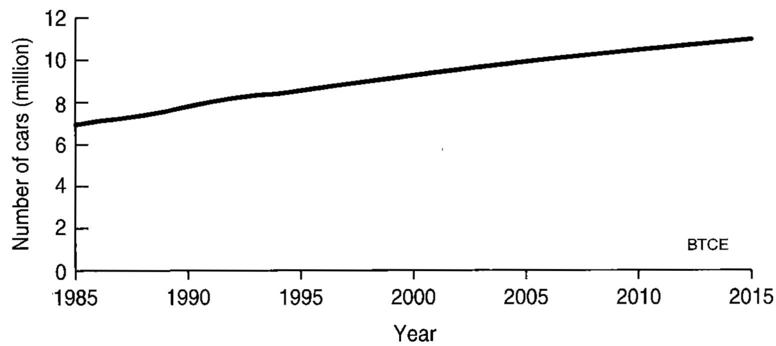
As shown in figure 2.4, a constant average annual vehicle kilometres travelled per car is assumed, in line with the historical trend over the last decade.

Fleet average fuel intensity, in litres consumed per 100 kilometres travelled (L/100 km), is estimated to decline from 12.08 in 1993 to 9.22 by 2015 (figure 2.5), as industry efficiency programs are assumed to reduce new car fuel intensities.



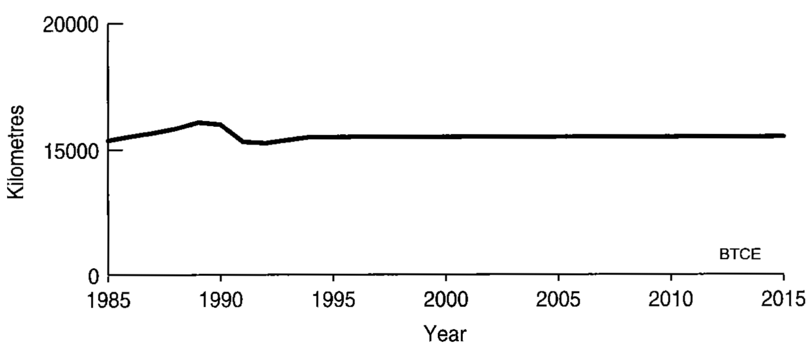
Source ABS (1994b).

Figure 2.2 Annual change in the Australian population



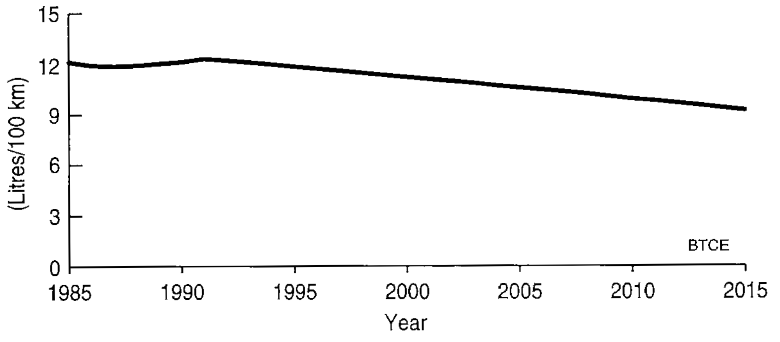
Sources ABS (1992b); BTCE estimates.

Figure 2.3 Number of cars in Australia



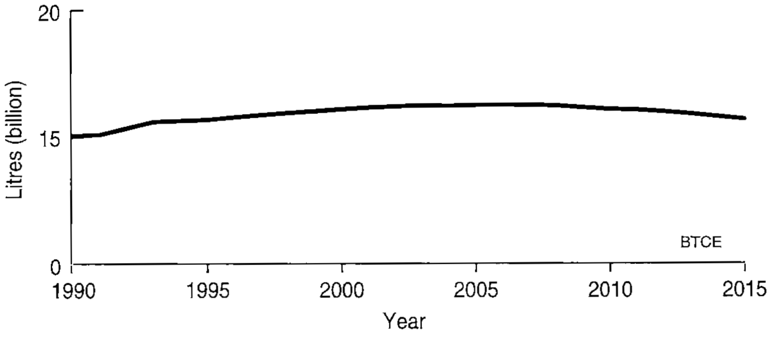
Sources ABS (1993a); BTCE estimates.

Figure 2.4 Average annual kilometres travelled per car



Sources ABS (1993a); BTCE estimates.

Figure 2.5 Average fuel intensity of the car fleet



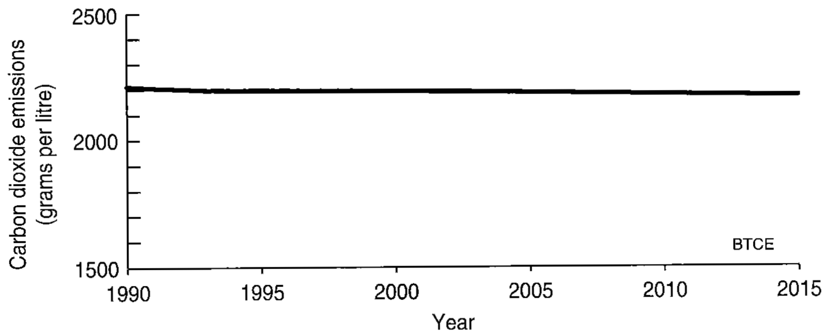
Sources ABS (1993a); BTCE estimates.

Figure 2.6 Total fuel consumed by Australian cars

In summary, car numbers are expected to rise by about a third by 2015, VKT is assumed to remain constant, and the average fuel intensity of the car fleet is projected to drop by a quarter by 2015.

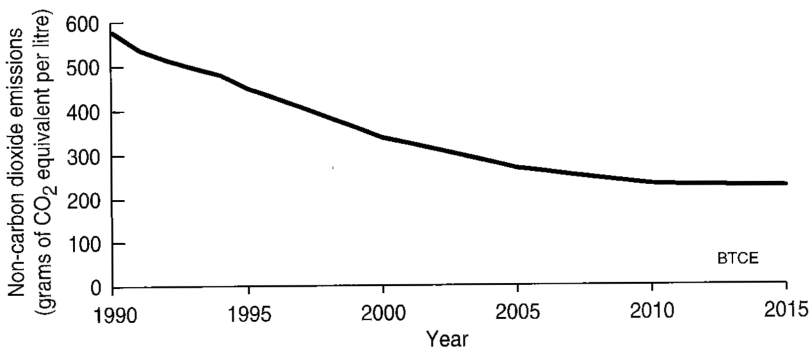
The net result is almost no change in total fuel consumed by cars by 2015, although consumption does rise slightly around the turn of the century before receding again (figure 2.6).

The second component of the projection framework is a model for estimating emissions, given fuel use. There are essentially two types of emissions of greenhouse gases from cars: CO_2 and non-CO_2 gases. Carbon dioxide emissions are linked directly to fuel consumption: each carbon atom in the fuel combines with two atmospheric oxygen atoms to produce about 3 times the weight of the original fuel in the form of CO_2 emissions (figure 2.7).



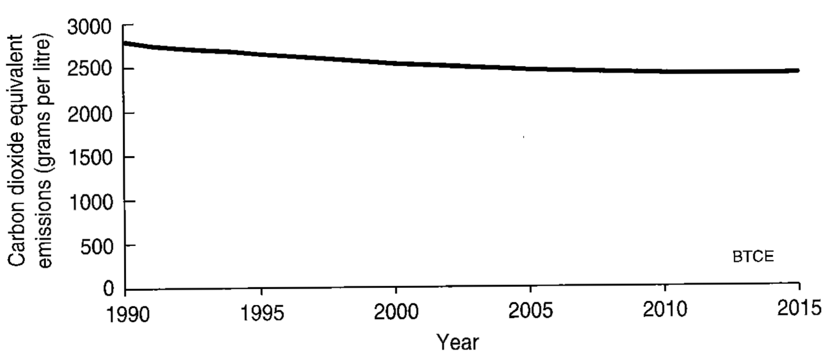
Source BTCE estimates.

Figure 2.7 Carbon dioxide emissions per litre of fuel consumed



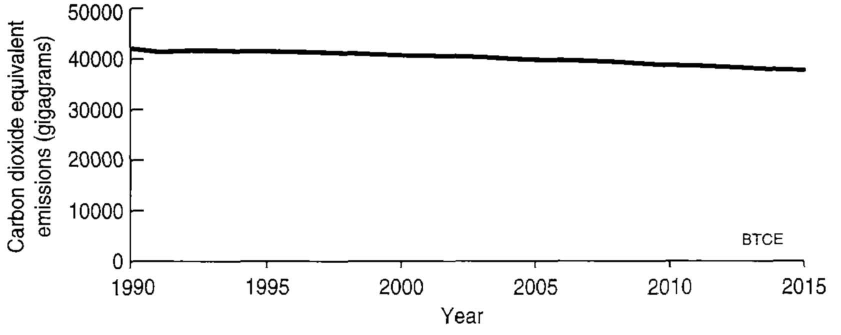
Source BTCE estimates.

Figure 2.8 Non-carbon dioxide emissions per litre of fuel consumed



Source BTCE estimates.

Figure 2.9 Average carbon dioxide equivalent emissions per litre of fuel consumed



Source BTCE estimates.

Figure 2.10 Carbon dioxide equivalent emissions from cars

Projecting emissions of non-CO_2 greenhouse gases is more complex. In Australia, emission standards for new cars were set in 1986, and are expected to be made more stringent in 1997. The gradual replacement of older vehicles in the fleet with newer, lower-emission vehicles is therefore reflected in the model. The results are shown in figure 2.8. Emissions of non-CO_2 gases from cars are expected to decline dramatically as vehicles purchased after 1986 and 1997 come to predominate in the fleet. Non-CO_2 greenhouse emissions vary in their global warming potential. The GWP values in this Report are given in table 1.1.

The BTCE projects the emission intensity for cars (in grams of *CO_2 equivalent emissions* per litre of fuel) to fall by about 10 per cent by the year 2015 (figure 2.9). With fairly constant overall fuel usage, overall greenhouse gas emissions from Australian cars are likely to fall by about 10 per cent between 1993 and 2015 (figure 2.10). This projection is conditional on the modelling and assumptions used in each of the steps above. The following sections examine the components of the analysis in more detail.

Cars per thousand population

The number of cars per 1000 population has been modelled as a logistic (S-shaped) function. This is in line with experience in a number of overseas economies, where exponentially increasing growth until the 1960s or 1970s has been replaced with slowing growth in the 1980s and 1990s.

Gruebler and Nakicenovic (1991) review overseas experience. In all twelve developed countries reviewed, a logistic formulation fits the data extremely well. Saturation rates are in the range 550–700 cars per 1000 population in North America, 300–550 in Europe and 200–250 in Japan. Some of these countries have already reached saturation; others are approaching it.

Fitting a logistic function to cars per 1000 population produces a forecast which depends only on time. Although the approach works well, the actual mechanism underlying the effect is not precisely known. It appears to be based on the tendency of differently aged cohorts within a population to behave in broadly predictable ways. It is possible that radical shifts in cohort behaviour could undermine this *average* system behaviour (Gallez 1994). However, logistic growth is a common pattern in many biological phenomena, in product marketing, in modal competition and in other areas. Its application to car ownership rests on generalised tendencies to product saturation and also on the limits to the 'carrying capacity' of the road systems of individual countries (based on the travel time costs of using personal vehicles in congested traffic). It may be argued that saturation occurs more in terms of personal travel (that is, cars per person times VKT per car) than in vehicle ownership. However, the BTCE has kept cars per person and VKT per car separate in the analysis to allow the assessment of future policy measures which may influence the elements of personal travel in different ways.

Based on curve fitting, the BTCE has estimated that the saturation for the Australian car fleet has a likely range of 490 to 540 cars per 1000 population, with saturation effectively attained during the first half of the next century (figures 2.1, 2.11). Gruebler and Nakicenovic (1991) derive a range of 440 to 550 for the Australian value of the saturation level, occurring at about the same time as the BTCE projections.

The basic form of the logistic equation relating cars per 1000 population (MVPER) to time (t) is the following:

$$\text{MVPER} = \frac{k}{1 + a \quad e^{-bt}}$$

where

k is the saturation level of the logistic function, or upper bound on cars per 1000 population (figure 2.11);
a and b are constants.

The combination $\ln(a)/b$ gives the time of the inflection point (that is, the point halfway to saturation).

The saturation level was obtained by a linear regression of the percentage growth rate, (annual change in MVPER) / MVPER, against MVPER, resulting in a 'best fit' estimate of $k = 520$ (and an initial estimate of b). Final values for a and b were then estimated by using the predicted value of 520 for k, and regressing $\ln((k\text{-MVPER})/\text{MVPER})$ against time. The results of the estimation are presented in table 2.2 and figure 2.11.

TABLE 2.2 ESTIMATION OF A LOGISTIC CURVE FOR CARS PER 1000 POPULATION, AUSTRALIA

Dependent variable: MVPER (cars per 1000 population)

Form of equation: $$\text{MVPER} = \frac{k}{1 + a\ e^{-bt}}$$

where, k is the saturation level, estimated as 520 cars per 1000 population

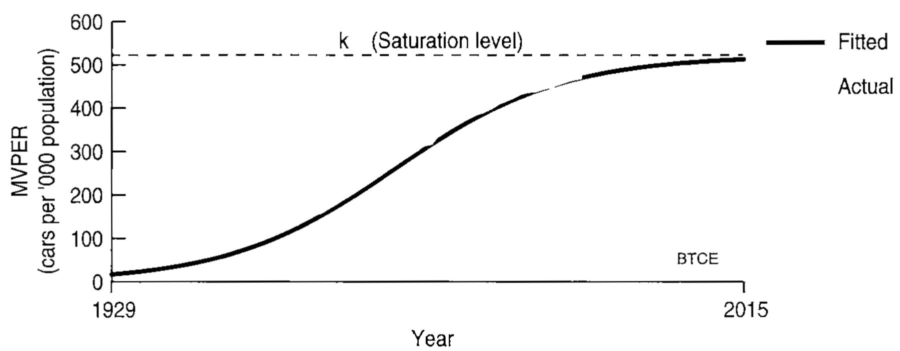
Estimation method: Iterative Ordinary Least Squares

Estimation period: 1957–58 to 1984–85 (t=1 in 1928–29)

Adjusted R squared: 0.999

Parameter	*Estimate*	*Standard error*	*t ratio*
a	32.5957	0.8500	38.35
b	0.0891	0.0006	145.71

Sources BTCE estimates; CBCS (1973, pp. 30, 31); ABS (1994a, p. 6 and earlier).



Source ABS (1993a and earlier, 1994d); BTCE estimates.

Figure 2.11 Form of logistic curve for motor vehicle ownership

The model estimation was restricted to the period before 1985, due to discontinuities in data for MVPER during the post-1985 period. There was one downward shift in the curve related to a sharp jump in car prices in 1986, and another related to vehicle type definition changes (within motor vehicle registry statistics) in 1991.

Population

Recent projections of the Australian population by the Australian Bureau of Statistics (ABS) are available on the basis of several scenarios. The one chosen for BTCE projections of fuel consumption is the 'A and B' scenario (ABS 1994a, p. 48). This scenario assumes medium levels of fertility and low levels of immigration, resulting in a projected Australian population in 2014–15 of 21.6 million people (up by 22 per cent on the 1993 level).

Average kilometres travelled per vehicle

Average vehicle kilometres travelled per car was assumed to remain constant at 15 500 km per year; in keeping with the trend over the last 10 years. There are several factors that might influence the average distance a car is driven. On the one hand, increasing incomes would tend to increase the demand for mobility, and therefore the utilisation of cars. On the other hand, traffic congestion in Australian cities is likely to increase over the next 20 years, as is the incidence of two and three-car households, tending to lower the average utilisation per vehicle.

On balance, it was considered that an assumption of constant VKT was a 'best guess' at future utilisation per vehicle.

Average fuel intensity of the car fleet

The average fuel intensity (L/100 km) of the cars in the Australian fleet is a crucial variable in forecasting fuel consumption. To forecast fuel intensity adequately, it is necessary to adopt an approach that monitors vehicles of different vintages from their entry into the fleet through to the time that they are scrapped. The BTCE has modified a model constructed by the Federal Office of Road Safety (FORS 1991b) that permits a vintage-by-vintage approach.

Connected with each vintage are fuel intensity characteristics. In making the forecasts, it was assumed that the fuel intensity (L/100 km) of new cars entering the fleet falls from its 1992–93 level of near 9 to 8.06 in 2004–05 (equal to the car industry product plan [FORS 1991a, p. 8]). Fuel intensity is assumed to fall further to 6.4 L/100 km (a maximum technology scenario for 2004–05) by 2014–15 (FORS 1991a, p. 8). That is, the BTCE assumes that what is considered the maximum fuel efficiency attainable in 2005 (using currently known technologies) becomes the readily achievable level 10 years later. Implicit in these projected declines in fuel intensity is the assumption that the shift to higher engine sizes apparent in the 1980s ceases.

In order to run the FORS model to track the penetration of the fleet by new and more fuel efficient vehicles, assumptions were made about scrappage rates. The average scrappage rate was assumed to fall slightly from a 1993 level of about 4 per cent per year to 3.7 per cent by 2014–15. Scrappage rates have exhibited a long-term downward trend since the mid 1970s because manufacturers produce increasingly longer lived vehicles. The BTCE scrappage rate projections represent a continuation (yet moderation) of this trend.

Emission intensities

The BTCE model also allows the tracking of average fleet emission characteristics (that is, the emissions of non-CO_2 greenhouse gases per litre).

It was assumed that new car emission rates were equal to those of the post-1985 fleet (see table V.6) until 1997, when new emission standards are expected to come into force for vehicles sold after that date. Studies have shown that, in fact, most new vehicles have better on-road emission performance than these emission standards. However, emission rates generally increase as a vehicle ages (particularly since catalytic converter efficiency decreases over time), so the maximum standard has been adopted as an approximation of average emissions over a vehicle's lifetime. The 1986 and 1997 emissions standards are detailed in table 2.3. As a result of the increasing penetration of catalytic converter technology throughout the fleet, the BTCE expects that there will be a halving of non-CO_2 greenhouse gas emissions from cars by early in the next century.

Buses

Fuel usage by buses was assumed to grow in line with the Australian population. This has roughly been the experience of the industry, except for a period of stronger growth following coach deregulation in the early 1980s (Cosgrove & Gargett 1992, pp. 238–239). It was assumed that half of the urban bus fleet would be using CNG by 2015. Petrol and LPG use by buses is small,

TABLE 2.3 INDUSTRY-AGREED EMISSION STANDARDS FOR NEW PASSENGER CARS

	Emission standard (g/km)		
Year of introduction	*CO*	*HC*	*NO_x*
1986	9.3	0.93	1.93
1997	2.1	0.26	0.63

HC Hydrocarbons

Source FORS (pers. comm. 1994).

and was assumed to remain constant to 2015. Diesel use is calculated as the remainder of the projected total fuel usage.

Emissions in CO_2 equivalents from the fuel usage projected for buses in 2014–15 are about 20 per cent above 1992–93 levels.

Passenger vehicle projections

The final fuel consumption projection for the Australian car and bus fleets to 2015 are given in table 2.4. The mix of fuel types changes markedly in the case of LPG and CNG, but total fuel consumption is relatively unchanged.

Using projected fuel consumption, emissions of individual gases (and of an overall total in CO_2 equivalents) are given in table 2.5. Total emissions from the road passenger sector (including buses) are expected to decline by about 10 per cent from 1993 to 2015. Detailed results are presented in appendix VIII (based on emission factors given in appendix V).

Sensitivity analysis

The main assumptions that might change the results of the BTCE projections relate to the fuel consumption forecasts for cars. Ignoring the population component, this leaves three major forecasting assumptions that might change the results: the saturation level (k) of cars per thousand population (MVPER),

TABLE 2.4 FUEL CONSUMPTION PROJECTIONS FOR ROAD PASSENGER VEHICLES
(megalitres)

Sector	*1992–93*	*2014–15*	*Per cent change*[a]
Passenger vehicles[b]	16079	16330	1.6
Passenger cars	15608	15754	0.9
Petrol	14067	13500	–4.0
ADO	456	480	5.3
LPG	1082	1460	35.0
CNG[c]	3	314	10370.0
Buses	471	576	22.3
Petrol	26	26	0.0
Diesel	428	403	–5.8
LPG	3	3	0.0
CNG[c]	14	144	928.6

a. Per cent change between 1992–93 and 2014–15.
b. Excludes motorcycles.
c. Megalitres of petroleum displaced by compressed natural gas (CNG).
Source BTCE estimates.

TABLE 2.5 GREENHOUSE GAS EMISSION PROJECTIONS FOR ROAD PASSENGER VEHICLES, 2014–15

	Emissions (gigagrams)							
Vehicle type	CO_2	NO_x	CH_4	*NMVOC*	*CO*	N_2O	CO_2 *equivalent*	*Change in CO_2 equivalent[a] (per cent)*
Cars	34192	112	6.0	111	412	3.74	37734	–9.5
Buses	1403	12.8	0.6	3.1	12.1	0.04	1568	18.1
Passenger Vehicles[b]	**35595**	**124.8**	**6.6**	**114.1**	**424.1**	**3.78**	**39302**	**–8.6**

a. Per cent change in CO_2 equivalent emissions between 1992–93 and 2014–15.

b. Excludes motorcycles, for which emissions are assumed to remain constant at 1992–93 levels (330 Gg).

Source BTCE estimates.

average vehicle kilometres travelled (VKT) per car and the fuel intensities of new vehicles.

Assuming fleet fuel intensity is fixed, percentage variations in the values of MVPER and VKT assumed for 2015 flow through to equal percentage changes in fleet fuel usage. Thus, if the value of MVPER for 2015 were taken as 530 instead of 508, projected car fuel consumption would be about 4 per cent higher than that of the flat base case curve. Combined with a 10 per cent drop in emission per litre of fuel consumed, this results in an alternative projection of a 6 per cent drop in emissions (versus the base case projection of a 10 per cent drop). The VKT assumption can be varied in a similar fashion. For example, taking average VKT in 2015 to be 16 000 km rather than 15 500 km would change the base case (from a 10 per cent drop) to a projected 7 per cent drop in emissions.

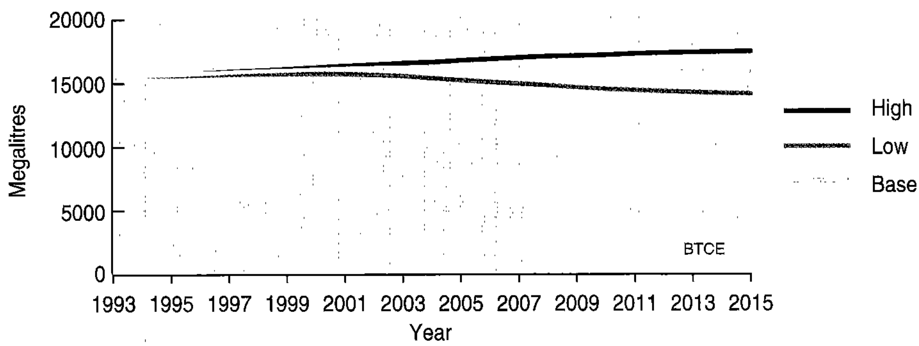
The fuel intensity assumptions must be tested using a model of fleet replacement dynamics. The BTCE has tested two additional scenarios related to assumed new vehicle fuel intensities:

High — Fuel intensities remain unchanged to 2005 (that is, a continued shift to larger engines balances an increase in engineering fuel efficiency), followed by a decrease to the 2005 industry product plan standard of 8.06 L/100 km by 2015.

Low — Fuel intensities drop to the lowest attainable value (using current technologies) of 6.5 L/100 km by 2005 (according to FORS 1991a) and stay at that level until 2015. Such a drop is probably reasonable only if new car purchases shift towards the mini and small car ranges.

The results of these two scenarios are shown in figures 2.12 and 2.13. The high scenario has fuel consumption up 10 per cent and emissions about constant by 2015. The low scenario has fuel consumption dropping by 12 per cent and emissions coming down by 20 per cent from 1993 to 2015.

Overall, the sensitivity tests suggest that unless all three assumptions turn out to be biased in one direction, the basic finding of a fairly flat to declining trend for car emissions is quite robust.



Source BTCE estimates.

Figure 2.12 Car fuel intensity scenarios: total fuel consumption

Source BTCE estimates.

Figure 2.13 Car fuel intensity scenarios: carbon dioxide equivalent emissions

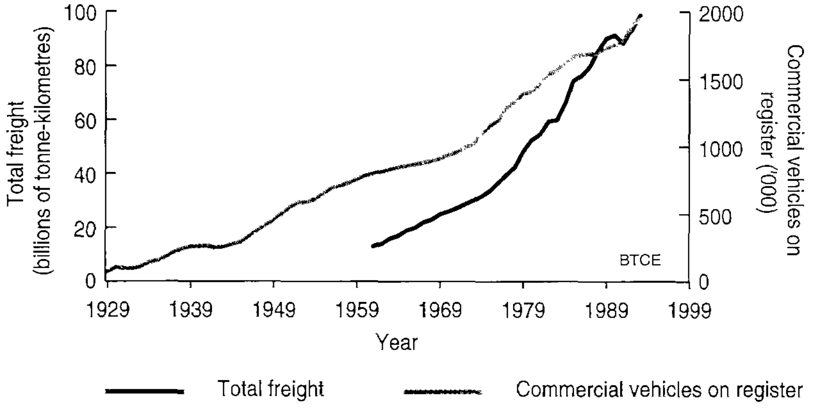
FREIGHT VEHICLES

Road freight transport is a derived demand, depending basically on economic activity. Activity levels could therefore be expected to show the same exponential growth as the general economy. Continued growth in fuel use and emissions by trucks is therefore likely. Trucking (including urban and non-urban tasks) currently accounts for about 28 per cent of CO_2 equivalent emissions from Australian domestic transport, making it an important (and growing) part of transport sector emissions.

Figure 2.14 shows the number of 'commercial vehicles' on register since 1929, together with estimates of the trucking task from 1960–61 to 1992–93. Two patterns are apparent. The first is the broad agreement between movements in the task (measured in tonne-kilometres) and in the number of commercial vehicles. The second is that the task is growing faster than the number of commercial vehicles. Data from the Survey of Motor Vehicle Use (ABS 1993a and earlier) imply that average truck sizes have been increasing, with the average carrying capacity (per vehicle) of the fleet growing by around 3 per cent per annum.

Previous studies of road freight activity

Two types of previous studies are relevant for comparison with the findings in the present study. One type gives estimates of road freight demand elasticities (both income and price). The other type presents previous forecasts of truck fuel use. Summaries of several studies of both types are presented below.



Sources ABS (1994a and earlier); Cosgrove and Gargett (1992); BTCE estimates.

Figure 2.14 Commercial vehicles and the freight task, Australia

Table 2.6 presents results from previous studies of income and price elasticities for road freight to compare with the findings in this Report.

Income elasticities range from +0.67 to +1.49, with the larger elasticities associated with models of Australian intercity freight that lacked a price variable. The income variable used in intercity models was non-farm gross domestic product (NFGDP), as this more closely reflects the source of demand for interstate trucking than total gross domestic product (GDP). The income variable used in the BTCE model was GDP because the dependent variable was total Australian road freight, which has a substantial farm component.

TABLE 2.6 PRICE AND INCOME ELASTICITIES OF DEMAND FOR TRUCKING

Independent variable	*Unit of demand*	*Area analysed*	*Nature of Elasticity*[a]	*Elasticity*	*Source*
INCOME					
GDP	VKT	United Kingdom	long	+0.67	Latham (1983, p. 20)
NFGDP	tonnes	Australia, intercity	long	+1.49	BTCE (1991c, p. 5)
GDP	tonnes	Australia, intercity	long	+1.40	BTE (1978, p.13)
NFGDP	tonnes	Melbourne–Sydney	long	+1.04	BTCE (1990, p. 27)
GDP	**tonne-kilometres**	**Australia**	**long**	**+1.1**	**BTCE estimates**
PRICE					
real freight rate	tonnes	Melbourne–Sydney	long	–0.7	BTCE (1990, p. 27)
real freight rate	tonnes	Canada, regional	cross-section	–0.3 to –1.0	Oum (1979a, p. 129)
relative freight rate	modal share	Canada	long	–0.2 to –0.5	Oum (1979b, p. 162)
real fuel price	fuel use	Japan	long	–0.4	Latham (1983, p. 20)
real freight rate	**tonne-kilometres**	**Australia**	**long**	**–0.9**	**BTCE estimates**

GDP gross domestic product

NFGDP non-farm gross domestic product

a. Whether long-term, short-term or based on cross-section data.

Sources As noted.

The income elasticity derived by the BTCE (estimated at +1.1) falls in the middle of the range.

Price elasticities are available from a more varied group of studies. Generally, they range from –0.3 to –1.3, with the BTCE estimate of –0.9 toward the high end of the range. The lower elasticities of Oum (1979b) are partly explained by the use of mode share as the dependent variable. The freight-generating effect of any general decline in freight rates would be missed in this formulation. This Report and a previous BTCE (1990) study were based on a period in which real road freight rates fell a massive 50 per cent over a decade. Associated with this price fall were large improvements in vehicle efficiencies and in road capacities. In addition, there was a significant switch toward large articulated vehicles. Thus the –0.9 price elasticity of the present study probably reflects a long-term restructuring of demand in response to a large fall in price. It might not necessarily predict the possible response (either long- or short-term) to price *rises*.

The base case scenario for real road freight rates assumes a slow (0.75 per cent per year) decline through to the year 2015, so that maintaining the current –0.9 elasticity is probably warranted. However, policy simulations that assumed price rises may require some judgmental alteration of the price elasticity of demand.

In table 2.7, forecasts of annual increases in fuel use by the trucking sector drawn from three studies are compared with the current BTCE forecasts.

The forecasts by ABARE and NIEIR are based on projections of truck numbers and average vehicle kilometres travelled (VKT), without direct reference to underlying demand. There is considerable variation in the total VKT estimates, with the current BTCE estimates at the high end of the range. BTCE assumptions of future declines in fuel intensity are roughly equal to the average decline forecast by NIEIR. The highest growth forecast for fuel use in table 2.7 (that by the AIP) is not strictly comparable to the others. The BTCE, ABARE and NIEIR projection (given in the table) are for rigid and articulated truck fuel use, whereas the AIP value includes diesel use in the fast-growing light commercial vehicle (LCV) sector.

Model for projecting road freight demand

The model adopted by the BTCE for freight demand (measured in tonne-kilometres performed) is a standard derived demand model. Freight demand is determined by real GDP and by real road freight rates. For much of the task, opportunity for mode switching is limited. For example, if one assumes that only intercapital freight is contestable by rail, only about 15 per cent of the current road task is affected.

TABLE 2.7 PROJECTED GROWTH IN FUEL USE BY RIGID AND ARTICULATED TRUCKS, 1995–2000

(annual per cent change)

Component	*AIP*	*ABARE*	*NIEIR*	*BTCE*
Number of trucks				
Rigid	n.a.	2.0	1.9	2.2
Articulated	n.a.	1.3	1.5	3.3
Average VKT				
Rigid	n.a.	0.5	1.1	0.0
Articulated	n.a.	0.4	1.1	0.0
Total VKT				
Rigid	n.a.	2.5	2.9	2.2
Articulated	n.a.	1.7	2.6	3.3
Fuel intensity				
Rigid	n.a.	–0.3	–0.4	0.0
Articulated	n.a.	–0.2	–0.5	–0.7
Total fuel use	3.6[a]			
Rigid	n.a.	2.2	2.5	2.2
Articulated	n.a.	1.5	2.1	2.6

n.a. not available

VKT vehicle kilometres travelled

a. Includes light commercial vehicles.

Notes 1. NIEIR forecasts are for 1993–94 to 1998–99.
2. Fuel intensity is typically measured in litres per 100 kilometres travelled.

Sources Bush et al. (1993, p. 65); NIEIR (1994, pp. 3.31–3.38); AIP (1994, p.7); BTCE estimates.

Thus:

$$\ln \text{TOTFRT} = \underset{(-3.6)}{-4.46} + \underset{(14.9)}{1.058} \ln \text{RGDP} - \underset{(-12.8)}{0.923} \ln \text{RROADLH}$$

where t ratios are given in parentheses,

TOTFRT is the estimated total Australian road freight task (billion tonne-kilometres),

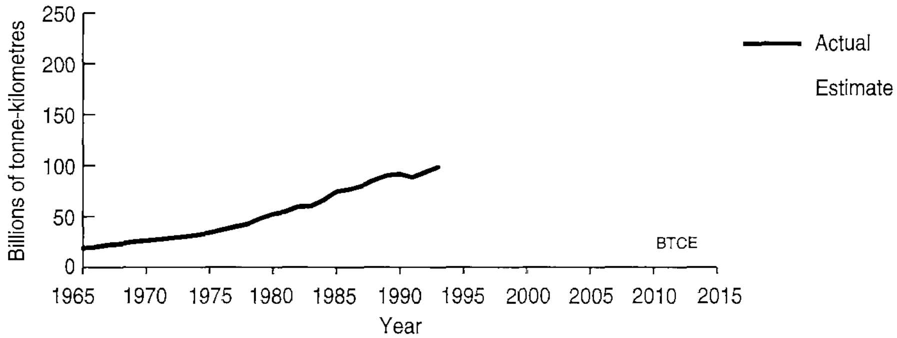
RGDP is real GDP (in 1989–90 dollars), and

RROADLH is an index of real long-haul road freight rates (derived from contract prices paid by large fleet operators).

The results of estimating this equation are given in table 2.8. The diagnostics are satisfactory and the agreement between actual and predicted is good, even out of sample (for example, see 1992 and 1993 values in figure 2.15). As expected, the real road freight rate has a very significant effect in the equation. Real rates fell by almost 50 per cent over the 1970s and 1980s. However, the rate of decline has eased since 1985 (figure 2.16) and this is a contributing factor to the lower growth rates seen in trucking since then. The freight rate used was a long-haul rate, but short-haul rates show almost identical movement.

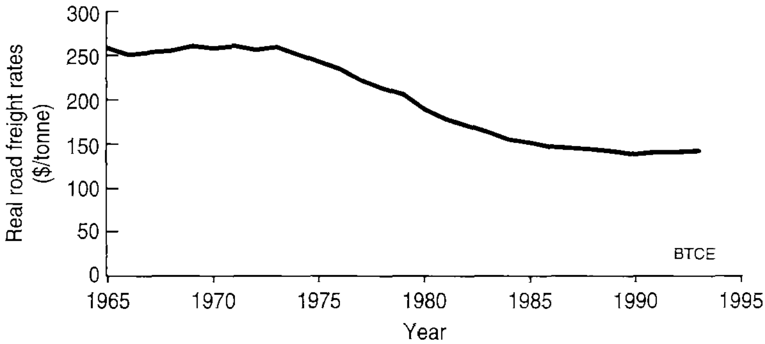
Assumptions and projected truck fuel consumption

In order to project future demand for road freight, real GDP was assumed to grow by 3.2 per cent per year to 1997–98 and by 3.3 per cent from 1997–98 to 2014–15. These assumptions were derived from BIS Shrapnel long-term forecasts for the Australian economy (BIS Shrapnel 1993).



Sources Cosgrove and Gargett (1992); BTCE estimates.

Figure 2.15 Actual and estimated road freight



Sources BTCE (1990); TransEco (1994); ABS (1994e).

Figure 2.16 Real road freight rates

TABLE 2.8 RESULTS OF ROAD FREIGHT MODEL

Dependent variable:	ln (TOTFRT)
Estimation method:	Cochrane–Orcutt
Estimation period:	1964–65 to 1990–1991
Adjusted R squared:	0.99

Independent variable	*Coefficient*	*Standard error*
Constant	–4.46	1.24
ln (RGDP)	1.058	0.071
ln (RROADLH)	–0.923	0.072

Source BTCE estimates.

Real road freight rates were assumed to fall by 15 per cent over the period from 1992–93 to 2014–15. The BTCE has assumed that heavier loads will be carried per truck as B-doubles and other trailer combinations spread though the Australian truck fleet, with resulting decreases in freight rates. Load factors should also increase with the spread of improved communications technology, allowing better route scheduling (such as more backloading).

Using the above assumptions about real GDP and real road freight rates results in a projected freight task in the year 2014–15 of 232 billion tonne-kilometres, a growth of about 4 per cent per year.

To allocate the growth of 4 per cent per year between vehicle types, the following assumptions were made:

- tonne-kilometres undertaken by rigid trucks were assumed to grow by 3 per cent per annum (similar to 1970s and 1980s rates);
- tonne-kilometres by light commercial vehicles were assumed to grow by 5.8 per cent per year (similar to growth during the 1980s);
- the remainder of the growth in projected tonne-kilometres was allocated to articulated trucks (which were thus assumed to perform 3.8 per cent more tonne-kilometres each year to 2014–15).

The average load of articulated trucks was assumed to grow by 0.7 per cent per year, similar to growth during the 1980s. Fuel intensity (L/100 km) was, however, assumed to decrease over the forecast period by 10 per cent for petrol vehicles and 15 per cent for diesel vehicles. Overall, a decrease approaching 20 per cent in fuel consumption per tonne-kilometre was assumed for articulated vehicles between 1993 and 2015. Loads of rigid trucks were assumed to increase by 1 per cent per year, while their fuel intensities remained unchanged. Though these assumptions are fairly arbitrary, they are not unrealistic, given past trends and likely future technologies.

Average loads for urban light commercial vehicles (LCVs) were assumed to increase at 1.6 per cent per year, and those for non-urban LCVs by 2.3 per cent per year (roughly equal to growth rates in the 1980s and early 1990s). LCV fuel intensities were assumed to remain unchanged. Thus technological advances in LCV design were assumed to allow larger vehicles to operate at the same average fuel intensity (L/100km) as the current LCV fleet.

The different freight vehicle types use quite different proportions of the road transport fuels (petrol, diesel, LPG and CNG). Articulated trucks are almost all diesel fuelled, and it was assumed that all but 1 per cent of fuel used by articulated trucks in 2014–15 would be diesel.

For rigid trucks, it was assumed that the shift from petrol to diesel is almost over, and that the 15 per cent of rigid trucks using non-diesel fuel in 1990–91 would be similar to the non-diesel percentage in 2014–15. Currently, most new rigid truck registrations are diesel vehicles. The non-diesel component was apportioned between CNG, LPG and petrol (see appendix VIII).

For LCVs, it was assumed that LPG would comprise 10 per cent of total fuel by 2000 and CNG a further 6 per cent. It was assumed that each fuel would account for 10 per cent of LCV fuel by 2015. The remainder of the projected fuel use was assumed to be split in the proportions 78/22 between petrol and diesel. Again, these are arbitrary assumptions, but they are based on an evaluation of likely incentives for fuel switching and on past trends.

Fuel usage by other trucks (that is, specialist vehicles such as cranes or ambulances) was assumed constant, and divided into diesel and LPG/petrol, based on the proportions obtaining in 1990–91.

Final fuel usage forecasts by type of truck are shown in table 2.9. Details are provided in appendix VIII.

Emission projections for road freight vehicles

The emissions implied by the freight task and fuel use projections (split by vehicle and fuel type) are shown in table 2.10. Detailed estimates (based on emission factors given in appendix V) are given in appendix VIII. In contrast to cars, the road freight sector maintains a fairly strong (exponential) growth in fuel usage and emissions because it is strongly dependent on growth in the economy. Even if the mass of freight transported does not continue to grow as strongly as in the past, due to the decreasing material content of (non-food) goods, the volume transported probably will. With improvements in processing technology, the mass of most manufactured goods has reduced over time, but their volume has not reduced to the same extent. The volume of trucking (and subsequent fuel consumption) required to satisfy demand will probably therefore continue to correlate closely with economic growth.

Since the emission projections for freight vehicles are based on constant (current day) emission rates, they will tend to be upper bounds on likely future emissions. Imported freight vehicles will tend to have reduced non-CO_2 emission rates in the future, as stringent overseas (United States, European and Japanese) emission standards bring new engine designs into the market.

TABLE 2.9 PROJECTIONS OF FUEL CONSUMPTION BY ROAD FREIGHT VEHICLES

	Fuel consumption (megalitres)		
Vehicle type	*1992–93*	*2014–15*	*Per cent increase 1992–93 to 2014–15*
Articulated truck	**2185**	**3754**	**72**
Diesel	2176	3716	71
LPG or CNG	9	38	322
Rigid truck	**1825**	**2821**	**55**
Petrol	198	244	23
Diesel	1564	2514	61
LPG	62	62	0
CNG	1	1	0
LCV	**3289**	**8428**	**156**
Petrol	2324	5259	126
Diesel	689	1483	115
LPG	272	843	210
CNG	4	843	20975
Other truck	**44**	**44**	**0**
Petrol	30	30	0
Diesel	14	14	0
Total	**7343**	**15003**	**104**
Petrol	2552	5533	117
ADO	4443	7727	74
LPG	338	924	173
CNG	10	863	8530

LCV light commercial vehicle

Notes 1. CNG figures refer to the volume of diesel displaced by CNG use.
2. Other trucks include ambulances, cranes and other non-freight-carrying commercial vehicles.

Source BTCE estimates (more detailed data are provided in appendix VIII).

TABLE 2.10 EMISSION PROJECTIONS FOR ROAD FREIGHT VEHICLES, 2014–15

Vehicle type	*Emissions (Gg)* CO_2	NO_x	CH_4	*NMVOC*	*CO*	N_2O	CO_2	*Change in CO_2 equivalent 1992–93 to 2014–15 (per cent)*
LCV	18383	97	13	142	1032	1	21881	148
ROT	7490	38	1	14	84	0	8070	61
AT	9829	136	1	25	83	0	11293	-75
Total	**35703**	**272**	**15**	**181**	**1200**	**1**	**41243**	**103**

LCV light commercial vehicle
ROT rigid and other trucks
AT articulated trucks
Note 1. Columns may not exactly sum vertically, due to rounding.
Source Emissions calculated from fuel consumption forecasts in table 2.9. Appendix VIII provides time series for emissions from road freight vehicles.

CHAPTER 3 RAIL TRANSPORT

Rail transport accounts for close to 5 per cent of current domestic transport emissions (in carbon dioxide equivalent terms) if emissions due to the generation of electricity for electric railways are included. End-use emissions from diesel trains account for around 2.7 per cent of domestic transport emissions. The BTCE projects that by the year 2015 rail's share of transport emissions will have risen only slightly (accounting for around 2.8 per cent of total carbon dioxide equivalent emissions from transport energy end-use or 6 per cent if electricity generation is included).

Diesel-powered trains are used mainly for the movement of freight on government or privately owned railways. Private railways carry mostly bulk commodities, especially iron ore. Over 75 per cent of government bulk freight is coal and grain. Non-bulk commodities constitute approximately 15 per cent of the total freight carried on government railways (BTCE 1991b, p. 7).

Railways presently account for only a small share of Australia's total passenger task. Urban railways (most of which are electrified) are still important for passenger movements within capital cities. However non-urban passenger railway use is diminishing due to the quicker services offered by air and the more convenient road services available (BTCE 1991b, p. 51). Most interstate rail passengers are tourists.

In 1991–92 Australian government and private railways accounted for 29.3 petajoules (PJ) of energy end-use, including about 5.7 PJ of electricity, 22 PJ of automotive diesel oil (ADO) and 1.7 PJ of industrial diesel fuel (IDF) (Bush et al. 1993, p. 112). Electricity is used mainly for the movement of urban rail passengers, although a small amount is used for the movement of government freight (Apelbaum 1993, p. 100).

RAIL MODEL SPECIFICATION

The BTCE is unaware of any published models for projecting fuel consumption by the Australian rail system. ABARE (pers. comm. 1993) does long-term projections of rail fuel consumption, but these are based on forecasts and surveys undertaken by the rail authorities. Forecasts by the rail authorities are based on previous trends, and no formal econometric models are used.

The Railway Industry Council (RIC 1990) developed a base case scenario for urban and non-urban passenger numbers and freight carried. It describes the expected development between the years 1986–87 and 2001–02. Econometric models were not used by the RIC, the projections being based on the extrapolation of existing trends. The RIC (1990, pp. 27, 46) forecast urban passenger journeys to increase by 36 per cent between 1986–87 and 2001–02, and non-urban freight tonne-kilometres to increase by 58 per cent during the same period.

The BTCE model uses a combination of mathematical and econometric models to project rail task levels and the resulting fuel consumption. Because railways use both liquid fossil fuels and electricity, 'fuel consumption' is expressed in petajoules of energy. Fuel consumption is modelled as the product of the railway task and of fuel intensity. The railway task is broken down into five sectors: urban passenger, non-urban passenger, government bulk freight, government non-bulk freight, and private freight. Passenger numbers and freight tonnages are modelled and then multiplied by average distances travelled to obtain task levels in passenger-kilometres (pkm) and tonne-kilometres (tkm).

The main bulk commodities carried on government railways are coal and grain, which are carried mostly from inland Australia to coastal ports for export. The tonnage of government bulk freight carried is therefore modelled as a function of total coal and grain export levels (BTCE 1991b, pp. 10–11).

The main commodity carried by private railway systems is iron ore. Production levels of iron ore are therefore used as the explanatory variable when modelling the tonnage of private freight carried.

Non-bulk freight tonnes carried on the government railways are assumed to be a function of income, as measured by the real gross non-farm product (BTCE 1991b, p. 8). Freight rates were found to be statistically insignificant and were not included as an explanatory variable.

Non-urban passenger numbers are modelled as a function of income (as measured by the real gross non-farm product). Originally fare levels were included in the model, but these were found to be insignificant as explanators of the number of passengers carried.

Urban rail passenger numbers include passengers travelling on both trains and trams. The major variables found to explain the number of urban rail passengers were income levels and fares. Income levels are measured by Australian private final consumption, and the fares variable (AUSTFAR) is an average over all urban public transport systems. As public transport fares increase (other things being equal) it is expected that fewer people will travel by train or tram.

Long-term projections are arguably best carried out using relatively simple models that rely only on variables of most significance in the longer term. The final specification of the model used by the BTCE is outlined in equations (1) to (6). See table 3.1 for summary statistics and diagnostics of the regression models.

TABLE 3.1 RESULTS OF THE RAIL MODEL

Dependent variable	*Diagnostics*	*Independent variables*	*Coefficient*	*Standard error*
ln GBT	Adj. R^2 = 0.99	constant	10.93	0.21
	DW = 1.74	ln CGEXP	0.67	0.02
	Period: 1978 to 1993 (A)			
	EM: OLS			
ln GNBT	Adj. R^2 = 0.85	constant	–9.42	0.73
	DW = 1.30	ln RGNF	1.01	0.06
	Period: 1981Q4 to 1993Q3			
	EM: OLS			
ln PFT	Adj. R^2 = 0.95	constant	0.33	0.28
	DW =2.31	ln IOP	0.99	0.06
	Period: 1978 to 1993 (A)			
	EM: OLS			
ln PASNU	Adj. R^2 = 0.54	constant	6.08	0.60
	DW = 1.36	ln RGNF	0.15	0.05
	Period: 1977Q1 to 1993Q4	SERDUM	–0.13	0.04
	EM: OLS	ADUM	–0.10	0.02
		AIRDUM	0.02	0.04
		DUM	–0.07	0.02
		BIDUM	0.05	0.03
ln PASU	Adj. R^2 = 0.78	constant	–2.18	0.77
	DW = 1.46	ln RAUSPFC	0.96	0.12
	Period: 1984Q3 to 1993Q1	ln AUSTFAR	–0.59	0.14
	EM: OLS	DISP	–0.06	0.02
		BIDUM	0.04	0.01
		SERDUM	–0.05	0.02

Notes
1. Adj R^2 refers to the adjusted R^2 statistic.
2. DW refers to the Durbin–Watson statistic.
3. Period refers to the estimation period, where Q denotes quarterly data and A denotes annual data.
4. EM refers to the estimation method used, where OLS denotes Ordinary Least Squares estimation.

Source BTCE estimates.

Fuel consumption is derived by multiplying the task level for each of the rail sectors by the estimated fuel intensity for each sector, and summing across all sectors.

$$(1)\ FC = \{(GBTKM \times FI_{GB}) + (GNBTKM\ \ FI_{GNB}) + (PFTKM\ \ FI_{PF})$$

$$+ (PASKMNU\ \ FI_{PASNU}) + (PASKMU\ \ FI_{PASU})\}$$

where FC is total rail fuel consumed (measured in petajoules of energy), GBTKM is government bulk freight tonne-kilometres (measured in billion tonne-kilometres), FI_{GB} is the fuel intensity of trains carrying government bulk freight (measured in megajoules per tonne-kilometre), GNBTKM is government non-bulk freight tonne-kilometres (measured in billion tonne-kilometres), FI_{GNB} is the fuel intensity of trains carrying government non-bulk freight (measured in megajoules per tonne-kilometre), PFTKM is private freight tonne-kilometres (measured in billion tonne-kilometres), FI_{PF} is the fuel intensity of trains carrying private freight (measured in megajoules per tonne-kilometre), PASKMNU is the number of non-urban passenger-kilometres travelled (measured in billion passenger-kilometres), FI_{PASNU} is the fuel intensity of non-urban trains carrying passengers (measured in megajoules per passenger-kilometre), PASKMU is urban passenger-kilometres (measured in billion passenger-kilometres) and FI_{PASU} is the fuel intensity of urban trains carrying passengers (measured in megajoules per passenger-kilometre).

Government bulk freight tonnes carried are modelled as a function of the combined export level for coal and grain. The model is estimated on the basis of Ordinary Least Squares estimation (OLS) using annual data.

$$(2)\ \ln GBT = 10.93 + 0.67 \ln CGEXP$$

where GBT is government bulk freight tonnes carried (measured in tonnes) and CGEXP is the aggregate level of coal and grain exports (measured in thousand tonnes).

Government bulk freight tonne-kilometres travelled is derived by multiplying government bulk freight tonnes carried by an average haul distance.

$$(2a)\ GBTKM = GBT \times \text{average haul distance}$$

where GBTKM is government bulk freight tonne-kilometres, GBT is government bulk freight tonnes carried and the average haul distance is the average distance travelled by government bulk freight (measured in kilometres).

Government non-bulk freight tonnes carried are modelled as a function of income, as measured by real gross non-farm product. The model is estimated on quarterly data using OLS.

(3) $\ln \text{GNBT} = -9.42 + 1.01 \ln \text{RGNF}$

where GNBT is government non-bulk freight tonnes carried (measured in million tonnes) and RGNF is the real gross non-farm product.

Government non-bulk tonne-kilometres travelled are derived by multiplying the government non-bulk tonnes carried by an average haul distance.

(3a) $\text{GNBTKM} = \text{GNBT} \times \text{average haul distance}$

where GNBTKM is government non-bulk freight tonne-kilometres, GNBT is government non-bulk freight tonnes carried and the average haul distance is the average distance travelled by government non-bulk freight (measured in kilometres).

Private freight tonnes carried are modelled as a function of iron ore production levels. The model is estimated on annual data using OLS.

(4) $\ln \text{PFT} = 0.33 + 0.99 \ln \text{IOP}$

where PFT is private freight tonnes carried (measured in million tonnes) and IOP is the level of iron ore production (measured in thousand tonnes).

Private freight tonne-kilometres travelled are derived by multiplying private freight tonnes carried by an average haul distance.

(4a) $\text{PFTKM} = \text{PFT} \times \text{average haul distance}$

where PFTKM is private freight tonne-kilometres, PFT is private freight tonnes carried and the average haul distance is the average distance travelled by private freight (measured in kilometres).

Non-urban passenger numbers are modelled as a function of real gross non-farm product. The model also includes a number of dummy variables to capture the effects of service frequency cuts in Victoria, the introduction of discount airfares, rail strikes, and the Bicentenary celebrations in 1988. The model is estimated on quarterly data using OLS.

(5) $$\ln \text{PASNU} = 6.08 + 0.15 \ln \text{RGNF} - 0.13\ \text{SERDUM} - 0.10\ \text{ADUM} + 0.02\ \text{AIRDUM} - 0.07\ \text{DUM} + 0.05\ \text{BIDUM}$$

where PASNU is the number of non-urban passengers, RGNF is real gross non-farm product, SERDUM is a dummy variable to account for service frequency cuts in Victorian trains from 1993Q3 (that is, the third quarter of

1993) onward, ADUM is a dummy variable which accounts for the introduction of discount airfares (from 1991 onwards), AIRDUM is a dummy variable to allow for the airline pilots' dispute (in 1989–90), DUM is a dummy variable for a low traffic period from 1979Q3 to 1980Q2 and BIDUM is a dummy variable for the Bicentenary (1988Q1 to 1988Q3).

Non-urban passenger kilometres (PASKMNU) are derived by multiplying non-urban passenger numbers (PASNU) by an average trip distance, that is

(5a) PASKMNU = PASNU × average trip distance.

Urban passenger numbers are modelled as a function of real Australian private final consumption and a real urban public transport fares index. The equation also includes a number of dummy variables to capture the effects of the Bicentennial celebrations in 1988, rail disputes and service frequency cuts in Victoria. The model is estimated on quarterly data using OLS.

$$(6)\ \ln PASU = -2.18 + 0.96 \ln RAUSPFC - 0.59 \ln AUSTFAR - 0.06\ DISP$$
$$+ 0.04\ BIDUM - 0.05\ SERDUM$$

where PASU is the number of urban passengers, RAUSPFC is real Australian private final consumption, AUSTFAR is a real urban public transport fares index (across all public transport modes), DISP is a dummy variable used to capture the rail dispute from 1989Q3 to 1990Q2, BIDUM is a dummy variable to account for the Bicentenary (1988Q1 to 1988Q4), and SERDUM is a dummy variable used to capture the effects of train and tram service frequency cuts from 1993Q3 onward.

Urban passenger kilometres (PASKMU) are derived by multiplying urban passenger numbers (PASU) by an average trip distance, that is

(6a) PASKMU = PASU × average trip distance.

Data collected for each of the variables in equations (1) to (6) are detailed in appendix IX, table IX.1.

All models assume constant elasticities and are estimated using Ordinary Least Squares. The government bulk tonnes (GBT) model and the private freight tonnes (PFT) model are estimated on annual data whereas the government non-bulk tonnes (GNBT), non-urban passenger (PASNU) and urban passenger (PASU) models are estimated using quarterly data (which are then summed to give yearly estimates). Annual data for the latter three models did not offer much variation in the task levels.

Figures 3.1 to 3.6 graph the historical (or 'actual') and the fitted (or 'predicted') values for the dependent variables in each of the models. Utilising equation (1), each of the calculated rail tasks can be multiplied by its relevant fuel intensity and the tasks can be summed to obtain an estimate of the total rail fuel consumption.

Variables used in the analysis are specified as follows:

RGNF. The seasonally adjusted real gross non-farm product is an income variable and uses 1990 as the base year. It has been increasing since 1978, with declines in some years. It can be expected that as income levels rise the number of non-urban rail passengers will increase, as will government non-bulk freight tonnes carried.

GNBT. Government non-bulk freight tonnes refers to tonnes carried, which differs from tonnes consigned. Tonnes carried is calculated for each State, even when the load travels from one State to another, and will be approximately 2.3 times the level of tonnes consigned (based on Apelbaum 1993, p. 37). Non-bulk commodities include beverages, tobacco, manufactured goods, machinery, transport equipment and live animals. Between 1983 and 1993 the level of government non-bulk tonnes carried has increased by 35 per cent.

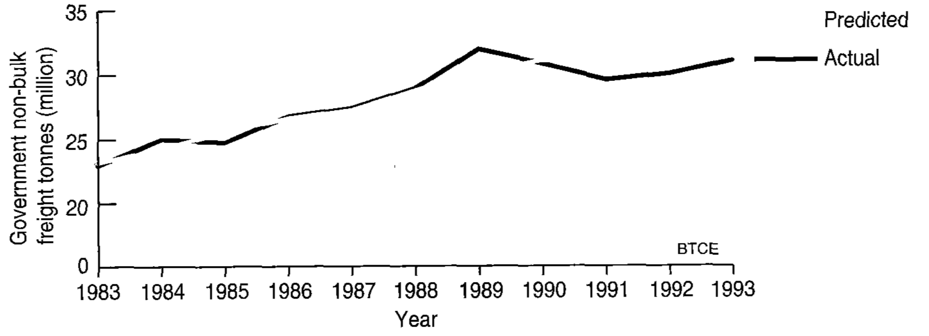
GBT. Government bulk freight carried consists of crude materials, mineral fuels, lubricants, animal and vegetable oils, fats and waxes, chemical products, briquettes, grains, food, cement, gypsum, bulk fertiliser, iron, steel and petroleum. The major commodities, coal and grain, constitute approximately 75 per cent of the bulk goods carried on government railways (BTCE 1991b, p. 10). Between 1983 and 1993 bulk freight tonnes carried increased by 68 per cent. It is expected that as export levels of coal and grain increase the level of bulk freight tonnes carried will also increase.

PFT. The major commodity carried on private railways is iron ore, though sugar and coal also constitute a substantial proportion of the freight carried. Between 1983 and 1993 tonnes carried by private railways increased by 45 per cent.

Rail passenger numbers (PASNU, PASU). Urban passenger numbers have increased by 12 per cent over the last 10 years, while non-urban rail passenger numbers have declined by 9 per cent during the same period.

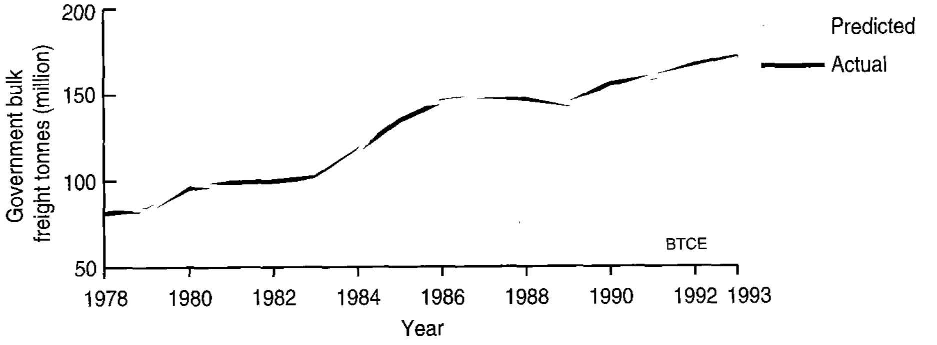
AUSTFAR. AUSTFAR is an index of real urban public transport fares (across all public transport modes) and uses 1990 as the base year. The data is collected from each State for the BTCE (1994a) Indicators Database. Since 1990, real fares have risen by approximately 12 per cent. It is expected that as fares increase fewer passengers will travel by public transport, including rail.

Average distances. Average distances were derived separately for each segment of the rail sector.



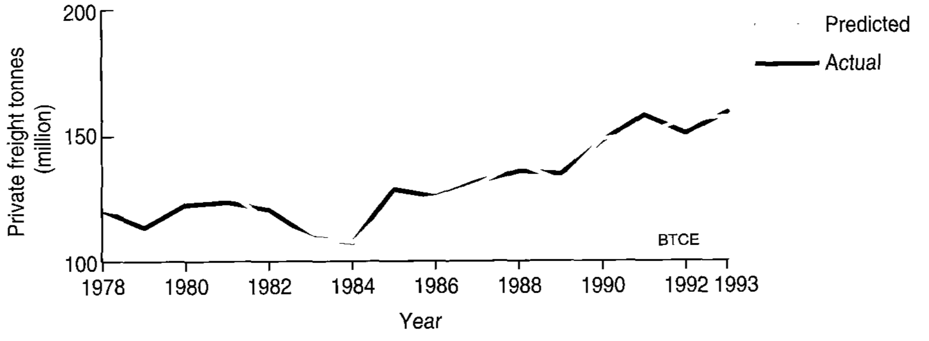
Sources BTCE (1994a) Indicators Database; BTCE estimates.

Figure 3.1 Government non-bulk freight tonnes carried: actual and predicted



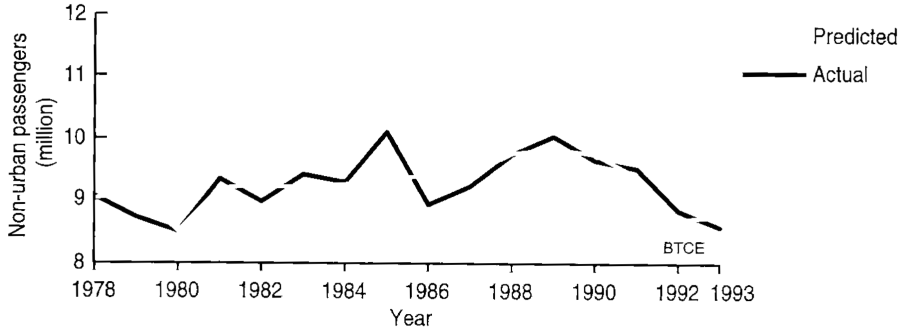
Sources BTCE (1994a) Indicators Database; BTCE estimates.

Figure 3.2 Government bulk freight tonnes carried: actual and predicted



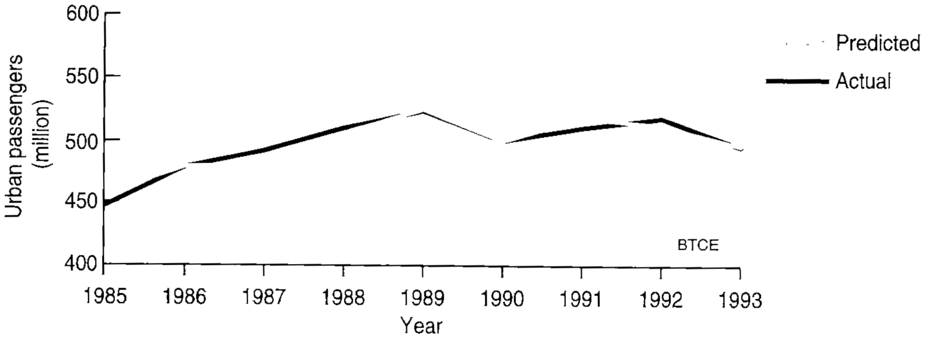
Sources BTCE (1994a) Indicators Database; BTCE estimates.

Figure 3.3 Private freight tonnes carried: actual and predicted



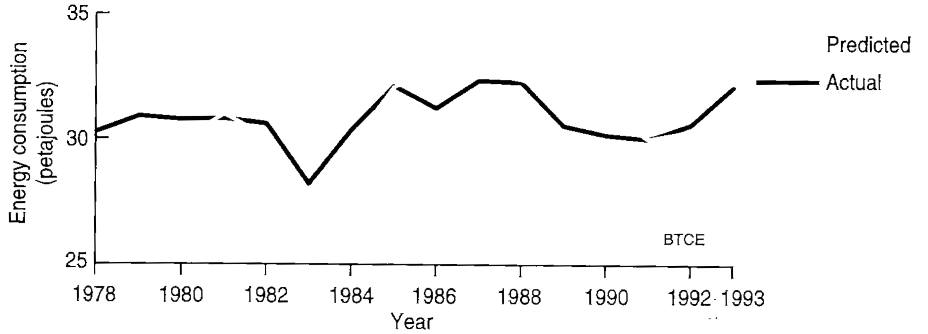
Sources BTCE (1994a) Indicators Database; BTCE estimates.

Figure 3.4 Non-urban passengers carried: actual and predicted



Sources BTCE (1994a) Indicators Database; BTCE estimates.

Figure 3.5 Urban passengers carried: actual and predicted



Sources Bush et al. (1993, p. 112); BTCE estimates.

Figure 3.6 Rail energy consumption: actual and predicted

For the government freight sector average distances travelled were calculated from data contained in Apelbaum (1993, p. 37) and from the ABS (1986a, p. 4) for the years 1977–78 to 1983–84. A figure for 1990–91 was calculated using data from Apelbaum (1993, p. 37). The average distance travelled was set to increase from 1984–85 at a trend growth rate to Apelbaum's figure for the year 1990–91. The 1990–91 figure was assumed to remain constant for the years 1991–92 and 1992–93.

The private freight average haul distance was calculated by dividing tonne-kilometres travelled by tonnes carried. The historical data needed are available for the years 1977–78 to 1990–91 in Cosgrove and Gargett (1992, pp. 234, 236). Data for 1991–92 and 1992–93 were obtained from the BTCE Indicators Database (BTCE 1994a).

For both urban and non-urban passengers, average trip lengths were calculated by dividing passenger-kilometres by passenger numbers from data available in Cosgrove and Gargett (1992 pp. 238–239) and the BTCE Indicators Database (BTCE 1994a). However, this was possible only from 1977–78 to 1990–91 for non-urban passengers; and the 1990–91 figure was assumed to remain constant to the year 1992–93.

TABLE 3.2 RAIL: AVERAGE DISTANCES TRAVELLED

(kilometres)

Year	*Urban passengers*	*Non-urban passengers*	*Private freight*	*Bulk freight*	*Government non-bulk freight*
1977–78	13.6	300.0	234.7	208.2	490.0
1978–79	13.6	303.5	224.6	203.2	505.8
1979–80	14.0	307.0	226.0	216.9	444.1
1980–81	14.1	317.8	233.1	211.3	548.6
1981–82	14.2	320.5	226.4	239.5	495.5
1982–83	14.2	314.2	227.3	224.6	485.6
1983–84	14.3	309.8	215.7	224.8	545.0
1984–85	14.3	292.9	220.2	224.9	557.7
1985–86	14.5	303.1	231.7	225.1	570.4
1986–87	14.6	293.4	229.5	225.3	583.1
1987–88	14.6	300.6	227.9	225.5	595.9
1989–89	14.6	287.9	212.6	225.6	608.6
1989–90	14.9	260.1	219.6	225.8	621.3
1990–91	14.7	260.5	223.4	226.0	634.0
1991–92	14.5	260.5[a]	232.6	226.0[a]	634.0[a]
1992–93	14.5	260.5[a]	224.9	226.0[a]	634.0[a]

a. Assumed values due to lack of data.

Sources BTCE estimates; ABS (1986a, p. 4); Apelbaum (1993, p. 37); Cosgrove & Gargett (1992, pp. 234, 236, 238, 239); BTCE (1994a) Indicators Database.

Table 3.2 records the average distances travelled for each of the five rail categories.

Fuel intensity. Fuel consumption is modelled as the product of the task and the fuel intensity (measured in megajoules of energy used per unit task). The task comprises the five categories: private freight tonne-kilometres, government non-bulk tonne-kilometres, government bulk tonne-kilometres, urban passenger-kilometres and non-urban passenger-kilometres. Historical fuel intensities were derived by dividing the energy consumed for a particular sector by its task level (table 3.3).

Due to lack of data on the amount of fuel consumed by each category, fuel intensities could only be calculated for the years 1984–85, 1987–88 and 1990–91. Time series for each category were derived by applying the trend growth rates for intervening years. Table 3.4 details the derived fuel intensity series for each of the rail tasks.

For 1977–78, the assumed fuel intensity for each task was determined by applying the change in the total average fuel intensity for rail (Average FI_{year}) from 1977–78 to 1984–85 to each of the specific rail tasks.

(7) $FI_{1978,\ sector} = (\text{Average } FI_{1978} \ / \ \text{Average } FI_{1985}) \times \text{Actual } FI_{1985,\ sector}$

An average fuel intensity index for the total rail sector can be calculated (using 1987–88 as a base year) by applying the 1987–88 fuel intensities to each of the rail tasks for each year (to determine an estimate of what annual fuel consumption would have been without any fuel efficiency improvements). The corrected fuel consumption (CFC) series divided by the actual annual fuel consumption given in Bush et al. (1993, p. 112) multiplied by 100 gives an average fuel intensity index. In 1987–88 (the base year), the average fuel intensity index equals 100. Equations (8) and (9) summarise the calculation.

(8) $CFC = \sum_{n} (Task_n \times FI_{1988,\,n})$

where n = GB, GNB, PF, PASNU and PASU

(9) $\text{Average FI (index)} = (CFC \ / \ FC) \times 100$

where CFC is the corrected fuel consumption (detrending for fuel intensity decreases), $Task_n$ is the specific rail task, $FI_{1988,n}$ is the specific fuel intensity in 1987–88 and FC is the actual total fuel consumption. (Appendix IX, table 2 presents the average fuel intensity series for rail transport.)

TABLE 3.3 ENERGY CONSUMPTION, TASK AND DERIVED FUEL INTENSITY FOR RAIL

	1984–85			*1987–88*			*1990–91*		
Rail sector	*Energy consumption*	*Task*	*Fuel intensity*	*Energy consumption*	*Task*	*Fuel intensity*	*Energy consumption*	*Task*	*Fuel intensity*
Freight	**(PJ)**	**(Billion tkm)**	**(MJ/tkm)**	**(PJ)**	**(Billion tkm)**	**(MJ/tkm)**	**(PJ)**	**(Billion tkm)**	**(MJ/tkm)**
Government bulk									
electric	0.42	n.a.	n.a.	1.22	n.a.	n.a.	2.18	n.a.	n.a.
non-electric	11.78	n.a.	n.a.	10.59	n.a.	n.a.	6.96	n.a.	n.a.
Total	12.21	30.42	0.40	11.81	33.25	0.36	9.14	36.00	0.25
Government non-bulk	9.63	13.80	0.70	9.95	17.25	0.58	9.93	18.77	0.53
Private	3.74	28.40	0.13	4.09	31.00	0.13	4.42	35.30	0.13
Passenger	**(PJ)**	**(Billion pkm)**	**(MJ/pkm)**	**(PJ)**	**(Billion pkm)**	**(MJ/pkm)**	**(PJ)**	**(Billion pkm)**	**(MJ/pkm)**
Urban electric rail	2.86	n.a.	n.a.	3.07	n.a.	n.a.	3.05	n.a.	0.46
electric tram	0.22	n.a.	n.a.	0.21	n.a.	n.a.	0.21	n.a.	0.36
non-electric	0.77	n.a.	n.a.	0.72	n.a.	n.a.	0.64	n.a.	1.30
Total	3.85	6.43	0.60	4.01	7.47	0.54	3.91	7.52	0.52
Non-urban	2.66	2.96	0.90	2.54	2.93	0.87	2.60	2.48	1.05

n.a. not available
pkm passenger-kilometre
tkm tonne-kilometre
PJ petajoule
MJ megajoule

Notes 1. Energy figures relate to end-use.
2. It is assumed that electricity is consumed in the freight sector only by trains carrying bulk freight.

Sources BTCE estimates using data contained in Bush et al. (1993, p. 112); Apelbaum (1993, pp. 94–95, 98, 100, 153, 158); Cosgrove & Gargett (1992, pp. 234, 238); and BTCE (1994a) Indicators Database.

TABLE 3.4 DERIVED FUEL INTENSITY SERIES FOR RAIL

Year	Urban passenger (MJ / pkm)	Non-urban passenger (MJ / pkm)	Government bulk freight (MJ / tkm)	Government non-bulk freight (MJ / tkm)	Private freight (MJ / tkm)
1977–78	0.682	1.016	0.453	0.788	0.149
1978–79	0.670	0.983	0.439	0.762	0.144
1979–80	0.658	0.950	0.424	0.736	0.139
1980–81	0.646	0.917	0.409	0.711	0.134
1981–82	0.634	0.912	0.407	0.707	0.134
1982–83	0.623	0.908	0.405	0.700	0.133
1983–84	0.610	0.903	0.403	0.697	0.132
1984–85	0.599	0.899	0.401	0.657	0.132
1985–86	0.578	0.888	0.386	0.617	0.132
1986–87	0.558	0.877	0.370	0.577	0.132
1987–88	0.537	0.866	0.355	0.561	0.132
1988–89	0.531	0.928	0.321	0.546	0.130
1989–90	0.526	0.989	0.288	0.530	0.127
1990–91	0.520	1.050	0.254	0.530	0.125
1991–92	0.520	1.050	0.254	0.530	0.125
1992–93	0.520	1.050	0.254	0.530	0.125

pkm passenger-kilometre
tkm tonne-kilometre
MJ megajoule

Notes 1. The figures for the years 1984–85, 1987–88 and 1990–91 are calculated actual figures. All other figures are interpolated.
2. 1991–92 and 1992–93 fuel intensities are assumed to remain unchanged from the 1990–91 level.
3. Part of the declines in urban passenger and government bulk freight intensities is due to the increasing penetration of electric rail. Since end-use figures do not include generation and transmission losses for electricity, MJ per unit task estimates for electric rail are substantially lower than for diesel rail.

Sources BTCE estimates derived from data contained in Apelbaum (1993, pp. 94–95, 98, 100, 153, 158); Bush et al. (1993, p. 112); Cosgrove & Gargett (1992, pp. 234, 238); and BTCE (1994a) Indicators Database.

Assumptions

In order to project total fuel consumption to the year 2014–15 it is necessary to make assumptions about the explanatory variables in equations (1) to (6).

Real gross non-farm product (RGNF) is assumed to increase by 3.2 per cent per annum to the year 1997–98 and by 3.3 per cent per annum for the years 1998–99 to 2014–15. Real Australian private final consumption (RAUSPFC) was assumed to grow at the same rate as RGNF. BIS Shrapnel (1993, p. 138) also assume a growth rate of 3.2 per cent to 1998 and 3.3 per cent to the year 2008 for real gross domestic product.

Iron ore production levels are forecast by ABARE (1993a, p. 525) to increase from 116.5 million tonnes in 1993 to 131 million tonnes in 1999. It was assumed that ABARE's trend increase over the period from 1993 to 1999 will continue to the year 2014–15.

ABARE (1993a, p. 509, 487) also forecast increases in coal and grain exports for the period 1993 to 1999, an increase of 5560 thousand tonnes per annum for coal exports and 372.63 thousand tonnes per annum for grain exports. These trends were assumed to continue to the year 2015.

The real urban fares index (AUSTFAR) was assumed to remain unchanged from the 1992–93 level over the projection period.

Average distances travelled by passengers were assumed to remain constant at the 1992–93 level of 260 kilometres for non-urban travel and 14.5 kilometres for urban travel.

Average freight haul distances were assumed to remain constant at their 1990–91 levels (634 kilometres) for the government railways and constant at their 1991–92 levels (225 kilometres) for private railways.

It was assumed that fuel efficiency (the inverse of fuel intensity) would improve by between 10 and 15 per cent by the year 2014–15 (depending on the sector, see table IX.1). This is a fairly arbitrary assumption. However, since rail is responsible for only a small proportion of total energy consumption, fuel intensity increasing or decreasing by, for example, an extra 5 percentage points would only vary projected total transport energy use by less than 0.2 per cent.

Fuel projection results and scenarios

Using the BTCE model and the assumptions about the independent variables detailed above, total rail energy consumption is projected to increase from 28.8 PJ in 1992–93 to 35.59 PJ in the year 2004–05 and to 42.11 PJ in the year 2014–15. Bush et al. (1993, p. 112) project rail energy consumption to increase to 36 PJ in the year 2004–05. Appendix IX (table 1) details the results of the projection models for each of the variables. Figure 3.7 graphs the projected rise in total rail energy consumption.

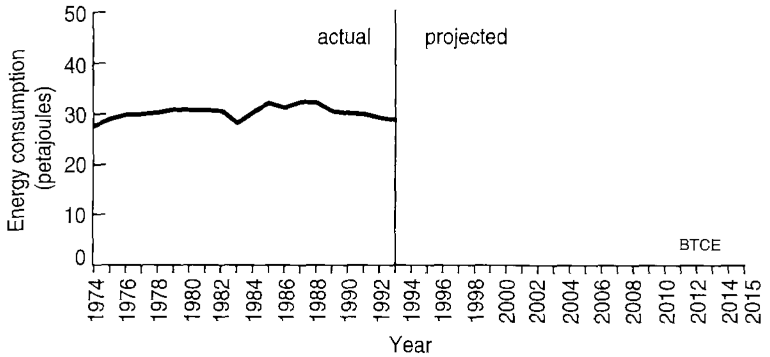
Rail energy end-use is estimated to increase by approximately 46 per cent between 1992–93 and 2014–15. During the same period government non-bulk tonnes carried is estimated to increase by 104 per cent, with government bulk tonnes increasing by 54 per cent and private freight tonnes carried by 42 per cent. For passengers, urban numbers are estimated to increase by 91 per cent and non-urban passenger numbers by only 11 per cent. Basically, after slowing throughout the recession, rail transport is projected to resume reasonably strong growth.

Table 3.5 details the effect of changing the assumption on fuel efficiency improvements. As fuel efficiency improves, the level of fuel consumption falls.

GREENHOUSE GAS EMISSIONS

Railway traction consumes automotive diesel oil (ADO), industrial diesel fuel (IDF) and electricity. Each fuel source of energy is responsible for different rates of emission for each of the greenhouse gases. Once projected, it is necessary to break total fuel consumed down into the separate fuel types in order to project emission levels.

It is assumed that IDF consumption remains constant at the 1992–93 level of 2.1 PJ. Bush et al. (1993, p. 112) also assumed IDF consumption would remain constant for their projections to the year 2004–05.



Sources Bush et al. (1993, p. 112); BTCE estimates.

Figure 3.7 Actual and projected rail energy consumption

TABLE 3.5 RAIL FUEL CONSUMPTION USING ALTERNATIVE LEVELS OF FUEL EFFICIENCY

(petajoules)

Fuel efficiency improvement by 2014–15	*Fuel consumption*
0 per cent	46.8
10–15 per cent[a]	42.1
20 per cent	36.6

a. Base case scenario. The base case scenario has slower projected efficiency than historically, for most sectors, and could be regarded as a likely upper bound.

Source BTCE estimates.

Electricity consumption is assumed to be used for the movement of urban passengers and some government freight. By multiplying urban passenger-kilometres by the urban passenger fuel intensity, total fuel consumed for the movement of urban passengers can be calculated. In 1990–91, over 90 per cent of the urban rail passenger transport task was accomplished by electric rail. It is assumed that this proportion will not change over the period 1990–91 to 2014–15.

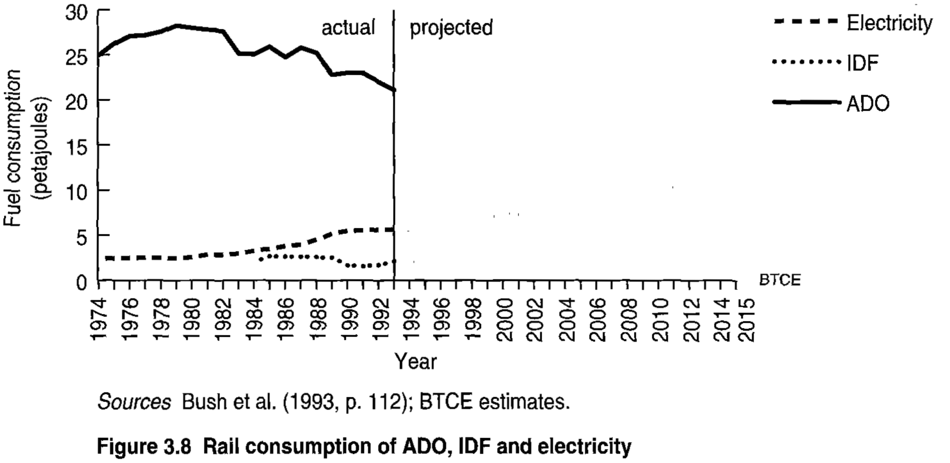
It is assumed that electricity will continue to increase its share of energy consumption by government bulk rail freight.

The level of ADO consumed is the residual of the total energy consumption projections once the IDF and electricity consumption projections have been subtracted. Appendix IX (table 3) details the projections and figure 3.8 graphs the projected consumption for each of the different fuel types.

Electricity consumption by railways is projected to increase from 5.63 PJ in 1992–93 to 8.61 PJ in 2004–05 and 11.51 PJ in the year 2014–15: an increase of 105 per cent in two decades. ADO consumption is projected to increase from 21.1 PJ in 1992–93 to 24.9 PJ in 2004–05 and 28.5 PJ in 2014–15: an increase of 35 per cent. Bush et al. (1993, p. 112) project electricity consumed by rail to be 8.7 PJ and ADO consumption by rail to be 25.5 PJ in 2004–05.

On an end-use basis, electricity use does not result in emissions of greenhouse gases. Yet the generation of electricity is responsible for significant rates of emission. Emissions from the generation of electricity to be used by trains and trams are estimated below.

Emission levels depend upon the primary fuel used to generate the electricity. New South Wales, Queensland, South Australia and Western Australia use



Sources Bush et al. (1993, p. 112); BTCE estimates.

Figure 3.8 Rail consumption of ADO, IDF and electricity

black coal as the major fuel to generate electricity, with smaller amounts of natural gas also being used. Victoria uses brown coal and natural gas.

The energy needed to generate electricity depends on the efficiency with which electricity is generated, and this varies from State to State. The efficiency of electricity generation and transmission is typically stated in terms of the percentage of energy input (PJ of coal, say) which is transformed into energy output (PJ of electricity). Based on figures from Apelbaum (1993, p. 155), the Australian efficiency, excluding Victoria, is 33.87 per cent and for Victoria 26.88 per cent. For every petajoule of electricity consumed by electric trains and trams, approximately 3 PJ of primary energy are required to generate the electricity needed. It was assumed that the efficiency of electricity generation will improve by 10 per cent by the year 2015.

Emission rates differ between the different fuels used to generate the electricity. For Victoria, emission rates will differ during the day because brown coal is used for the base load and natural gas for peak loads (Armour and Jordan 1992, p. 7). Using figures contained in Armour and Jordan (1992, p. 9) and statistics provided by the Victorian Public Transport Corporation (pers. comm. October 1994) on proportions of rail car kilometres travelled during peak and off-peak times, it is calculated that on average approximately 283 grams of CO_2 are released for every megajoule of end-use electricity consumed. For the rest of Australia, approximately 271 grams of CO_2 are released for every megajoule of end-use electricity consumed (derived using data contained in NGGIC 1994a, p. 11 and Apelbaum 1993, p. 155). A weighted average gives 273 grams of CO_2 per megajoule of electricity consumed for Australian railways. Taking the efficiency improvement assumption into consideration, the electricity emission factor will decline by 10 per cent by the year 2014–15.

Table 3.6 details all conversion factors used to calculate greenhouse gas emissions from the generation of electricity used by trains and trams and from the use of ADO and IDF.

Multiplying the fuel consumption of each fuel type by the relevant emission factor (and summing over all fuels), rail carbon dioxide equivalent emission levels are projected to increase from 3580 Gg in 1992–93 to 4610 Gg in 2004–05 and to 5560 Gg in the year 2014–15. Excluding emissions from electricity generation, carbon dioxide equivalent emission levels are projected to increase from about 1990 Gg in 1992–93 to 2315 Gg in 2004–05 and to 2625 Gg in the year 2014–15. Figure 3.9 graphs the rise in carbon dioxide equivalent emission levels (including electricity generation emissions), and appendix IX (table 4) details the actual and projected results.

TABLE 3.6 RAIL EMISSION FACTORS

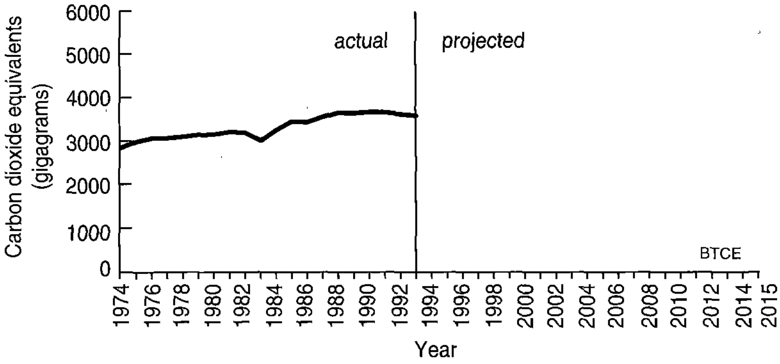
(grams per megajoule)

Gas	*Electricity*[a]	*ADO*	*IDF*	*Black coal*
CO_2	273.0	69.70	70.20	90.00
NO_x	1.030	1.710	1.710	0.300
CH_4	0.016	0.006	0.006	0.002
NMVOC	0.0	0.124	0.124	0.0
CO	0.043	0.580	0.580	0.088
N_2O	0.002	0.002	0.002	0.001

a. These factors are for the year 1992–93. It is assumed that the electricity emission factors will have declined by 10 per cent by the year 2014–15, which is approximately 0.4 per cent per annum.

Notes 1. 0.0 assumed negligible.
2. Emission factors for electricity use include the combustion of primary fuels by electric power stations, whereas all other conversion factors refer solely to energy end-use.

Sources IPCC/OECD (1994, p. 1.44); BTCE estimates based on NGGIC (1994a, p. 12); Armour & Jordan (1992, p. 9); and appendix V.



Source BTCE estimates.

Figure 3.9 Projected carbon dioxide equivalent emission levels for rail

CONCLUSION

The models used to project fuel consumption for rail depend on both the rail task levels and fuel intensity. The BTCE models were derived for use in long-term projections and therefore do not include all variables which may be relevant in the short-term. The results of the BTCE projections also depend heavily on the assumptions used.

CHAPTER 4 AVIATION

Air transport is currently the second largest source of greenhouse gas emissions in the Australian transport sector behind road. Air transport accounts for around 11 per cent of total transport carbon dioxide equivalent emissions for Australia; with bunker fuel used by international aviation accounting for 53 per cent, and domestic aviation 47 per cent of this share.

As yet, there is no international agreement on how to attribute emissions from international air transport to individual countries. The models developed by the BTCE project emissions resulting from the fuel which is uplifted in Australia, but do not imply their attribution to Australia. Around 42 per cent of the fuel required for international air passenger movement to and from Australia is uplifted in Australia (derived from figures contained in Apelbaum 1993, p. 113).

If recent trends continue, air travel will become increasingly more affordable. Increased demand for travel will generally lead to higher levels of fuel use and thus higher emissions. However, improvements in fuel efficiency and emissions reduction technology, combined with higher passenger load factors and larger aircraft, should partially counteract the expected increase in emissions. Nevertheless, by the year 2014–15, the BTCE expects air transport to increase its share of total Australian transport emissions to 24 per cent, or almost double the current share.

Separate models are estimated below for *domestic* and *international* air travel. The domestic aviation industry is essentially split into two groups, depending on the type of fuel used. Aviation gasoline (avgas) is used primarily by the general aviation market and aviation turbine fuel (avtur) is used primarily by scheduled airline services. The general aviation market (consisting of commuter and charter services, private and training flights, and aerial agricultural work) is relatively small compared to the domestic airline market, accounting for less than 10 per cent of domestic aviation fuel use. International aviation uses only aviation turbine fuel.

AIRCRAFT EMISSIONS

Emissions from aircraft depend on engine technology and the type and amount of fuel consumed. The main aircraft emissions are carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x) and non-methane volatile organic compounds (NMVOCs) which essentially consist of hydrocarbon (HC) species. Small amounts of methane (CH_4) and nitrous oxide (N_2O) are also emitted.

Each combination of aircraft type and engine model will have its own specific emissions profile (Alamdari and Brewer 1994, p. 149). CO_2 emissions are essentially proportional to the amount of fuel burned. The rate at which the non-CO_2 gases such as CO, HC and NO_x are emitted varies according to the stage of an aircraft's operations, as shown in table 4.1. Of the non-CO_2 gases, an aircraft will emit mainly NO_x while cruising. An aircraft idling emits mainly HC. Take-offs use the most engine power and emit a large amount of NO_x.

Of the non-CO_2 gases from aircraft, nitrogen oxides have the highest overall emission rate and are the most difficult to control. Increasing fuel efficiency can reduce emission levels of CO_2, CO and HC. According to which engine technology is employed, however, emission levels of NO_x may increase (Alamdari and Brewer 1994, p. 151).

The effects of nitrogen oxides (and other gaseous emissions) depend on the altitude at which they are emitted. Nitrogen oxides contribute to two major environmental problems: ozone formation in the troposphere (the lower atmosphere) leading to global warming, and stratospheric (above 15 kilometres altitude) ozone depletion (Alamdari and Brewer 1994, p. 150).

TABLE 4.1 AVERAGE AIRCRAFT EMISSION RATES

			Grams per kilogram of fuel burnt		
Stage (of aircraft operation)	*Average time spent in stage (per cent)*	*Average engine power (per cent of maximum load)*	*CO*	*HC*	*NO_x*
Idle	5	5	5	20	5
Take-off	1	100	0	0	40
Cruise	92	60	0	0	20
Approach	2	30	5	2	10

Source Reproduced from Alamdari, F.E and Brewer, D "Taxation policy for aircraft emissions" *Transport Policy* 1994 (3) 149-159 by permission of the publishers, Butterworth-Heineman Ltd.©

Aircraft emission levels can be estimated as the product of consumption of a particular aviation fuel and a conversion factor which converts fuel consumed into the quantity emitted of any particular gas. Aviation turbine fuel and aviation gasoline have different emission factors (table 4.2) for each of the greenhouse gases, due to the different compositions of the two fuel types. Averaging over the composition of the domestic and international airline fleets (by main engine type) and over the times spent in their various operating modes gives slightly differing emission factors for domestic and international avtur use. For example, international flights spend a greater proportion of total flight time cruising than do domestic flights.

For forecasting purposes, the average emission factors shown in table 4.2 are assumed to remain constant over the period from 1993–94 to 2014–15, due to the lack of alternative data.

TABLE 4.2 AVERAGE AVIATION EMISSION CONVERSION FACTORS

(grams per megajoule of fuel)

Gas	*Avgas*	*Domestic avtur*	*International avtur*
CO_2	68.0	67.8	67.8
NO_x	0.076	0.27	0.26
CH_4	0.057	0.0011	0.0004
NMVOCs	0.513	0.01	0.004
CO	22.8	0.079	0.05
N_2O	0.0009	0.002	0.002

Source Appendix V.

DOMESTIC AVIATION

Domestic aviation currently accounts for about 47 per cent of total greenhouse gas emissions (in CO_2 equivalent terms) from the Australian aviation industry. If recent trends continue, air travel will become more affordable. Increased demand for travel, in turn, will lead to higher fuel use and thus higher emissions.

Demand for domestic air services depends on both the number of passengers and the amount of freight to be carried on the network. As passenger numbers and freight increase, it can be expected that more fuel will be consumed due to higher loads carried and/or the need to employ more aircraft.

Over the last 10 years domestic aircraft passenger numbers have grown steadily. Between 1983 and 1993, aircraft passengers increased by 65 per cent. However, the pilots' dispute of 1989–90 resulted in a large fall in the number of passengers carried on the domestic network during that year.

In terms of tonnes carried, air freight is only a very small component of the total freight task within Australia, although the share is substantially higher in terms of the value of the goods carried (BTCE 1991b, p. 13). Due to the short transit times offered by aircraft compared to road and rail, air transport attracts mainly perishable, non-bulk goods. Scheduled airline services carried approximately 98 per cent of total domestic air freight in 1990–91 (Apelbaum 1993, p. 49).

Tonnes of air freight carried remained fairly constant for the 10 years prior to the 1989–90 pilots' dispute, rising by only 12 per cent over the decade. Since 1989, however, the reporting of air freight statistics to the relevant authorities has not been consistent; and statistics are unavailable for some airlines. Since air freight is carried almost completely on regular scheduled passenger services, it has not been included in the analysis as a determinant of the overall demand for aircraft fuel.

Fuel consumption models

Hensher and Young (BTCE 1991c, p. 41) model the demand for avtur as a function of the fuel price, aircraft weight, real gross domestic product and the demand for travel (depicted by the number of passenger-kilometres flown), resulting in the form of equation (1) below. Passenger-kilometres are modelled as a function of real gross domestic product, real airfares, and petrol prices (used as a proxy for alternative modes of travel), as shown in equation (2). The model is estimated using the Three-stage Least Squares (3SLS) procedure on quarterly data for the period 1977 to 1988.

The model does not include a fuel efficiency variable but includes the average fleet weight per aircraft as a proxy. Hensher and Young (BTCE 1991c, p. 41) state that for a sample of aircraft in the United States the maximum landing weight of an aircraft can, by itself, explain 93 per cent of the variation in fuel use.

$$(1)\quad \ln AD = -8.46159 - 0.149002 \ln ARFP + 0.0553705 \ln PK + 0.348419 \ln AFW + 0.867561 \ln RGDP$$

$$(2)\quad \ln PK = -0.288288 + 5.12733 \ln RGDP - 0.200787 \ln RAF + 0.129037 \ln RPP - 0.148932\, D_1 - 0.425704\, D_2 - 0.190482\, D_3 + 0.261211\, BD + 0.092315\, AMD + 0.142737\, CGD$$

where AD is avtur demand, ARFP is the avtur real fuel price, PK is passenger-kilometres, AFW is average fleet weight per aircraft, RGDP is real gross domestic product, RAF is the real airfare, RPP is the real petrol price, D_1 is a first quarter dummy, D_2 is a second quarter dummy, D_3 is a third quarter dummy, BD is a Bicentennial year (1988) dummy, AMD is a 1980 airline merger dummy and CGD is a Commonwealth Games year (1982) dummy.

The Hensher and Young model (BTCE 1991c, p. 41) implies that an increase in avtur demand will result from an increase in the demand for travel (as measured by passenger-kilometres), aircraft weight or an increase in real income. As expected, the fuel price has a negative effect on the demand for avtur. Passenger-kilometres travelled will increase as airfares decline, as incomes increase or if the cost of alternative transport choices (as depicted by the petrol price index) increases.

Bush et al. (1993, pp. 62–63) model avtur consumption as a function of the number of seat-kilometres flown (number of passenger seats on aircraft times the distance flown by aircraft). Seat-kilometres are derived by dividing passenger-kilometres travelled by the passenger load factor, which measures the proportion of the available seats that are utilised.

Passenger-kilometres are modelled separately as a function of the real gross domestic product, real airfares, lagged passenger-kilometres and a dummy variable for the year of the pilots' dispute (1989–90). The model was estimated for the period 1969–70 to 1990–91 with the following specification and results:

$$(3) \log PKM_t = \underset{(2.07)}{0.56} + \underset{(9.75)}{1.37} \log RGDP_t - \underset{(-3.12)}{0.27} \log RAF_t - \underset{(-10.99)}{0.48}\, D + \underset{(3.81)}{0.34} \log PKM_{t-1}$$

Adjusted $R^2 = 0.98$, Durbin's h statistic = 0.10

$$(4) \quad SKM_t = PKM_t' \;/\; U_t$$

$$(5) \quad \log DAC_t = \underset{(1.80)}{0.38} + \underset{(31.67)}{0.70} \log SKM_t$$

Adjusted $R^2 = 0.98$, Durbin–Watson statistic = 1.46

where t-ratios are given in parentheses, PKM_t is the number of passenger-kilometres flown in year t, $RGDP_t$ is the real gross domestic product, RAF_t is real domestic airfares, D is a dummy variable used to allow for the effect of the pilots' dispute (1989–90), SKM_t is seat-kilometres travelled, U_t is a system wide load factor, PKM_t' is the projected passenger-kilometres series from equation (3) and DAC_t is the aviation turbine fuel consumption of domestic airline operators.

Passenger-kilometres are shown to increase as airfares fall or as income levels rise; as passenger-kilometres rise so will seat-kilometres unless offset by higher load factors. The model implies that fuel sales will also increase as seat-kilometres increase.

Bush et al. (1993, p. 30) use their model to project the growth rate of fuel consumption for domestic air carriers. Real air fares are assumed to decline by 1.3 per cent per year, the system wide load factor is assumed to increase from 0.77 in 1992–93 to 0.80 in 2004–05, and the real gross domestic product is assumed to grow at a varying yearly rate of between 3.0 and 4.5 per cent. Between 1992–93 and 2004–05 domestic avtur consumption is projected to increase by approximately 4.6 per cent per annum (Bush et al. 1993, p. 30).

The National Institute of Economic and Industry Research (NIEIR 1990, p. 2.25) forecasts domestic avtur demand using total tonne-kilometres (of passengers and freight) flown. Unspecified assumptions are used for the average fuel efficiency of the existing fleet and average system load factors. Variations in passenger-kilometres travelled are explained by income per capita, real gross non-farm product and real domestic airfare variables. Passenger-kilometres are then transformed to total passenger tonne-kilometres using an average passenger weight (NIEIR 1990, p. 2.25). NIEIR (1990, p. 2.26) projects domestic avtur sales to increase by 2.51 per cent per annum between 1989 and 1995.

Although the three models differ in their structure, the major variable used to determine avtur consumption is the task level (generally measured by passenger-kilometres flown). Real income and airfare variations appear to explain most of the variation in the passenger task level.

BTCE model specification

Due to the long-term nature of the projections (from 1992–93 to 2014–15), the specification of the BTCE model is focused on *simplicity* while incorporating the major determinants affecting domestic avtur consumption.

As the aim of the modelling process is to assist in projections of greenhouse gas emission levels, the derived models are fairly aggregated. Military fuel use, for example, is not modelled separately (though it would require different explanators to those for scheduled passenger services). Approximately 15 to 20 per cent of domestic avtur sales are to the military, but there is no time series available. Consequently, total avtur consumption is modelled based on the demand for civil aviation.

Fuel consumption is modelled as the product of the domestic aviation task level (measured by the number of seat-kilometres) and the average fuel intensity of the aircraft fleet (measured in litres consumed per seat-kilometre), which takes into account changes in technology. As the fuel efficiency of the aircraft fleet improves, fuel consumption required to undertake the same task will decline. If the domestic task increased faster than the improvement in fuel efficiency improved, fuel consumption would be expected to increase.

The task level, measured in seat-kilometres travelled, can be derived by dividing passenger-kilometres travelled by the passenger load factor. The passenger load factor measures the proportion of seats which are filled by passengers. For example, if the load factor was 100 per cent, then all the aircraft's seats would be filled and seat-kilometres would be equal to passenger-kilometres. With a load factor of 50 per cent, however, seat-kilometres are twice the magnitude of passenger-kilometres.

As seat-kilometres increase, more fuel is consumed because more aircraft are required to undertake the task. An increase in seat-kilometres may result from an increase in passengers travelling under the same load factor or from the same number of passengers travelling under a reduced load factor. Since aircraft operators tend to schedule service frequencies to maintain high load factors, forecasting seat-kilometres essentially relies on forecasting passenger-kilometres travelled. Passenger numbers are modelled and then multiplied by an average distance travelled to derive passenger-kilometres.

Passengers numbers have been split into two segments: Australian resident passengers flying on the domestic network (APASS) and foreign passengers flying on the domestic network (FPASS). The variables which affect the number of Australian residents are likely to differ from the variables affecting foreigners travelling on the domestic network.

The major variables which were found to affect the number of Australians travelling on the domestic air network are the level of income (depicted by the real gross non-farm product), the price of airfares (depicted by an index of average real airfares for a medium distance journey) and the price of competing modes of transport. The real petrol price index was used as a proxy for travel by other modes (such as buses, rail or car). Similar variables were also used by Hensher and Young (BTCE 1991c, p. 41), Bush et al. (1993, pp. 62–63) and NIEIR (1990, p. 2.25).

To determine the number of foreign travellers on the domestic air network, it is assumed that 75 per cent of the total number of foreign international passengers arriving in Australia will make a journey on the domestic air network. The proportion of 0.75 is an estimate made by the BTCE (1991b, p. 45) utilising the *International Visitors Survey* from the Bureau of Tourism Research (reported in BTR 1992), which determines the average number of domestic air passenger movements generated by each short-term (staying in Australia for less than 12 months) foreign arrival. Foreign arrivals were estimated using equation (25) below.

Domestic consumption of avtur is estimated on the basis of the following set of equations.

Fuel consumption is derived by multiplying seat-kilometres travelled by the average aircraft fleet fuel intensity,

(6) FC = SKM x fuel intensity

where FC is total domestic aviation turbine fuel consumption (measured in million litres), SKM is the total number of seat-kilometres flown on domestic flights (measured in million seat-kilometres) and fuel intensity refers to an average domestic aircraft fleet fuel intensity (measured in litres of fuel consumed per seat-kilometre flown).

Seat-kilometres are derived by dividing passenger-kilometres flown by the passenger load factor,

(7) SKM = PASSKM / LF

where SKM is the total of domestic seat-kilometres flown (measured in million seat-kilometres), PASSKM is the total number of domestic revenue passenger-kilometres flown (millions) and LF is the average passenger load factor (expressed as a proportion of aircraft passenger capacity).

Total domestic passenger-kilometres are the sum of kilometres flown by both Australian residents and by foreigners on the domestic air network,

(8) PASSKM = APASSKM + FPASSKM

where PASSKM is the total number of passenger-kilometres flown on the domestic network (millions), APASSKM is the number of Australian resident passenger-kilometres flown on the domestic network (millions) and FPASSKM is the number of passenger-kilometres travelled by foreigners on the Australian domestic network (millions).

Passenger-kilometres flown by residents on the domestic network are derived by multiplying resident passenger numbers by an average distance,

(9) APASSKM = APASS x AVKM

where APASSKM is the number of Australian resident passenger-kilometres flown on the domestic network (millions), APASS is the number of Australian resident passengers travelling on the domestic network (millions) and AVKM is an average distance flown (kilometres).

Australian residents flying on the domestic network are modelled as a function of real gross non-farm product, real (medium distance) airfares and a dummy variable for the pilots' dispute in 1989–90. The model is estimated using quarterly data and the Cochrane-Orcutt procedure. See table 4.3 for a summary of the regression statistics and diagnostic results.

(10) $\ln APASS = -10.77 + 1.19 \ln RGNF - 0.32 \ln RMEDF - 0.89\ AIRDUM$

where APASS is the number of Australian passengers travelling on the domestic network (measured in millions), RGNF is real gross non-farm product, RMEDF is an index of real medium distance airfares and AIRDUM is the dummy variable for the pilots' dispute in 1989–90.

Passenger-kilometres flown by foreigners on the domestic network were estimated by multiplying total short-term foreign international arrivals by the average distance flown and 0.75 (the BTCE estimate of the proportion of foreign arrivals that undertake a domestic trip by air),

(11) FPASSKM = INPASS x 0.75 x AVKM

where FPASSKM is the number of passenger-kilometres travelled by foreigners on the Australian domestic air network (millions), INPASS is the total number of short-term foreign arrivals in Australia (millions) and AVKM is the average distance flown (kilometres).

Data collected for each of the variables in equations (6) to (11) are detailed in appendix X, table 1.

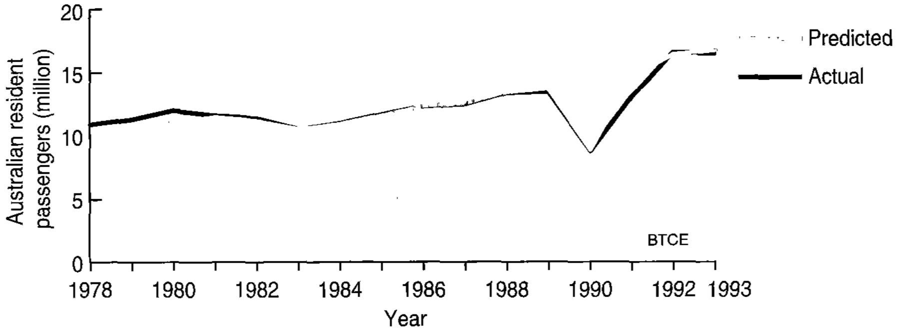
Figure 4.1 graphs the historical actual and predicted levels of APASS using the BTCE model specification (using annual summation of quarterly data). The model assumes constant elasticities. Originally it was expected that income, airfares and the real petrol price index (a proxy for competition by road transport) would all influence the number of Australian residents travelling on the domestic air network. However, the real petrol price index was removed from the final model because it was highly correlated to real airfares and did not offer any different information with which to model passenger

TABLE 4.3 RESULTS OF THE BTCE DOMESTIC AVIATION MODEL

Dependent variable	*Diagnostics*	*Independent variables*	*Coefficient*	*Standard error*
ln APASS	Adj. R^2 = 0.98	constant	–10.77	0.80
	DH = 0.69	ln RGNF	1.19	0.07
	Period: 1978Q1 to 1993Q4	ln RMEDF	–0.32	0.05
	EM: CORC	AIRDUM	–0.89	0.03

Notes 1. Adj. R^2 refers to the adjusted R^2 statistic.
2. DH refers to Durbin's h statistic.
3. Period refers to the estimation period, where Q denotes quarterly data.
4. EM refers to the estimation method used, where CORC denotes Cochrane–Orcutt estimation.

Source BTCE estimates.



Sources BTCE (1994a) Indicators Database; BTCE estimates.

Figure 4.1 Actual and predicted levels of the number of Australian residents travelling on the domestic air network

numbers. The coefficient on RGNF of 1.19 suggests that passenger numbers are quite responsive to changes in national income levels. As expected, airfares have a negative impact on passenger numbers.

Fuel intensity. Historical data on fuel consumption and seat-kilometres travelled permit the use of equation (6) to obtain a series on the fuel intensity of the domestic aircraft fleet. The fuel intensity series is derived by dividing fuel consumption by seat-kilometres to obtain litres per seat-kilometre. Table 4.4 provides the time series for the period 1977–78 to 1992–93.

The derived aircraft fleet fuel intensity series is not the same as the average rated fuel intensity (using engineering data), because a number of factors are not taken into account in the derived series. For example, the fuel consumption series measures total domestic fuel sales, including sales to the military and to international Qantas flights carrying domestic passengers. Seat-kilometres performed do not include those undertaken by the military or by international Qantas flights undertaking a domestic task. The kilometres flown for repositioning aircraft (to meet schedules, for example) are also not taken into account. Hence the derived litres consumed per seat-kilometre will be overstated compared to actual engineering fuel intensities. The derived fuel intensity series will be used in this chapter as representative of the movement over time of actual fuel intensity levels of the aircraft fleet.

Average domestic aircraft fleet fuel intensity (gained from engineering data) can be derived by summing the fuel intensity of each aircraft type, weighted by the number of aircraft multiplied by the number of seats:

TABLE 4.4 DERIVED FUEL INTENSITY SERIES FOR THE DOMESTIC AIRLINE FLEET

Year	(1) Fuel consumption (million litres)	(2) Seat-kilometres (million)	(3) Fuel efficiency (L/SKM) (3) = (1) / (2)
1978	1 098.5	11 963	0.092
1979	1 081.1	12 174	0.089
1980	1 127.9	12 816	0.088
1981	1 123.8	12 407	0.091
1982	1 205.6	13 959	0.086
1983	1 168.5	13 246	0.088
1984	1 163.3	13 263	0.088
1985	1 193.2	14 164	0.084
1986	1 283.4	15 402	0.083
1987	1 333.6	16 585	0.080
1988	1 427.8	17 561	0.081
1989	1 406.9	17 994	0.078
1990	1 124.3	13 868	0.081
1991	1 437.7	20 503	0.070
1992	1 569.5	24 339	0.064
1993	1 642.1	24 767	0.066

Sources ABARE (pers. comm. 1994); BTCE (1994a) Indicators Database; DTC (1993a and earlier); BTCE estimates.

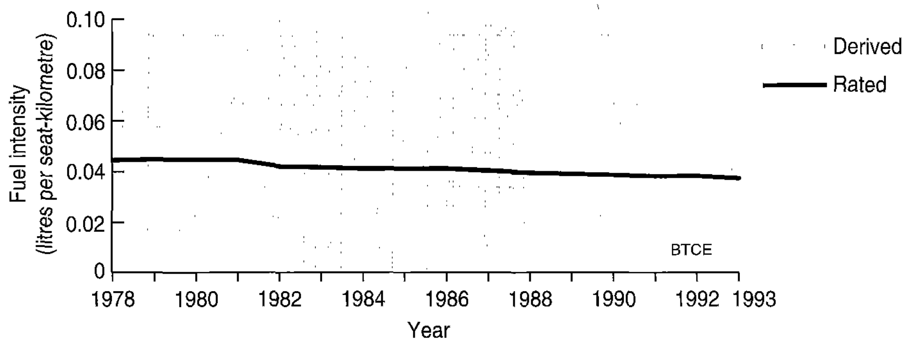
$$(12)\ \mathrm{AFI} = \sum_{A=1}^{n}\left(\mathrm{FI}_A \times \left[\frac{(\text{no. of aircraft}_A \times \text{seats}_A)}{\sum_{A=1}^{n}(\text{no. of aircraft}_A \times \text{seats}_A)}\right]\right)$$

where AFI is the average rated fuel intensity of the domestic aircraft fleet and FI_A is the individual fuel efficiency for aircraft type A.

Figure 4.2 illustrates the derived fuel intensity series (from table 4.4) and the 'rated' domestic airline fleet fuel intensity gained from engineering data (using equation 12).

The general trend between the two series is similar, supporting the use of the derived series in the BTCE model as an index for fuel efficiency improvements.

Average kilometres flown. This series is derived by dividing total domestic revenue passenger-kilometres flown by the total number of domestic passengers. Revenue kilometres refer to the number of kilometres travelled with fee-paying passengers. They do not include kilometres flown for the repositioning of aircraft. Average kilometres flown have been increasing steadily from approximately 707 in 1978 to approximately 1022 in 1993.



Note The 'rated' series is derived from engineering data.

Sources BTCE estimates using data from Ansett (pers. comm. April 1994); Qantas (pers. comm. March 1994); DTC (1993a and earlier issues); BTCE (1992); ABARE (pers. comm. 1994).

Figure 4.2 Domestic airline fleet fuel intensity

Australian passengers. The number of Australian passengers travelling on the domestic air network is calculated by subtracting the estimated foreign passenger component from statistics on total domestic passengers. Between 1978 and 1989 Australian passenger numbers increased from 10.91 million to 13.47 million: an increase of approximately 23 per cent. Growth was stifled in 1989–90 by the pilots' dispute, and Australian resident passenger numbers fell to 8.81 million (a fall of 35 per cent in the one year). Since the pilots' dispute, passenger numbers have grown strongly, increasing to 16.49 million in 1993.

Foreign passengers. The number of foreign visitors travelling on the Australian domestic air network was estimated to be 75 per cent of the total number of short-term foreign arrivals. Numbers of foreign passengers have been increasing strongly since 1978, with only a small decline due to the pilots' dispute in 1989–90. Numbers grew from 0.44 million in 1978 to approximately 2.1 million in 1993. The pilots' dispute led to a fall in foreign passengers in 1990 of only 3 per cent from 1989 levels.

Real gross non-farm product. Real gross non-farm product represents national income and uses 1990 as the base year. It has been increasing since 1978, with declines for the recession years of 1983–84 and 1991–92. As income levels increase more people will be able to afford to travel by air.

Real airfares. The price level was represented by an index (base 1984) of average real air fares on medium distance air routes. Real airfares increased between 1978 and 1984 and have been declining ever since, due mostly to airline deregulation. It is expected that if real airfares increase fewer people will be able to afford to travel, causing a negative impact on Australian passenger numbers.

AIRDUM. Airdum is a dummy variable which reflects the year of the pilots' dispute. It is equal to 0 for all years except those of the pilots' dispute: from the second quarter of 1989 to the third quarter of 1990. AIRDUM is equal to 0.2 in 1989Q2, 0.8 in 1989Q3, 1 in 1989Q4, 0.4 in 1990Q1, 0.2 in 1990Q2, 0.1 in 1990Q3 and 0 elsewhere. Different coefficients are used to account for the degree of the effect in a particular quarter.

Foreign arrivals. Foreign arrivals are the total number of short-term foreign arrivals in Australia (INPASS). The modelling of foreign arrivals is detailed below, especially in equation (25). Foreign arrivals have shown strong growth since 1978, increasing by approximately 380 per cent by 1993.

Assumptions

For the purposes of projecting domestic aviation turbine fuel consumption to the year 2014–15, it was necessary to make a number of assumptions about the independent variables. Table 4.5 summarises these assumptions.

It was assumed that the real gross non-farm product (RGNF) will increase by 3.2 per cent per annum to the year 1997–98 and will increase at an annual rate of 3.3 per cent thereafter. On average these figures are slightly lower than those assumed by Bush et al. (1993, p. 23), who assume RGNF to vary between 3 and 4.5 per cent per annum to the year 2004–05. BIS Shrapnel (1993, p. 138) assumes growth of 3.2 per cent to 1998 and 3.3 per cent to 2008 for real gross domestic product. The BTCE follows the assumptions made by BIS Shrapnel, with the 3.3 per cent growth assumption extended to the year 2014–15.

Real airfares (RMEDF) are assumed to decline by 1.3 per cent per annum (Cosgrove, Gargett & Viney 1989, p.12) to the year 2014–15. The decline in real airfares will be most likely due to airline cost savings which are then passed on to the consumer. Bush et al. (1993, p. 63) use the same assumption.

TABLE 4.5 DOMESTIC AVIATION: PROJECTION ASSUMPTIONS

(per cent change per annum)

Variable	*1993–1998*	*1999–2015*
Real gross non-farm product (RGNF)	+ 3.2	+ 3.3
Real airfares (RMEDF)	–1.3	–1.3
Average kilometres travelled (AVKM)	0.0	0.0
Passenger load factor (LF)	0.0	0.0

Sources BTCE estimates; BIS Shrapnel (1993, p. 138); Cosgrove, Gargett & Viney (1989, p. 12).

The passenger load factor (LF) is assumed to remain constant at the 1992–93 figure of 76.7 per cent, due to lack of data on future passenger load factor levels. This assumption may prove to be conservative if airline operators undertake to increase current load factors as a means of cutting costs to remain competitive. A number of scenarios outlined in the next section alter the assumption made about passenger load factors. Bush et al. (1993, p. 63) assume that load factors increase to 80 per cent by the year 2004–05.

Average kilometres travelled per passenger (AVKM) are assumed to remain constant at the current 1992–93 value.

The BTCE (1992) has calculated the likely improvements to the domestic aircraft fleet fuel efficiency under a number of scenarios. Likely improvements will depend upon when the fleet is replaced. Between 1988 and 2005 the BTCE (1992, p. 44) estimated improvements in fuel efficiency to be 33 per cent if aircraft are replaced after 15 years; 22 per cent if replaced after 20 years; and 14 per cent if replaced after 25 years. Using these figures and extending them to the year 2015, the improvements in fuel efficiency between 1993 and 2015 would become 43 per cent for a fleet replaced after 15 years; 28 per cent after 20 years; and 18 per cent after 25 years. Qantas (pers. comm. 1994) suggests that a fuel efficiency improvement of 40 per cent by the year 2015 is unlikely. Therefore it is assumed that by 2015 the fuel efficiency of the domestic aircraft fleet will improve by 28 per cent in the base case scenario.

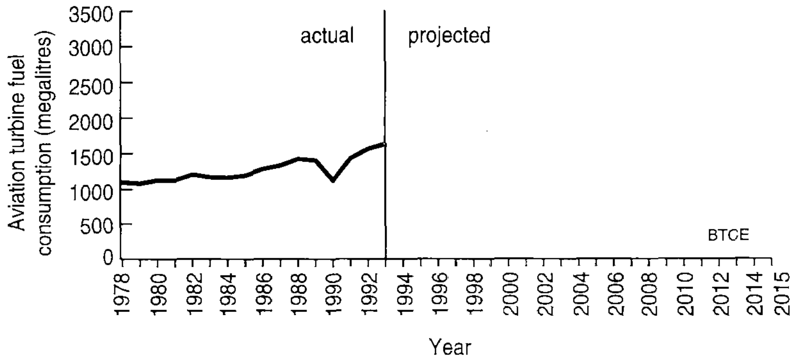
Appendix X, table 1 details the actual projected levels for each variable for each year to 2014–15.

Projection results and scenarios

Using the BTCE model and the assumptions in table 4.5, domestic avtur consumption is projected to increase from 1642 million litres in 1992–93 to 2328 million litres in the year 2004–05 and to 3386 million litres in 2014–15. Figure 4.3 shows the projected levels of domestic aviation turbine fuel consumption.

On the basis of the assumptions in table 4.5, Australian residents travelling on the domestic network are projected to increase from 16.75 million in 1992–93 to 25.95 million in 2004–05 and to 40.73 million in 2014–15. The total number of seat-kilometres travelled on the domestic air network (including Australian and foreign passengers) increases from 25 123 million in 1992–93 to 42 046 million in 2004–05 and to 71 948 million in the year 2014–15. Appendix X, table 1 details all projection results.

Tables 4.6 and 4.7 detail how changing the assumptions on fuel efficiency and load factors affects projected levels of fuel consumption and seat-kilometres



Sources ABARE (pers. comm. 1994); BTCE estimates.

Figure 4.3 Actual and projected levels of domestic aviation turbine fuel consumption

travelled. As fuel efficiency improves, total fuel consumption falls. As load factors are increased, seat-kilometres and fuel consumption both decline.

Aviation gasoline

Avtur is by far the major fuel consumed in the domestic aviation market. However aviation gasoline (avgas) is also used, mainly in the general aviation market. The level of fuel consumption by general aviation is only a very small component of total aviation fuel consumption and does not warrant an extensive econometric modelling procedure.

Growth in the use of avgas of 0.05 petajoules per year is assumed, based on Bush et al. (1993, pp. 30, 112).

Figure 4.4 illustrates the growth in avgas consumption to the year 2014–15. Aviation gasoline fuel use is projected to increase from 106 megalitres in 1992–93 to 116 megalitres in the year 2004–05 and to 139 megalitres in the year 2014–15.

Appendix X, table 2, details the actual and projected levels of avgas.

Projected emissions from domestic aviation

Projected levels of greenhouse gas emissions can be calculated from the fuel consumption projections for domestic aviation.

Conversion of fuel consumption in litres to megajoules of energy is made by multiplying litres consumed and the relevant energy density conversion

TABLE 4.6 SCENARIOS FOR DOMESTIC AVIATION TURBINE FUEL CONSUMPTION IN 2014–15

(million litres)

	Load factor in the year 2014–15		
Fuel efficiency improvement by 2014–15 (per cent over 1992–93)	*0.7*	*0.767*	*0.8*
10	4 637	4 232	4 058
18	4 225	3 856	3 697
28	3 710	3 386	3 246
30	3 607	3 292	3 156

Note 1. Base case assumption is load factor of 0.767 and fuel efficiency improvement of 28 per cent.

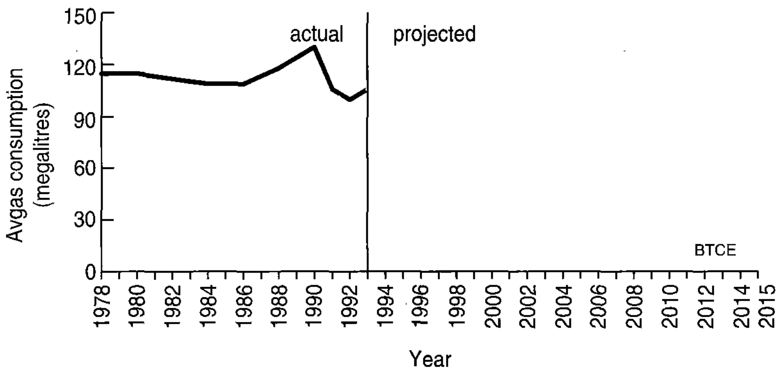
Source BTCE estimates.

TABLE 4.7 SCENARIOS FOR DOMESTIC SEAT-KILOMETRES TRAVELLED IN 2014–15

Load factor in 2014–15	*million seat-kilometres*
0.700	78 834
0.767	71 948
0.800	68 980

Note 1. Base case assumption load factor is 0.767.

Source BTCE estimates.



Sources Bush et al. (1993, p. 112); BTCE estimates.

Figure 4.4 Aviation gasoline fuel consumption projections

factor: for avtur, the energy density is 36.8 megajoules per litre of fuel; for avgas, 33.1 megajoules per litre of fuel.

Megajoules of fuel consumed are multiplied by the relevant emission conversion factors (table 4.2) to obtain emission levels for each of the greenhouse gases.

Carbon dioxide equivalent emission levels for the total domestic aviation market (both major airlines and general aviation) are projected to increase by a total of 101 per cent between 1992–93 and 2014–15. The increase in emissions is due mostly to the scheduled airline market, where carbon dioxide equivalent emissions increase by 106 per cent between 1992–93 and 2014–15. The carbon dioxide equivalent emissions from the general aviation market increase by only 31 per cent over the same period. Table 4.8 and appendix X, tables 3–5, contain projected levels of greenhouse gases by aviation.

Table 4.9 outlines alternative scenarios with respect to passenger load factors and fuel efficiency.

As expected, increasing passenger load factors and/or improving fuel efficiency lead to reduced fuel consumption and carbon dioxide equivalent emissions.

TABLE 4.8 DOMESTIC AVIATION: PROJECTIONS OF TOTAL CARBON DIOXIDE EQUIVALENT EMISSIONS

(gigagrams)

Fuel type	*1992–93*	*2014–15*	*Per cent change*
Avtur	4 277	8 820	106
Avgas	340	447	31
Total	4 617	9 267	101

Note 1. Per cent change refers to the total per cent change between 1992–93 and 2014–15.

Sources BTCE estimates; Bush et al. (1993, p. 112).

TABLE 4.9 SCENARIOS FOR TOTAL CARBON DIOXIDE EQUIVALENT EMISSIONS FOR THE DOMESTIC AVIATION MARKET IN 2014–15

(gigagrams)

	Load factor in the year 2014–15		
Fuel efficiency improvement by 2014–15 (per cent over 1992–93)	*0.7*	*0.767*	*0.8*
10	12 526	11 471	11 018
18	11 453	10 492	10 078
28	10 111	9 267	8 903
30	9 843	9 023	8 668

Note 1. Base case assumption is load factor of 0.767 and fuel efficiency improvement of 28 per cent.

Source BTCE estimates.

INTERNATIONAL AVIATION

International aviation currently accounts for 53 per cent of total greenhouse gas emission levels from the Australian aviation industry.

The level of aviation turbine fuel (avtur) uplifted in Australia will in part depend upon the projected level of international travel to and from Australia.

Foreign passenger arrivals in Australia have been growing strongly since 1978 as Australia has become a more popular tourist destination. Between 1986 and 1993 foreign arrivals increased by 120 per cent, and Australian passenger departures increased by 54 per cent.

Fuel consumption models

Bush et al. (1993, p. 62) model fuel consumption by international airline operators as a function of the total number of international passengers and fuel consumption in the previous period. The regression is estimated for the period 1969–70 to 1990–91, and results in the following specification:

$$(13)\ \log IAC_t = \underset{(2.7)}{1.13} + \underset{(2.69)}{0.30} \log IP_t + \underset{(2.52)}{0.48} \log IAC_{t-1}$$

$$\text{Adjusted } R^2 = 0.97;\ \text{Durbin's h statistic} = 1.70$$

where t-ratios are given in parentheses, IAC_t is aviation turbine fuel consumption by international operators in the year t, and IP_t is the number of international passengers arriving in and departing from Australia in year t.

Bush et al. (1993, p. 30) assume that international passenger numbers will grow at an annual rate of 7.5 per cent for all years between 1990–91 and 2004–05. Using their model, avtur consumption by international operators is expected to increase by approximately 5 per cent per annum to the year 2004–05 (Bush et al. 1993, p. 30).

The model developed by the National Institute of Economic and Industry Research (NIEIR 1990, p. 2.25) takes a very similar approach to Bush et al. (1993, p. 62). Aviation turbine fuel consumption by international operators is modelled as a function of the number of international passenger arrivals in Australia. The total number of passenger arrivals in Australia is determined on the basis of (unspecified) assumptions about long-term (for a period of more than 12 months) and short-term passenger movements (NIEIR 1990, p. 2.25).

Hensher and Young (BTCE 1991c, p. 41) estimate a Three-stage Least Squares (3SLS) model using quarterly data for the period 1977 to 1988. International avtur demand is explained by the fuel price, the number of departing passengers and income levels as depicted by Australia's real gross domestic product.

$$(14)\ \ln AD = -0.828285 - 0.102374 \ln ARFP + 0.130572 \ln DP + 1.17139 \ln RGDP$$

$$\begin{aligned}(15)\ \ln DP = &-0.622476 + 0.004010 \ln RTWI + 1.38093 \ln RAF - 0.1799994\, D_1 \\ &+ 0.0425447\, D_2 + 0.478477\, D_3 - 0.028435\, BD - 0.043498\, AMD \\ &+ 0.041005\, CGD\end{aligned}$$

where AD is avtur demand, ARFP is the avtur real fuel price, DP is the number of departing passengers, RGDP is the real gross domestic product, RTWI is the real trade weighted index, RAF is real airfares, D_1 is a first quarter dummy, D_2 is a second quarter dummy, D_3 is a third quarter dummy, BD is a Bicentennial year dummy (1988), AMD is the 1980 airline merger dummy, and CGD is a 1982 Commonwealth Games dummy.

A higher fuel price is likely to reduce the demand for avtur, while an increase in passenger numbers will increase the demand for avtur. However, the Hensher and Young model has an unexplained positive coefficient for real airfares. Higher airfares should result in fewer passengers travelling rather than more.

The RTWI is a measure of relative prices between Australia and overseas countries. As the RTWI increases, more people from Australia are likely to travel.

The Hensher and Young approach (BTCE 1991c, p. 41) is more detailed than the models derived by Bush et al. (1993, p. 62) and NIEIR (1990, p. 2.25), because it models passenger numbers separately. Note that Hensher and

Young (BTCE 1991c, p. 41) consider passengers departing from Australia, whereas NIEIR (1990, p. 2.25) uses only passenger arrivals in Australia, and Bush et al. (1993, p. 62) use total passenger numbers.

A number of models have been developed to estimate passenger numbers. Two of the more recent models on passenger numbers have been constructed by the Bureau of Tourism Research (1992) and by Henchy and Swanton (1992).

Henchy and Swanton (1992, pp. 642–646) derived separate models to forecast short-term Australian resident departures (that is, passengers who are leaving the country for less than 12 months) to various countries, including the United States, the United Kingdom, Singapore and Japan. For each country, Australian passenger departures were assumed to be a function of the relative price between the destination country and Australia, airfares, the household disposable income for the destination country, and lagged passenger departure numbers. The models suggest that household disposable income is the main contributor to passenger movements. Airfares were found to be statistically insignificant for short-term passenger movements to Japan and Singapore.

The Henchy and Swanton (1992, p. 642) models are very detailed. Replication would require a great deal of data collection to undertake regressions for each of Australia's major departure destinations. A similar approach would also need to be carried out for foreign arrivals in Australia, to determine total international traffic to and from Australia.

The Bureau of Tourism Research (BTR 1992, pp. 7–13) has formulated a model for predicting international visitor arrivals from a number of countries to the year 2001.

For each country of origin a model is developed using quarterly data for the period 1978 to 1991. The general model specification is outlined in equations (18) and (19). The general model allows for a maximum of four lags on each of the independent variables. However, this approach generates models which are overspecified. A more specific model was therefore used by the BTR for each country of origin by deleting the insignificant variables.

$$(18)\quad NTi_t = \alpha_0 + \sum_{j=1}^{4} \alpha_j NTi_{t-j} + \sum_{k=0}^{4} \beta_k Yi_{t-k} + \sum_{l=0}^{4} \gamma_l Ri_{t-l}$$

$$(19)\quad Ri_t = PA \times Ei_t / Pi_t$$

where NTi is the number of international arrivals from country i, Yi is the level of gross domestic product in country i, Ri is the real exchange rate of country i with respect to the Australian dollar, PA and Pi are the consumer price indices in Australian and country i respectively, and Ei is the exchange rate of the currency in country i with the Australian dollar.

Ordinary Least Squares (OLS) was used to estimate the models. For every country of origin modelled, the BTR found that only lagged values of the gross domestic product (Yi) and the real exchange rate (Ri) were found to be important.

Airfares were not included in the BTR model for passenger numbers, due to the lack of relevant data (BTR 1992, p. 12). An out-of-model adjustment was made, based on the expected impact of the deregulation of the international aviation industry on international airfares that was suggested might be possible in the absence of restrictions by the Industries Assistance Commission. Fare elasticities were calculated for each country and used in the forecasting model on the assumption that airfares would decline by 2 per cent per year to the year 2001 (BTR 1992, p. 3).

The BTR (1992, pp. 7–12) model is thus similar to that developed by Henchy and Swanton (1992, pp. 642–644) except that the airfares are an out-of-model adjustment rather than being included explicitly (as in the Henchy and Swanton model).

BTCE model specification

Due to the long-term nature of the projections (from 1992–93 to 2014–15), the BTCE model specification is developed with the aim of achieving a *simple* formulation that incorporates all of the major determinants affecting international avtur consumption.

Fuel consumption was modelled as the product of the international task to and from Australia (measured in seat-kilometres performed) and the fuel intensity of the international aircraft fleet arriving in and departing from Australia (measured in litres per seat-kilometre). If the fuel efficiency of the aircraft fleet improves, then fuel consumption will fall. Alternatively, if the task (and thus seat-kilometres) declines, fuel consumption will also decline.

Seat-kilometres were derived by dividing international passenger-kilometres by the average passenger load factor (which is a measure of the percentage of the aircraft seats which are being utilised). As seat-kilometres increase, so will fuel consumption. Seat-kilometres may increase if load factors decline and/or passenger-kilometres increase.

Short-term international passenger-kilometres were derived by multiplying short-term passenger numbers by the average distance flown. Passenger numbers were split into two groups: short-term foreign arrivals and Australian resident departures. Total international passenger numbers were derived by doubling short-term foreign arrivals and Australian resident departures (to account for the return journey) and increasing the result by approximately 2 per cent to account for long-term or permanent movements (derived from data contained in BTCE 1988).

The major variables which were found to affect both foreign arrivals and Australian resident departures were income levels, real airfares and relative prices in Australia compared to overseas countries (represented by the real trade weighted index of the exchange rate).

The level of freight carried by international aircraft was not found to be a significant variable when determining fuel consumption. International air freight is carried on passenger flights if there is sufficient space available, but tonnages are very small. In the export industry only 0.1 per cent of trade is carried by air and in the imports industry only 0.5 per cent (BTCE 1991b, p. 20). Most international trade is carried by ships.

Equations (20) to (25) outline the final BTCE model specification for international avtur fuel consumption. Table 4.10 presents a summary of the regression results and diagnostic tests.

Fuel uplifted in Australia is calculated by an identity linking it to total seat-kilometres times the average fleet fuel intensity times 0.42. The latter is an estimate of the proportion of total aviation fuel consumed by aircraft flying to and from Australia which is uplifted in Australia (derived from data contained in Apelbaum 1993, p. 113).

(20) AFC = SKM x FI x 0.42

where AFC is international avtur uplifted in Australia (measured in million litres), SKM is the total number of international seat-kilometres travelled by aircraft arriving in and departing from Australia (millions), and FI is the average aircraft fleet fuel intensity (measured in litres consumed per seat-kilometre travelled).

For the years prior to 1992-93 a series for the average fleet fuel intensity can be calculated by dividing the total fuel consumed for Australia's international task by the total seat-kilometres travelled.

(20a) FI = TFC / SKM

where FI is the average aircraft fleet fuel intensity (measured in litres consumed per seat-kilometre travelled), TFC is the total fuel consumed by international aviation travelling to and from Australia (million litres) and SKM is the total number of international seat-kilometres travelled by aircraft arriving in and departing from Australia (millions).

TABLE 4.10 RESULTS OF THE INTERNATIONAL AVIATION MODEL

Dependent variable	*Diagnostics*	*Independent variables*	*Coefficient*	*Standard error*
ln OUTPASS	Adj. $R^2 = 0.95$	constant	–9.38	2.19
	DW = 1.54	ln RGNE	1.36	0.19
	Period: 1985Q3 to 1993Q4	ln ROFARE	–0.35	0.05
	EM: OLS	ln RTWI(–4)	0.13	0.07
		BIDUM	–0.05	0.02
ln INPASS	Adj. $R^2 = 0.98$	constant	1.44	2.60
	DH = –1.07	ln G7GDP	2.79	0.49
	Period: 1978Q1 to 1993Q4	ln RIFARE(–4)	–0.19	0.12
	EM: CORC	ln RTWI(–4)	–0.27	0.18
		BIDUM	0.14	0.05
		CDUM	0.10	0.06
		D1	–0.15	0.02
		D2	–0.35	0.02
		D3	–0.26	0.02

Notes 1. Adj R^2 refers to the adjusted R^2 statistic.
2. DW refers to the Durbin–Watson statistic and DH refers to Durbin's h statistic.
3. Period refers to the estimation period, where Q denotes quarterly data.
4. EM refers to the estimation method used. OLS denotes Ordinary Least Squares estimation, and CORC denotes the Cochrane-Orcutt procedure.

Source BTCE estimates.

Seat-kilometres travelled for Australia's international task were calculated by dividing total passenger-kilometres travelled by the average passenger load factor.

(21) SKM = TIPKM / LF

where SKM is the total number of international seat-kilometres travelled by aircraft arriving in and departing from Australia (millions), TIPKM is the total number of passenger-kilometres travelled by short-term and long-term travellers arriving in and departing from Australia (millions) and LF is the passenger load factor (expressed as a proportion of total aircraft capacity).

The total number of international passenger-kilometres travelled to and from Australia is equal to the number of passenger-kilometres travelled by short-term travellers divided by α (an estimate of the proportion of the total number of passengers who are short-term travellers).

(22) TIPKM = IPKM / α

where TIPKM is the total number of international passenger-kilometres travelled to and from Australia by short-term and long-term travellers (millions) and IPKM is the total number of international passenger-kilometres travelled to and from Australia by short-term travellers (millions).

International passenger-kilometres travelled to and from Australia by short-term travellers were modelled by summing the number of short-term Australian resident departures and the short-term foreign arrivals multiplied by their respective average distances travelled. The identity was then multiplied by two to account for the return journey.

(23) $IPKM = \{(OUTPASS \times AVKMOUT) + (INPASS \times AVKMIN)\} \times 2$

where IPKM is the total number of international passenger-kilometres travelled to and from Australia by short-term travellers (millions), OUTPASS is the total number of short-term Australian resident departures (millions), AVKMOUT is the average distance travelled by international passengers leaving Australia (kilometres), INPASS is the total number of short-term foreign arrivals in Australia (millions) and AVKMIN is the average distance travelled by international passengers arriving in Australia.

Short-term Australian resident departures were modelled as a function of Australian real gross national expenditure, real outbound airfares, the real trade weighted index lagged four quarters and a dummy variable for the Bicentennial year (1988). The model uses quarterly data and was estimated by using Ordinary Least Squares estimation.

$$(24)\ \ln OUTPASS = -9.38 + 1.36 \ln RGNE - 0.35 \ln ROFARE + 0.13 \ln RTWI(-4) - 0.05\ BIDUM$$

where OUTPASS is the seasonally adjusted number of short-term Australian resident departures (measured in millions), RGNE is Australian real gross national expenditure, ROFARE is the weighted average of real outbound airfares, RTWI(–4) is the real trade weighted index lagged four quarters and BIDUM is a dummy variable for quarters 1, 2 and 3 of 1988 (for the Bicentenary).

Short-term foreign arrivals in Australia were modelled as a function of overseas income levels as measured by the gross domestic product of seven major OECD economies, real inbound airfares lagged four quarters, the real trade weighted index lagged four quarters, and dummy variables for the Bicentennial celebrations (1988) and each quarter to account for seasonality. The model uses quarterly data and was estimated by Cochrane-Orcutt estimation.

$$(25)\ \ln INPASS = 1.44 + 2.79 \ln G7GDP - 0.19 \ln RIFARE(-4) - 0.27 \ln RTWI(-4) + 0.14\ BIDUM + 0.10\ CDUM - 0.15\ D_1 - 0.35\ D_2 - 0.26\ D_3$$

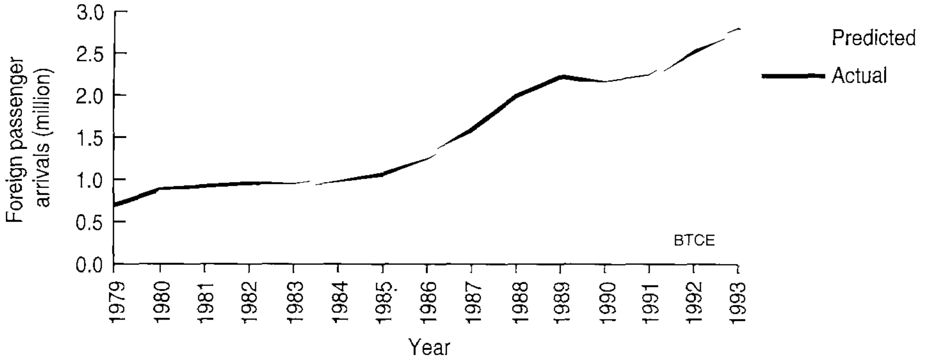
where INPASS is the total number of short-term foreign arrivals (millions), G7GDP is the sum of gross domestic products of seven major OECD economies (the United States, Japan, Germany, France, Italy, the United Kingdom and Canada), RIFARE(–4) is the weighted average of real inbound airfares lagged four quarters, RTWI(–4) is the real trade weighted index lagged four quarters, BIDUM is a dummy variable for quarters 1, 2 and 3 in 1988, CDUM is a dummy variable for decreased airfare prices to Fiji (from 1991Q2 onwards), and D_1, D_2 and D_3 are seasonal dummy variables for quarters 1, 2 and 3 respectively.

Data collected for each of the variables outlined in equations (20) to (25) are detailed in appendix X, table 6.

Quarterly figures were used to model foreign arrivals (INPASS), estimated using the Cochrane–Orcutt procedure over the period 1978Q1 to 1993Q4. Figure 4.5 illustrates the historical (actual) and predicted levels for INPASS (summed over quarters to give annual data).

The coefficient for G7GDP of 2.79 suggests that overseas tourism to Australia is highly responsive to changes in income levels. Higher income levels in other countries should produce an increased affordability of international travel as well as a relatively greater increase in the affordability of long-haul travel in comparison to short-haul travel (BTCE 1991b, pp. 41–42). This should result in a rise in foreign arrivals in Australia.

Lagged airfare levels were included to capture the long lead time presumably required by foreign tourists when planning to visit Australia (BTCE 1991b, p. 42). The coefficient on RIFARE(–4) of –0.19 suggests that foreign tourism is relatively unresponsive to fare changes, but an increase in fares would result in a slightly lower number of tourists. A lag was used for the real trade



Sources BTCE estimates; DTC (1993b and earlier).

Figure 4.5 Actual and predicted levels of foreign passenger arrivals

weighted index (RTWI) for the same reason. The negative coefficient of –0.27 suggests that, as travel to Australia becomes relatively more expensive, passenger numbers will decline.

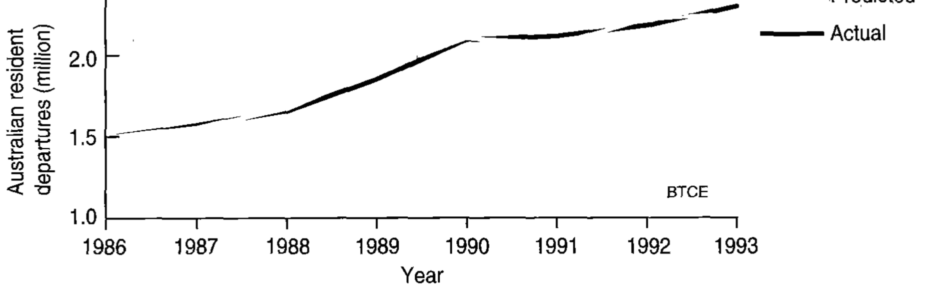
Australian resident (short-term) departures (OUTPASS) is estimated by Ordinary Least Squares estimation using seasonally adjusted quarterly data over the period 1985Q3 to 1993Q4. Figure 4.6 shows the historical (actual) and predicted levels for OUTPASS.

The coefficient of 1.36 for the income variable (RGNE) suggests that, as Australian income levels increase, overseas travel will also increase because it becomes more affordable. The coefficient of –0.35 for the airfare variable (ROFARE) suggests a fairly low but negative response to travel resulting from changes in airfares. The real trade weighted index is a measure of the relative cost to Australian tourists to travel overseas and the small positive coefficient of 0.13 shows a fairly unresponsive effect.

A discussion of some of the variables used in the analysis follows.

Fuel intensity. It is difficult to derive a series for average fleet fuel intensity for international aircraft arriving in and departing from Australia, as data are readily available only for Qantas aircraft. However, a series was derived using historical data on fuel consumption and seat-kilometres travelled, in a manner similar to the derived domestic aviation fuel intensity series. Fuel intensity was derived by dividing the total fuel uplifted by the total seat-kilometres travelled (table 4.11).

Average kilometres. Average kilometres travelled were split into outbound and inbound average kilometres. Ten regions were identified and data on passenger numbers travelling between Australia and the destination region were collated. The average distance flown was calculated by multiplying the



Sources BTCE estimates; BTCE (1994a) Indicators Database.

Figure 4.6 Actual and predicted levels of Australian resident departures

TABLE 4.11 DERIVED FUEL INTENSITY SERIES FOR THE INTERNATIONAL AIRLINE FLEET SERVICING AUSTRALIA

Year	(1) AFC (ML)	(2) SKM (million skm)	(3) TFC (ML) (3)=(1)/0.42	(4) FI (L/SKM) (4)=(3)/(2)
1986	1136.4	59050.9	2705.7	0.046
1987	1200.1	65903.6	2857.4	0.043
1988	1357.3	73175.1	3231.7	0.044
1989	1567.0	85060.6	3730.9	0.044
1990	1711.6	90579.5	4075.2	0.045
1991	1780.6	96385.5	4239.5	0.044
1992	1889.1	99665.0	4497.8	0.045
1993	2042.0	111845.0	4861.9	0.043

Note 1. AFC refers to avtur uplifted in Australia, SKM refers to total seat-kilometres travelled,TFC is total fuel consumed by aircraft arriving in and departing from Australia, and FI is the derived fuel intensity series for international aircraft travelling to and from Australia.

Sources ABARE (pers. comm. 1994); BTCE (1994a) Indicators Database; Apelbaum (1993, p. 113); DTC (1993b and earlier); BTCE estimates.

proportion of total passengers to a particular region by the stage distance, and summing over all regions. Appendix X (tables 7 and 8) details the calculation and results.

The average number of kilometres travelled by both inbound and outbound passengers has been declining. Between 1979 and 1993 the average distance travelled by inbound passengers fell by approximately 26 per cent; for outbound passengers, by approximately 20 per cent. Most of the decline was between the years 1979 and 1981. Since 1981, however, the average distance travelled by inbound passengers has fallen by approximately 10 per cent; and for outbound passengers the average distance travelled has fallen by approximately 2.5 per cent.

OUTPASS. The number of short-term Australian resident departures is a seasonally adjusted series. In 1986, passenger departures totalled approximately 1.5 million, increasing to approximately 2.3 million in 1993 (an increase of 54 per cent).

INPASS. The number of short-term foreign passenger arrivals in Australia grew from approximately 1.26 million in 1986, to approximately 2.79 million in 1993 (an increase of 120 per cent).

α. Alpha is an estimate of the number of international passengers who are short-term travellers. Between 1978 and 1993 the proportion increased: in 1978, 94 per cent of visits were classified as short-term (that is, for a period of less than 12 months); in 1986, 97 per cent; and in 1993, 98 per cent (derived from data contained in BTCE 1988). A trend growth rate is assumed for estimating values of the intervening years.

RGNE. Real gross national expenditure is used as an income variable for Australian residents. As income levels rise, more people will be able to afford to travel, resulting in increased Australian departures. Between 1986 and 1993, RGNE rose by approximately 15 per cent.

Airfares. RIFARE is the aggregated average of real economy and minimum airfares into Australia in Australian dollars (as in BTCE 1991b, p. 89). ROFARE is the aggregated average of real economy and minimum airfares out of Australia (as in BTCE 1991b, p. 89). Generally airfares into and out of Australia have been declining in real terms. It is expected that as real airfares fall the number of passengers travelling will increase.

G7GDP. The G7 gross domestic product is used as an overseas income variable. It is an index of the real gross domestic product for the group of seven major industrial countries of the OECD (Canada, France, Germany, Italy, Japan, the United Kingdom and the United States) (BTCE 1991b, p. 92). It increased by approximately 45 per cent between 1978 and 1993. As overseas income levels increase, it is expected that the number of foreign passengers travelling to Australia will also increase.

RTWI. The real trade weighted index of the Australian dollar is equal to the trade weighted index multiplied by the Australian consumer price index (CPI) (using 1990 as a base year) divided by the OECD CPI. It is expected that as the real trade weighted index increases (that is, prices in Australia increase relative to overseas) there will be fewer foreign arrivals and more Australian departures.

Dummy variables. A number of dummy variables have been used in the modelling process. BIDUM is a dummy variable used for the Bicentennial celebration. It is equal to 1 for 1988Q1, Q2 and Q3, and equal to zero otherwise. CDUM is a dummy variable used to capture the increase in airfares to Fiji. It is equal to 0 prior to 1991Q2, 0.2 in 1991Q2 and 1 thereafter. Seasonal dummy variables have also been included in the model for foreign arrivals as the series has not been adjusted for seasonality. D1 is equal to 1 in the first quarter, D2 is equal to 1 for all second quarters, and D3 is equal to 1 for all third quarters.

Assumptions

For the purposes of projecting aviation turbine fuel uplifted in Australia by international aviation to the year 2015, it was necessary to make a number of assumptions about the independent variables. Table 4.12 summarises the assumptions used.

Overseas income levels (G7GDP) were assumed to increase by 2.8 per cent per annum from 1993 to 1997 and by 3 per cent per annum (BIS Shrapnel 1993, p. 22) thereafter to the year 2015. The assumptions are higher than those assumed by the International Civil Aviation Organisation (ICAO 1992, p. 29) of 2.6 per cent per annum. However, the assumption is fairly conservative when compared to the Boeing forecast of 3.2 per cent growth per year until the year 2000 (Boeing 1994, p. 2) and the Airbus Industrie forecast of 3.3 per cent growth per year until the year 2001 (ICAO 1992).

Inward and outward real airfares were assumed to decline by 1 per cent per year to the year 2015. Boeing predicts an annual decline of approximately 1 per cent until the year 2001. ICAO (1992, p. 30) and Airbus Industrie estimate a 0.5 per cent per annum decline in airfares. The BTR (1992, p. 12) assumes that airfares will decline by 2 per cent per annum to the year 2001.

The real trade weighted index (RTWI) was assumed to grow by 1.8 per cent per year until 1998, fall by 0.8 per cent per year to the year 2003, fall by 0.4 per cent per year to the year 2008 (BIS Shrapnel 1993, p. 54), and remain constant thereafter.

Real Australian GNE was assumed to increase by 3.2 per cent per year to 1998 and by 3.3 per cent per year thereafter (the same assumption as used for RGNF in the domestic model).

TABLE 4.12 INTERNATIONAL AVIATION: PROJECTION ASSUMPTIONS

(per cent change per annum)

Variable	*1993–1998*	*1999–2003*	*2004–2008*	*2009–2015*
Overseas income (G7GDP)	+ 2.8	+ 3.0	+ 3.0	+ 3.0
Real inbound airfares (RIFARE)	–1.0	–1.0	–1.0	–1.0
Real outbound airfares (ROFARE)	–1.0	–1.0	–1.0	–1.0
Real trade weighted index (RTWI)	+ 1.8	–0.8	–0.4	0.0
Real gross national expenditure (RGNE)	+ 3.2	+ 3.3	+ 3.3	+ 3.3
Short-term proportion of travellers (α)	0.0	0.0	0.0	0.0
Average inbound distance (AVKMIN)	0.0	0.0	0.0	0.0
Average outbound distance (AVKMOUT)	0.0	0.0	0.0	0.0

Sources BIS Shrapnel (1993, pp. 22, 54); BTCE estimates.

In the absence of alternative information, the load factor was assumed to increase to 0.8 by the year 2015. As this was an arbitrary assumption, the following section considers a number of scenarios, including changes to the passenger load factor assumption.

The average number of kilometres travelled by an international passenger was assumed to remain constant at the 1993 level: approximately 6557 kilometres for foreign arrivals and approximately 7080 kilometres for Australian resident departures.

It is assumed that long-term and permanent movements will account for 2 per cent of total international passenger numbers. In 1993, 98 per cent of total international passengers travelling to and from Australia were short-term travellers (derived from data contained in BTCE 1988).

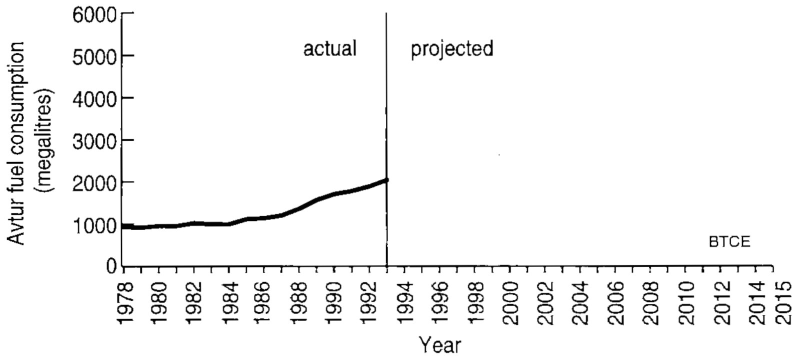
BTCE (1992) calculated the likely improvements to international aircraft fleet fuel efficiency for a number of scenarios. Likely improvements depend upon the rate at which the fleet is replaced. The BTCE (1992, p. 44) estimated improvements in fuel efficiency between 1988 and 2005 to be 28 per cent if aircraft are replaced after 15 years; 17 per cent if replaced after 20 years; and 16 per cent if replaced after 25 years. Using these figures and extending them to the year 2015, the improvements in fuel efficiency between 1993 and 2015 would be 36 per cent for a fleet replaced after 15 years; 22 per cent after 20 years; and 21 per cent after 25 years. Qantas (pers. comm. 1994) suggests that a fuel efficiency improvement of 40 per cent by the year 2015 is unlikely. It was therefore assumed that by 2015 the fuel efficiency of the aircraft fleet would improve by 22 per cent.

A base case projection of fuel consumption for avtur uplifted in Australia can be calculated on the basis of these assumptions. Appendix X, table 6, gives the projected levels of each of the variables to the year 2014–15.

Projection results and scenarios

Using the BTCE model and the assumptions made about the independent variables detailed above, avtur consumption by international aviation was projected to increase from 2042 megalitres in 1992–93 to 3510 megalitres in 2004–05 and to 5984 megalitres in 2014–15. Figure 4.7 graphs the projected levels of international avtur uplifted in Australia.

Using the assumptions in table 4.12, foreign arrivals are projected to increase from 2.79 million in 1992–93 to 7.45 million in 2004–05 and further to 17.65 million in 2014–15. Similarly, Australian departures are projected to increase from 2.3 million in 1992–93 to 3.83 million in 2004–05 and further to 6.2 million in 2014–15. In seat-kilometres travelled, this adds up to a overall increase of approximately 276 per cent between 1992–93 and 2014–15.



Sources ABARE (pers. comm. 1994); BTCE estimates.

Figure 4.7 Actual and projected levels of international aviation turbine fuel uplifted in Australia

TABLE 4.13 SCENARIOS FOR INTERNATIONAL AVIATION TURBINE FUEL UPLIFTED IN AUSTRALIA

(megalitres)

Fuel efficiency improvement by 2014–15 (per cent over 1992–93)	*Load factor in the year 2014–15* 0.75	0.8	0.85
15	6 956	6 521	6 137
22	6 383	5 984	5 632
30	5 728	5 370	5 054
36	5 237	4 910	4 621

Note 1. Base case assumption is a load factor of 0.8 and a fuel efficiency improvement of 22 per cent.

Source BTCE estimates.

TABLE 4.14 SCENARIOS FOR INTERNATIONAL SEAT-KILOMETRES TRAVELLED TO AND FROM AUSTRALIA (TSKM)

(million kilometres)

Decline in airfares per annum	*Load factor in the year 2014–15* 0.75	0.8[a]	0.85
0.5 per cent	423 794	397 307	373 936
1.0 per cent	434 320	407 175	383 224
1.3 per cent	440 801	413 251	388 942

Note 1. Base case assumption is a load factor of 0.8 and a decline in airfares by 1 per cent.

Source BTCE estimates.

Tables 4.13 and 4.14 demonstrate the effect of changing the assumptions (about fuel efficiency improvements, load factors and airfares) on fuel consumption and seat-kilometres travelled. As fuel efficiency improves and/or the load factor increases, fuel consumption will fall.

Projected emissions from international aviation

Projected levels of greenhouse gas emissions can be calculated from the projections of international avtur use.

Fuel consumption data were converted from megalitres consumed to megajoules of energy consumed, by multiplying litres consumed by the relevant energy density conversion factor. For avtur, the energy density is 36.8 megajoules per litre (Bush et al. 1993 p. 52). Megajoules consumed were multiplied by the relevant emissions conversion factor (outlined in table 4.2) to obtain emission levels for each of the greenhouse gases.

Carbon dioxide equivalent emission levels for international aircraft using fuel uplifted from Australia are projected to increase by a total of approximately 193 per cent between 1992–93 and 2014–15. Appendix X, table 9, reports the projected levels of each of the greenhouse gases for each year up to the year 2014–15.

Table 4.15 summarises different scenarios and their effects on carbon dioxide equivalent emission levels.

Figure 4.8 graphs carbon dioxide equivalent emission levels for international aviation fuel uplifted in Australia.

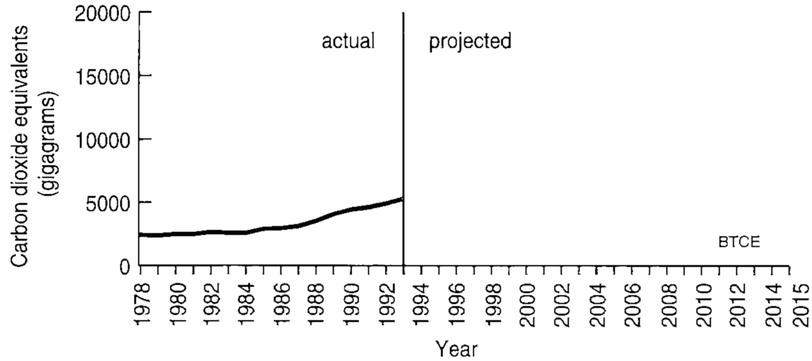
TABLE 4.15 SCENARIOS FOR CARBON DIOXIDE EQUIVALENT EMISSIONS FOR INTERNATIONAL AIRCRAFT UPLIFTING FUEL IN AUSTRALIA

(gigagrams)

	Load factor in the year 2014–15		
Fuel efficiency improvement by 2014–15 (per cent over 1992–93)	*0.75*	*0.8*	*0.85*
15	18 075	16 945	15 947
22	16 586	15 550	14 635
30	14 884	13 954	13 133
36	13 608	12 759	12 008

Note 1. Base case assumption is a load factor of 0.8 and a fuel efficiency improvement of 22 per cent.

Source BTCE estimates.



Source BTCE estimates.

Figure 4.8 Carbon dioxide equivalent emission levels for international aircraft uplifting fuel in Australia

CONCLUSION

The BTCE model specifications are fairly simple yet incorporate the major determinants of fuel use by domestic and international aviation.

The BTCE projects that fuel consumption and thus greenhouse gas emissions will increase considerably by the year 2014–15. Figure 4.9 illustrates the actual and projected levels of aviation turbine fuel consumption in Australia.

Aviation turbine fuel use is projected to increase from a total of 3684 megalitres in 1992–93 to 4646 megalitres in 1999–2000, 5878 megalitres in the year 2004–05 and 9419 megalitres in the year 2014–15, using the BTCE model specification and assumptions. Bush et al. (1993 p. 152) project fuel sales to be 5173 megalitres in 1999–2000 and 6401 megalitres in the year 2004–05. The Australian Institute of Petroleum (AIP) forecasts fuel sales to be 4932 megalitres in 1999–2000 (AIP 1992, p. 19). Figure 4.10 graphs the projections.

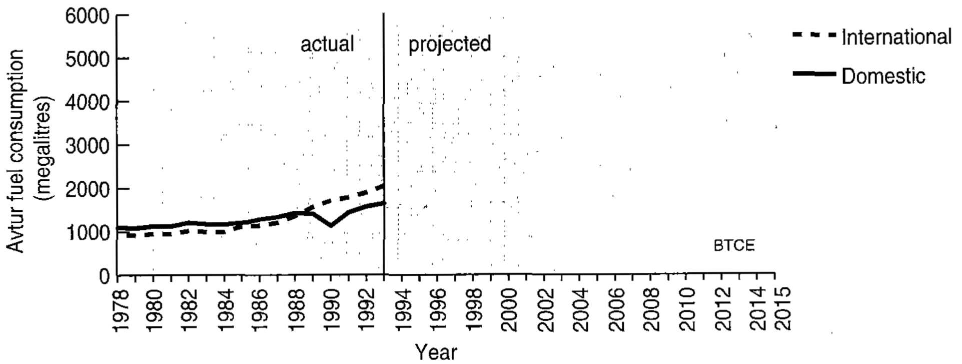
Aviation gasoline use has been projected to increase from 106 megalitres in 1992–93 to 116 megalitres in the year 2004–05 and to increase further to 139 megalitres in the year 2014–15.

The total aviation sector is projected to increase greenhouse gas emissions between 1993 and 2015 by approximately 150 per cent.

It should be noted that it was necessary to derive a number of variables used in the analysis (for example, fuel intensity), due to lack of data. The values of these variables may therefore not be very accurate, and may be useful only as an indication of how the series are changing over time.

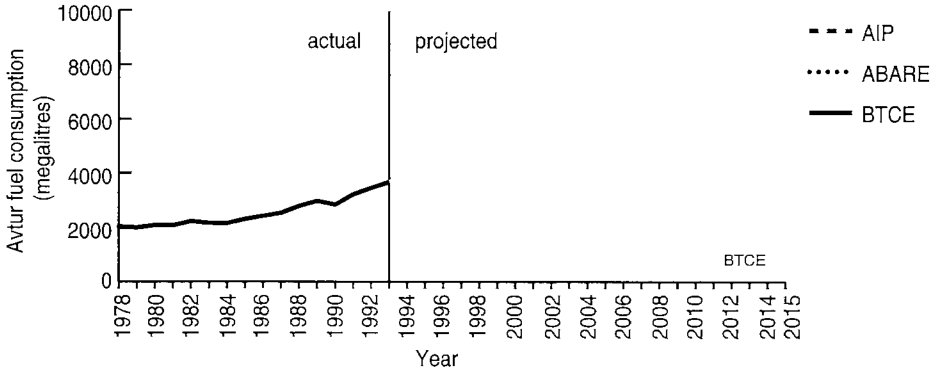
The BTCE models rely heavily on the assumptions made. Bush et al. (1993, pp. 23, 63) assumed a higher growth rate for income and for passenger load factors than did the BTCE. Higher incomes lead to increased demand for travel, resulting in higher fuel consumption. Increased load factors and larger aircraft, however, will partially counteract the increase in fuel consumption, because fewer aircraft will be needed to undertake the task. Bush et al. (1993) do not explicitly allow for improvements in the fuel efficiency of the aircraft fleet (unlike the BTCE model). Overall, the BTCE model projects slightly less fuel consumed than do Bush et al (1993).

The BTCE models are derived for use in long-term projections and therefore do not include all variables which may be relevant in the short-term. For instance, passengers arriving in the year 2000 for the Olympic Games will not be included in the models, because such shocks are better estimated using short-term or medium-term models, and then adjusting the results of the long-term projections. Due to the long-term nature of the projections, the BTCE models were derived on an aggregated basis and do not consider specific origin–destination pairs. For example, tourism growth to and from Asian countries has not been modelled separately. For these reasons, the BTCE models should be used only for long-term projections and on an aggregated level, rather than for specific origin–destination pairs.



Sources ABARE (pers. comm. 1994); BTCE estimates.

Figure 4.9 Aviation turbine fuel consumption in Australia



Sources BTCE estimates; ABARE (pers. comm. 1994); Bush et al. (1993, p. 152); AIP (1992, p. 19).

Figure 4.10 Aviation turbine fuel consumption comparison

CHAPTER 5 SHIPPING

INTRODUCTION

Shipping has been an important mode of transport throughout Australia's history. In the nineteenth century, sea transport offered the readiest means of transport for passengers and freight between coastal cities. Early patterns of colonial railway development did not reduce the need for sea transport—railways radiated outwards into the hinterland from coastal cities, rather than linking them. Until recent times, when air travel became an affordable mode of transport to many people, the main means of entering or leaving Australia was by sea.

Australia produces and exports large quantities of bulk commodities such as iron ore, alumina, coal and grain. Large tonnages, coupled with large distances to overseas destinations, allow economies of scale that make shipping a cost-effective mode of freight transport and suggest that shipping will continue to play a role in the Australian transport task well into the future.

A major issue in modelling greenhouse gas emissions by international shipping is the attribution of bunker fuel use among the various countries. According to Intergovernmental Panel on Climate Change (IPCC) guidelines, the attribution problem is still subject to debate. To ensure that all fuel use is accounted for, the IPCC recommends that *countries should record separately the quantities of fuel uplifted by international ships* (IPCC/OECD 1994, p. 1.11). In accordance with this recommendation, the BTCE has modelled separately fuel uplifted in Australia by international and coastal shipping.

INTERNATIONAL SHIPPING

Fuel is more expensive in Australia than in other countries, and only a small proportion of the fuel required for the international shipping task is therefore uplifted in Australia (about 15 per cent). The approach adopted by the BTCE in modelling the uplift of bunker fuel in Australia for international shipping involves two parts. A model of the total international shipping task and consequent total fuel use is the basic model. Once total fuel use has been modelled, the fraction of this total fuel that is uplifted in Australia is estimated. Both parts of the modelling procedure are documented below, starting with the model of the fraction of fuel uplifted in Australia.

Modelling the fraction of total fuel for international shipping uplifted in Australia

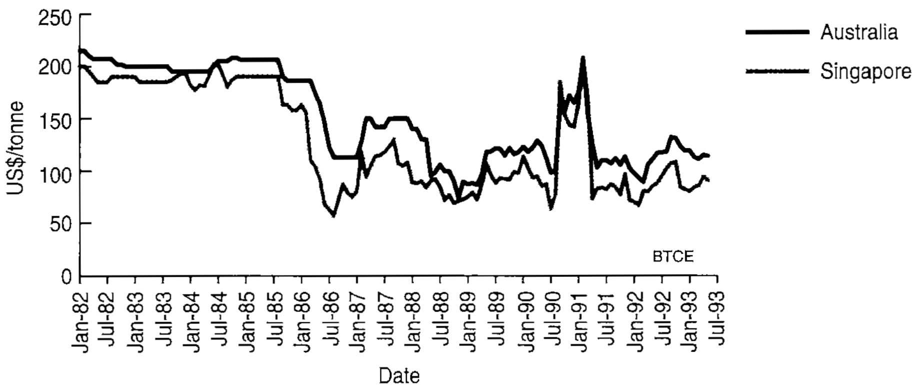
The fraction of the total bunker fuel needed for the international shipping task into and out of Australia is dependent on what might be termed the 'mix effect'. Non-bulk ships are more likely to uplift fuel in Australia than are bulk ships. Large bulk ships are generally company ships on regular runs between specified ports. Refuelling is generally arranged at the least expensive port (usually overseas). Liner ships, on the other hand, have more changeable port call schedules and are therefore obliged to refuel in Australia more often (because of port call logistics). If there is an increase in the proportion of non-bulk ships undertaking Australia's international shipping task, it is likely that the proportion of fuel uplifted in Australia will increase.

The operation of the mix effect is heavily influenced by changes in Australia's exchange rate. If the value of the Australian dollar falls in relation to other currencies, imports into Australia become relatively more expensive, leading to a fall in the level of non-bulk imports and in the number of liner ships visiting Australia. As a result, the proportion of fuel uplifted in Australia would be expected to decrease.

Relative prices of bunker fuel do not affect the proportion of fuel uplifted in Australia. Figure 5.1 shows that bunker prices (in US dollars) in Australia and Singapore follow each other closely.

The theoretically relevant exchange rate in the operation of the mix effect is an 'import weighted' exchange rate. This is because bulk exports (which comprise around 95 per cent of exports) from Australia are quite often under long-term contract and are relatively unresponsive to short-term changes in exchange rates. Therefore, a theoretical model should link the fraction of fuel uplifted in Australia with an import weighted exchange rate. Because an exchange rate weighted solely by import shares is not readily available, the modelling has been done using the US dollar to Australian dollar exchange rate as a proxy.

In the fuel consumption model outlined in equation (1), the fraction of fuel uplifted in Australia has been regressed against the real exchange rate between Australia and the United States (quoted in US dollars per Australian dollar).



Note Australia refers to the scheduled contract price of ships' bunkers in Fremantle. Singapore refers to the scheduled contract price of ships' bunkers in Singapore. All prices are given in US$/t.

Source Petroleum Press (1993 and earlier issues).

Figure 5.1 Price of bunker fuel in Australia and in Singapore

(1) $\ln(\mathrm{tc/tft}) = -2.219 + 1.054 \ln \mathrm{XRATE}$

where tc is the amount of fuel uplifted *in Australia* by international ships (megalitres), tft is the total fuel required to undertake the international shipping task to and from Australia (megalitres) and XRATE is the real exchange rate between Australia and the United States (US dollars per Australian dollar). As expected, the positive coefficient for XRATE indicates that as the exchange rate of the Australian dollar against the US dollar rises, so does the proportion of fuel uplifted in Australia. Because the equation is estimated in double log form, the 1.054 coefficient on the exchange rate indicates that a 10 per cent devaluation of the Australian dollar against the US dollar would lead to about a 10 per cent fall in the proportion of fuel uplifted in Australia. Detailed diagnostics for the equation are given later in the chapter.

Modelling total fuel used in trade to and from Australia

To estimate the model defined in equation (1), it was necessary to calculate tft, the amount of fuel required to complete Australia's international shipping task. Australia's international shipping task was split into three categories: the inward freight task, fuel task (in), the outward freight task, fuel task (out), and the passenger task, fuel task (pass). The amount of fuel required to complete each category was calculated as shown in equations (2) to (5), where FI refers to fuel intensity:

$$\text{(2)}\quad \underset{\text{(litres)}}{\text{fuel task(in)}} = \underset{\text{(km)}}{\text{average distance(in)}} \times \Big[\underset{\text{(litres / tkm)}}{FI_{liner}} \times \underset{\text{(tonnes)}}{\text{non - bulk imports}} + \underset{\text{(litres / tkm)}}{FI_{dry\ bulk\ ship}} \times \underset{\text{(tonnes)}}{\text{bulk imports}} \Big]$$

$$\text{(3)}\quad \underset{\text{(litres)}}{\text{fuel task(out)}} = \underset{\text{(km)}}{\text{average distance(out)}} \times \Big[\underset{\text{(litres / tkm)}}{FI_{liner}} \times \underset{\text{(tonnes)}}{\text{non - bulk exports}} + \underset{\text{(litres / tkm)}}{FI_{dry\ bulk\ ship}} \times \underset{\text{(tonnes)}}{\text{bulk exports}} \Big]$$

$$\text{(4)}\quad \underset{\text{(litres)}}{\text{fuel task(pass)}} = \underset{\text{(km)}}{\text{average distance(pass)}} \times \underset{\text{(litres / tkm)}}{FI_{passenger\ ship}} \times \underset{\text{(tonnes)}}{\text{passengers}}$$

$$\text{(5)}\quad \underset{\text{(litres)}}{\text{total fuel task}} = \underset{\text{(litres)}}{\text{fuel task (in)}} + \underset{\text{(litres)}}{\text{fuel task (out)}} + \underset{\text{(litres)}}{\text{fuel task (pass)}}$$

In order to use these identities in forecasting, models had to be derived for bulk exports, non-bulk imports, bulk imports and non-bulk exports. Simple assumptions were used to project the passenger task, so no explanatory equations were required.

Projection models for bulk and non-bulk freight entering and leaving Australia were obtained by estimating the series of regression equations (6) to (9). All are estimated using annual data from 1982–83 to 1992–93. A summary of the regression results for all models is given in table 5.1.

Tonnages of bulk exports were re-estimated using earlier BTCE (1992, p. 18) work and are described by equation (6):

(6) bulk exports = 11780.0479 + 1.0849 EXP

Bulk exports (measured in thousand tonnes) is explained by EXP, the sum of six major bulk exports: iron, coal, alumina, oil/petroleum products, grain and sugar (measured in thousand tonnes).

Non-bulk imports were modelled using gross national expenditure and capacity utilisation as the explanatory variables.

(7) ln (non-bulk imports) = 7.913 + 0.622 ln SGNE85 + 0.006 CAPCON

where non-bulk imports is the level of non-bulk imports in thousand tonnes, SGNE85 is real Australian seasonally adjusted gross national expenditure in 1984–85 prices and CAPCON is a capacity utilisation dummy for the Australian economy. CAPCON is equal to 1 when capacity utilisation in

TABLE 5.1 RESULTS OF THE INTERNATIONAL SHIPPING MODEL

Dependent variable	*Diagnostics*	*Independent variables*	*Coefficient*	*Standard error*
ln(tc/tft)	Adj. $R^2 = 0.988$	constant	–2.219	0.061
	DH = –0.278	lnXRATE	1.054	0.030
	Period: 1982–83 to 1992–93			
	CORC, Rho = 0.682			
bulk exports	Adj. $R^2 = 0.989$	constant	11780.047	8222
	DW = 1.633	EXP	1.0849	0.037
	Period: 1982–83 to 1992–93			
	OLS			
ln(non-bulk imports)	Adj. $R^2 = 0.762$	constant	7.913	2.515
	DW = 1.8	lnSGNE85	0.622	0.204
	Period: 1982–83 to 1992–93	CAPCON	0.006	0.002
	OLS			
bulk imports	Adj. $R^2 = 0.619$	constant	9966.4	4192.85
	DH = 1.553	IMP	1.7248	0.667
	Period: 1982–83 to 1992–93			
	CORC, Rho = 0.355			
ln(non-bulk exports)	Adj. $R^2 = 0.692$	constant	–4.482	4.122
	DW = 1.965	lnG7GDP	1.213	0.300
	Period: 1982–83 to 1992 –93	lnRTWI	–0.390	0.285
	OLS			

Notes 1. Adj R^2 refers to the adjusted R^2.
2. DW refers to the Durbin–Watson statistic and DH refers to Durbin's h statistic.
3. Period refers to the estimation period. All models were estimated on the basis of annual data.
4. OLS denotes Ordinary Least Squares estimation, and the CORC denotes Cochrane–Orcutt estimation procedure.

Source BTCE estimates.

Australia is 80 per cent or above and is equal to zero otherwise. A detailed description of CAPCON and capacity utilisation is given in the next section.

The regression equation for bulk imports was constructed in a similar manner to the bulk exports equation. The tonnage of bulk imports is regressed on the sum of two major bulk imports: fuel and chemicals (measured in millions of dollars). The model is outlined in equation (8).

(8) bulk imports = 9966.4 + 1.7248 IMP

where bulk imports is the level of bulk imports in 1000 tonnes and IMP is the sum of the values of the tonnages of fuel and chemicals imported (in millions of dollars).

Non-bulk exports are considered to be determined by the income of the Group of Seven (G7) major OECD economies and the real trade weighted index (an index of exchange rates between Australia and its major trading partners). G7GDP was chosen because it is more readily available both historically and for future projections than a trade weighted measure of overseas income. Although G7GDP is calculated from the gross domestic products of seven countries, it is considered to be a measure of world GDP because, when GDP is high in the G7 countries, it is also high in non-G7 countries as a result of flow-on effects. For instance, when GDP is high in the G7 countries, more goods are demanded from non-G7 countries which then increases the GDP of non-G7 countries. This implies that G7GDP is an appropriate measure for the income of Australia's trading partners, despite a significant portion of Australia's trade being undertaken with non-G7 countries.

(9) $\ln(\text{non-bulk exports}) = -4.482 + 1.213 \ln \text{G7GDP} - 0.390 \ln \text{RTWI}$

where non-bulk exports is the level of non-bulk exports (thousand tonnes), G7GDP is an index of real gross domestic product in the G7 countries and RTWI is Australia's real trade weighted index.

Passenger numbers were taken from Australian Bureau of Statistics data (ABS 1993c and earlier issues) and converted into tonnes on the assumption that one passenger and their luggage weigh about 90 kilograms (Apelbaum, 1993, p. 184).

The average distance variables used in equations (2) to (4) represent the length of a typical voyage in any given year. Historical values for the average distances for inward and outward freight were calculated by weighting a series of representative distances by the freight tonnages to or from eight regions as shown in equations (10) and (11). For the passenger task, average distances were weighted by passenger numbers and regions that differ slightly from those used for the freight task. The average distance for the passenger task was calculated by equation (12). These identities were then used in projecting changes in regional shares in Australia's international sea traffic.

(10) $$\text{average distance (out)} = \frac{\sum_{a} \text{tonnes of freight to region a} \times \text{distance to region a}}{\text{total tonnes of freight from Australia}}$$

(11) average distance (in) = $\dfrac{\sum_{a} \text{tonnes of freight from region a} \times \text{distance to region a}}{\text{total tonnes of freight to Australia}}$

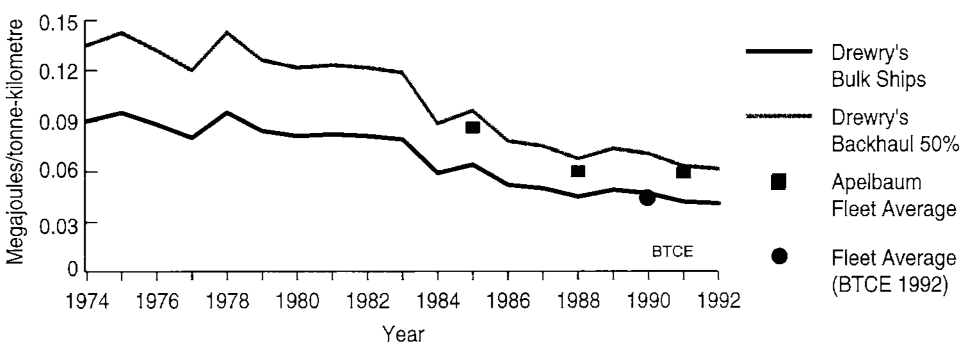
(12) average distance (pass) = $\dfrac{\sum_{a} \text{passengers to / from region a} \times \text{distance to region a}}{\text{total passengers from / to Australia}}$

Fuel intensity variables have been split into the categories of bulk ships, liner ships and passenger ships.

Using data on deadweight tonnage (DWT), speed, fuel consumption and voyage of reported dry cargo trip charters (Drewry Shipping Consultants 1993 and earlier issues), an average annual fuel intensity (measured in megajoules/tonne-kilometre) for bulk ships calling into Australia was calculated.

Figure 5.2 compares the fuel intensity time series with several alternative fuel intensity figures for international shipping. The *Fleet Average* was calculated from a fuel consumption figure estimated by the BTCE (1992, p. 71). It represents an average fuel consumption for the entire (bulk and non-bulk) Australian flagged international fleet. Apelbaum's figures are for the fuel intensity of ships undertaking Australia's shipping task.

Fuel intensities were calculated using two different methods. The first method used fuel consumption figures in conjunction with information about the ship's speed and DWT. This method was used to calculate the Drewry's fuel intensity time series and the 1990 Australian flagged fleet average fuel intensity (BTCE 1992, p. 71). The second method derived fuel intensities from



Sources Drewry Shipping Consultants (1993 and earlier issues); BTCE (1992, p. 71); Apelbaum (1993, p. 119).

Figure 5.2 Fuel intensities in international shipping

estimates of fuel uplifted in Australia and overseas and the Australian shipping task (as in Apelbaum 1993, p. 119).

As figure 5.2 illustrates, there is a significant difference in the results obtained from each method. The apparent discrepancy is a result of the backhauling problem where ships may be forced to travel empty for part of the voyage. This problem is prevalent in the bulk shipping industry where bulk goods are transported overseas and the ships return empty. In calculating the fuel intensity from fuel consumption figures, it was assumed that ships carried freight equal to 90 per cent of their DWT. If a ship travels with freight at 90 per cent of DWT for half the journey and empty for the rest of the journey, the average quantity of freight carried on the voyage is equivalent to 45 per cent of DWT. In figure 5.2, *Backhaul = 50%* has been constructed using the Drewry's Bulk Ships series on the assumption that 50 per cent of ships entering Australia experience a backhaul problem and arrive empty. As the *Backhaul = 50%* series (figure 5.2) indicates, if it is assumed that 50 per cent of bulk ships experience backhauling problems, then the fuel intensity time series almost coincides with Apelbaum's (1993, p. 119) findings. This suggests that the Drewry's (1993 and earlier issues) data under the assumption of 50 per cent backhaul provide an acceptable time series to use to represent the fuel intensity of bulk ships.

Very little data are available on the fuel intensity of liner ships. BTCE (1992, p. 71) calculated the average fuel consumption per day, DWT and speed for the 1990 Australian flagged international liner ship fleet. A time series for liner ships was constructed by applying the percentage changes in fuel efficiencies from the Drewry's bulk ships time series (under the assumption of 50 per cent backhaul) to the 1990 fuel intensity for Australian flagged international liner ships. For instance, from 1990 to 1991 there was a 4.1 per cent improvement in the fuel efficiency of dry bulk ships. In constructing the fuel intensity time series for liner ships, it was therefore assumed that between 1990 and 1991, there was also a 4.1 per cent decline in fuel intensity. In the absence of further data, this was considered to be a plausible assumption as it captures the long-term trend towards less fuel intense ships, and reductions in the fuel intensity of liner ships are likely to be of a similar magnitude to those for bulk ships.

It was assumed that the fuel intensity of passenger ships remained constant from 1983 to 1993. This assumption was adopted because of a lack of data on the fuel intensity of passenger ships and, as the passenger task is small in comparison to the freight task, the inaccuracies will be negligible.

Applying the time series for fuel intensities, freight tasks, passenger task and distances to equations (2) to (4), the fuel tasks were calculated. These were then substituted into equation (5) to construct a time series for the total amount of fuel required to complete Australia's international shipping task. From the calculation of the total fuel task and using data on exchange rates and the fuel uplifted in Australia, the model defined in equation (1) was estimated to calculate the proportion of fuel uplifted in Australia.

The relationship between the estimated and actual values of (tc/tft) from 1983 to 1993 is shown in figure 5.3. The correlation of the two values is close, with an adjusted R^2 of 0.988.

Variables used

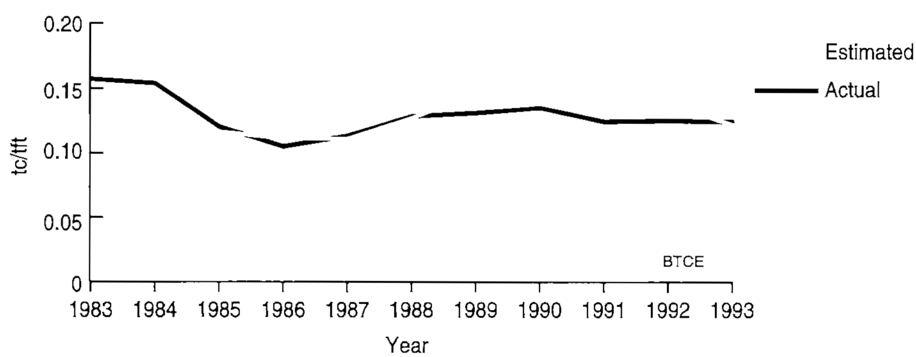
There are a number of variables included in equations (1) to (9) whose inclusion, for various reasons, may not be readily apparent.

G7GDP. G7GDP is an index of the gross domestic products of the Group of Seven major industrialised countries (the United States, Canada, the United Kingdom, Germany, Italy, France and Japan). G7GDP is included in the model for non-bulk exports to capture the effect of overseas economic activity on the level of non-bulk exports. As G7GDP rises, the economies of the G7 countries are assumed to require increased amounts of raw materials. Australian non-bulk commodity exports should increase as a result. The coefficient of G7GDP can be expected to be positive as a result.

RTWI. The real trade weighted index is calculated as:

(13) $\quad \text{RTWI} = \text{TWI} \times (\text{CPI}/\text{G7CPI})$

where RTWI is Australia's real trade weighted index, TWI is Australia's trade weighted index, CPI is Australia's consumer price index and G7CPI is the average of the consumer price indexes in the G7 countries. RTWI is included



Note (tc/tft) is the proportion of fuel required to complete Australia's international shipping task that is uplifted in Australia.

Source BTCE estimates.

Figure 5.3 Actual and estimated proportion of fuel uplifted in Australia

to capture the effect of exchange rates on the level of non-bulk exports. When the RTWI falls, Australian exports become cheaper overseas and demand increases. RTWI can therefore be expected to have a negative coefficient in the non-bulk exports model.

SGNE85. Seasonally adjusted gross national expenditure, measured in 1984–85 prices, is a measure of the level of spending in Australia. When SGNE85 rises, Australians are spending more and hence demanding more goods. The demand for imports will rise as a result of the increased demand in the Australian economy. The coefficient on non-bulk imports is therefore expected to be positive.

CAPCON. CAPCON is a dummy included to capture the effect of the Australian economy reaching a capacity constraint in the quantity of non-bulk imports. Without including CAPCON in the non-bulk imports model, there are periods when the model would underpredict the level of non-bulk imports. CAPCON is based on Australian Chamber of Commerce and Industry (ACCI) and Westpac Banking Corporation (WBC) data on capacity utilisation (ACCI/WBC, 1994 and earlier issues). Capacity utilisation is a survey-based measure in which the number of manufacturers operating below normal capacity is subtracted from the number of manufacturers working above normal capacity. In theory, when levels of capacity utilisation are high, the economy faces difficulties in meeting demand, and imports rise as a result. During the periods in which the non-bulk imports model was underpredicting, it was observed that levels of capacity utilisation were in excess of 80 per cent. It was therefore reasonable to assume that when capacity utilisation reaches 80 per cent, the economy finds it difficult to meet demand. This finding led to CAPCON being assigned a value of 1 when capacity utilisation in Australia is 80 per cent or above and a value of zero when capacity utilisation is below 80 per cent.

Assumptions

The projection of total fuel uplifted in Australia by international ships was calculated in three stages. First, projections of the explanatory variables in equations (6) to (9) were substituted into the equations used to project future tonnages of bulk and non-bulk exports and imports. Second, the projections of bulk and non-bulk exports and imports, along with projections of average distance, fuel intensity and passengers, were substituted into equations (2) to (5) to obtain a projection for the total fuel task. Third, by rearranging equation (1) and substituting in projections of the total fuel task and Australian–United States exchange rate, a projection of the total fuel uplifted in Australia by international ships was estimated.

For some variables, projections are not obtained through modelling, and assumptions were made regarding their future behaviour. The following is a list of these variables and the relevant assumptions.

EXP. EXP is the sum of the tonnages of six major bulk exports. The EXP projection was calculated from projections of the six major bulk exports. The projections of the bulk exports for 1994 to 1999 were taken from ABARE (1993a). From 2000 to 2015, the ABARE trend is continued. The bulk exports projections are summarised in more detail below.

Iron ore:	1994–1999, ABARE (1993a, p. 525) projections for exports of iron ore. 2000–2015, an increase of 2 200 thousand tonnes per year (continuation of ABARE trend).
Coal:	1994–1999, ABARE (1993a, p. 509) projection for exports of coal. 2000–2015, an increase of 5 560 thousand tonnes per year (continuation of ABARE trend).
Alumina:	1994–1999, ABARE (1993a, p. 520) projection for exports of alumina. 2000–2015, an increase of 154 thousand tonnes per year (continuation of ABARE trend).
Oil/petroleum:	1994–1999, ABARE (1993a, p. 515) projections for exports of crude oil, LPG, petroleum products and liquefied natural gas (LNG). 2000–2015, a decrease of 2.16 thousand tonnes per year. This is derived by taking the ABARE trend from 1996–1999. There is a significant increase in the exports between 1994 and 1995 as growth in LNG exports will outweigh the reduction in exports of other forms of oil and petroleum. In 1996, LNG processing plants will be operating at capacity and exports will fall as the level of crude exports falls.
Coarse grain:	(comprised of the export tonnages of oats, wheat and barley) 1994–1999, ABARE (1993a, p. 484) projects Australia's production of wheat. To obtain a projection of export tonnages, it is necessary to make an assumption regarding the proportion of Australia's total production which is exported. As the proportion varies significantly from year to year, an average of the last 10 years was calculated using the level of wheat exports (ABARE 1993b, p. 93): a proportion of 0.798. The ABARE

	projections for oats and barley exports are included with sorghum, triticale and maize. Past data are available on the tonnages of each of these grains exported (ABARE 1993b, p. 106–109). By taking a 10-year average for each grain's share of the total of coarse grain exports and applying it to the projection of grain exports, a projection of oats and barley exports was derived. 2000–2015, an increase of 372.63 thousand tonnes per year. (1994–1999 trend continued).
Sugar:	1994–1999, ABARE (1993a, p. 492) projection for exports of sugar. 2000–2015, an increase of 122.4 thousand tonnes per year (continuation of ABARE trend).

SGNE85. According to BIS Shrapnel (1993, p. 138), seasonally adjusted gross national expenditure in 1984–85 prices can be assumed to increase by 3.2 per cent per year to 1998 and 3.3 per cent per year from 1999 to 2008. Beyond 2008, SGNE85 is assumed to increase by 3.3 per cent per year.

CAPCON. Capacity utilisation will exceed 80 per cent only in periods of exceptional demand. Because it is difficult to make long-term predictions of when periods of exceptional demand will occur, it was assumed that the economy would not reach its capacity constraint. Capacity utilisation was therefore assumed to remain below 80 per cent from 1993 to 2015 and hence CAPCON will be equal to zero over the entire projection period.

IMP. IMP is the sum of the two major bulk imports: fuel and chemicals. The quantities of fuel and chemicals imported between 1983 and 1992 both exhibit upward trends. As there are no projections available for the quantities of fuel and chemicals imported, the 1983 to 1992 trends were assumed to continue to 2015. Imports of fuels were assumed to grow by $196 million per year and imports of chemicals were assumed to grow by $378 million per year.

G7GDP. G7GDP was assumed to grow by 2.8 per cent per year from 1993 to 1997 and by 3 per cent per year from 1998 to 2015 (BIS Shrapnel, 1993, p. 22).

RTWI. The real trade weighted index (RTWI) was assumed to increase by 1.8 per cent per year from 1994 to 1998, decrease by 0.8 per cent per year from 1999 to 2003, decrease by 0.4 per cent per year from 2004 to 2008 (BIS–Shrapnel, 1993, p. 54) and not change from 2009 to 2015.

Average distance. The average distance in and out of Australia also changes over time as Australian markets change, and thus a projection of average distance is required. These projections were formulated in three stages. Firstly, the past growth rates for the four categories of bulk and non-bulk exports and imports were estimated. Secondly, these rates were applied to the 1992 tonnages to obtain an estimate for the tonnages to and from each region for the years 1993–2015. Thirdly, the sum of these estimates were scaled to equate the year 2015 tonnages to the regression tonnages. The scaling factor was then applied to the remainder of the projections. The rates at which the tonnages to and from Australia are expected to grow are listed in table 5.2.

Fuel intensity. Between 1974 and 1992, the fuel intensities for bulk and liner ships decreased on average by 1.02 per cent per year. Fuel intensities for bulk and liner ships are assumed to decrease by 1.02 per cent per year until 2015. The fuel intensity of a passenger ship was previously assumed to remain constant from 1983 to 1993. This assumption was extended to 2015 because the passenger task represents a small proportion of overall shipping and thus any inaccuracies will be negligible.

Passenger numbers. The passenger task has remained relatively stable over the past seven years and, consequently, the average distance and the passenger numbers are assumed to remain constant.

XRATE. There are no published long-term projections for the exchange rate between Australia and the United States. If the relativities between the US dollar and other currencies are maintained, then the Australian dollar–US dollar exchange rate will behave in a similar manner to the Australian real

TABLE 5.2 PROJECTED EXPORT AND IMPORT GROWTH RATES BY REGION, 1993–2015

(per cent per year)

Region	*Bulk exports*	*Bulk imports*	*Non-bulk exports*	*Non-bulk imports*
Europe	1.2	0[a]	1.7	0.5
East Asia	2.3	2.4	3.8	2.2
North America	1.4	3.4	1.4	1.2
South America	2.0	3.9	2.0	2.2
Africa	0.4	0.8	0.4	0.5
Other Asia	2.8[b]	3.0	1.5	2.9
Local	1.1	0.8	1.5	1.2

a. Bulk imports from Europe are assumed to remain constant at 1 million tonnes.

b. The growth rates for bulk exports to Other Asia are 4.4 per cent per year from 1993 to 1997, 3.1 per cent per year from 1998 to 2002 and 2.2 per cent per year from 2003 to 2015.

Notes 1. East Asia is comprised of China, Hong Kong, Macau, Philippines, Taiwan, Japan Democratic People's Republic of Korea, Republic of Korea, Mongolia and the eastern ports of USSR.

2. Local is New Zealand, Papua New Guinea and the Pacific Islands.

Source BTCE estimates.

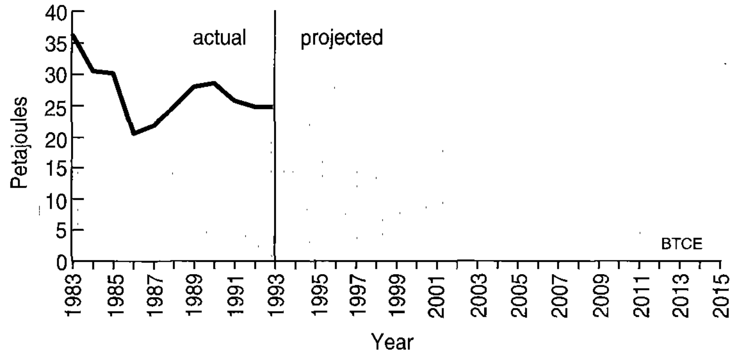
trade weighted index. Given the long-term nature of the projections, the BTCE therefore assumes that changes in XRATE will follow RTWI movements (increase by 1.8 per cent per year from 1994 to 1998, decrease by 0.8 per cent per year from 1999 to 2003, decrease by 0.4 per cent from 2004 to 2008 and not change from 2009 to 2015).

Fuel consumption and emission projections

As figure 5.4 shows, the total amount of fuel uplifted in Australia by international ships is expected to remain relatively constant. Over the projection period, the average growth rate is 0.7 per cent per year.

To convert fuel consumption to greenhouse gas emissions, the total fuel consumption has to be divided into the different types of fuel. Three types of fuel are used in international shipping: industrial diesel fuel (IDF), automotive diesel oil (ADO) and fuel oil (FO). The proportions of each fuel type have remained relatively constant over time. In addition, ABARE (S. Bush, pers. comm. 2 March 1994), which projects the uplift of ships' bunkers by fuel type to 1999, predicts that the proportions will remain relatively constant. The projections for the amount of fuel uplifted in Australia by international ships is therefore divided into the three fuel types based on the 1993 shares of 6.2 per cent IDF, 13.5 per cent ADO and 80.3 per cent FO. The fuel consumption figures were converted to greenhouse gas emissions by multiplying by the conversion factors in table 5.3.

Using the proportions of ADO, IDF and FO given in the previous paragraph, greenhouse gas emissions are projected to increase slightly between 1994 and 2015. The carbon dioxide equivalent increase between 1994 and 2015 is, on average, 0.7 per cent per year (figure 5.5). The projections for carbon dioxide equivalent emissions (and the individual greenhouse gases) are listed in appendix XI, table XI.4.



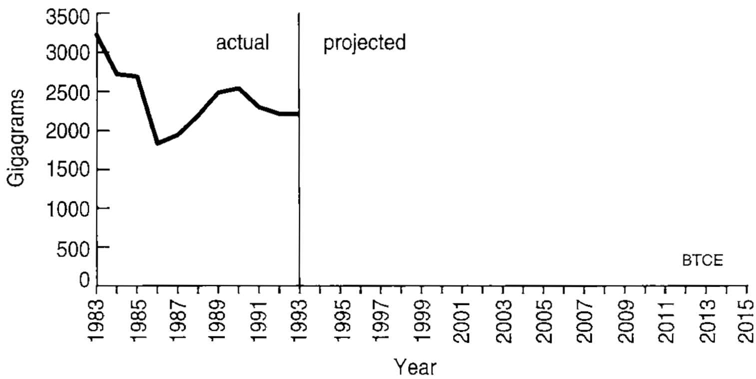
Sources ABARE (S. Bush pers. comm. 2 March 1994); BTCE estimates.

Figure 5.4 Total fuel uplifted in Australia by international ships

TABLE 5.3 EMISSION FACTORS FOR INTERNATIONAL SHIPPING
(g/MJ)

	Fuel		
Gas	*Automotive diesel oil*	*Industrial diesel fuel*	*Fuel oil*
CH_4	0.005	0.005	0.003
N_2O	0.002	0.002	0.002
NO_x	1.520	1.520	1.520
CO	0.475	0.475	0.475
NMVOCs	0.105	0.150	0.105
CO_2	69.700	70.200	73.300

Source Appendix V.



Source BTCE estimates.

Figure 5.5 Carbon dioxide equivalent emissions from fuel uplifted in Australia by international ships

COASTAL SHIPPING

Modelling fuel consumption

The proportion of Australian transport fuel consumed by coastal shipping is relatively small in comparison to other modes (in particular road transport). Consequently, few attempts have been made to develop models of fuel consumption for coastal shipping. The Australian Bureau of Agricultural and Resource Economics (ABARE) produces a series of estimates for the uplift of bunkers by coastal ships to 2004–05. These estimates are based on the assumption that consumption will increase by 1.6 per cent per year (Bush et al. 1993a, p. 31).

The BTCE developed a model to provide long-term projections of greenhouse emissions from coastal shipping.

The amount of fuel consumed in coastal shipping is calculated in the BTCE model by:

(14) FU = coastal task x average distance x fuel intensity

(MJ) (tonnes) (km) (MJ/tkm)

where FU is the quantity of fuel uplifted as coastal bunkers, coastal task is tonnes of coastal freight shipped and the fuel intensity refers to the coastal fleet. By obtaining projections for the coastal task, average distance and fuel intensity, it is therefore possible to estimate future fuel consumption.

The coastal task is comprised of both freight and passenger tasks. The freight task was divided into two components: bulk and non-bulk. Each component was modelled separately.

Bulk freight was modelled with the sum of seven major bulk commodities (bauxite/alumina, petroleum products, petroleum oil, sugar, iron ore, coal/coke and fertilisers/minerals) as the explanatory variable, as outlined in equation (15).

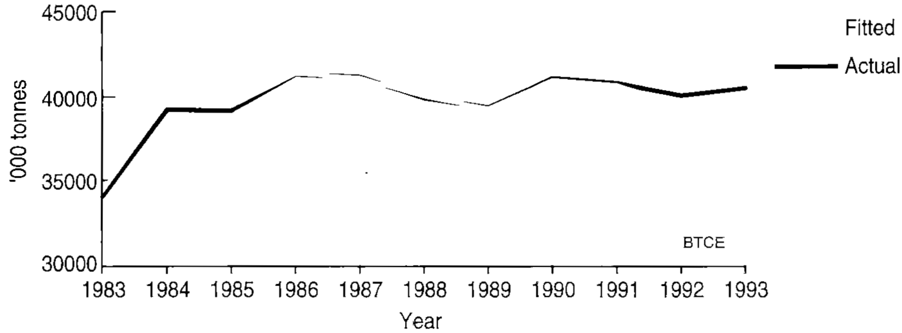
$$\text{(15)} \quad \ln \text{CBLK} = \underset{(0.332)}{1.284} + \underset{(0.0318)}{0.886} \ln \text{CCOM}$$

Estimation method: Cochrane–Orcutt, Rho = 0.778
Adjusted R^2: 0.990
Durbin's h: 0.877
standard errors are given in parentheses,

where CBLK is the tonnage of coastal bulk freight and CCOM is the sum of the tonnages of seven major bulk commodities.

As the results show, CCOM explains 99 per cent of the variation in CBLK. Figure 5.6 illustrates the closeness of the fit. The positive coefficient on CCOM indicates that, as the tonnages of the seven major bulk exports increase, so does the total bulk tonnage.

Non-bulk freight is a relatively small proportion of the total freight carried by coastal ships. In 1993, it comprised 8.3 per cent of total coastal freight. This figure remained relatively stable during the period 1983–1993. Since 1983, non-bulk freight has been growing on average by 14.28 thousand tonnes per year. Given that non-bulk freight is only a small section of the market, is growing slowly and there is a lack of suitable data for modelling purposes, a model for non-bulk freight was not constructed.



Note Actual bulk coastal freight refers to the tonnages of bulk freight carried by coastal ships between 1983 and 1993. Fitted bulk coastal freight refers to the tonnages of bulk freight calculated from equation (15) and the actual tonnages of bauxite/alumina, petroleum products, petroleum oil, sugar, iron ore, coal/coke and fertilisers/minerals between 1983 and 1993.

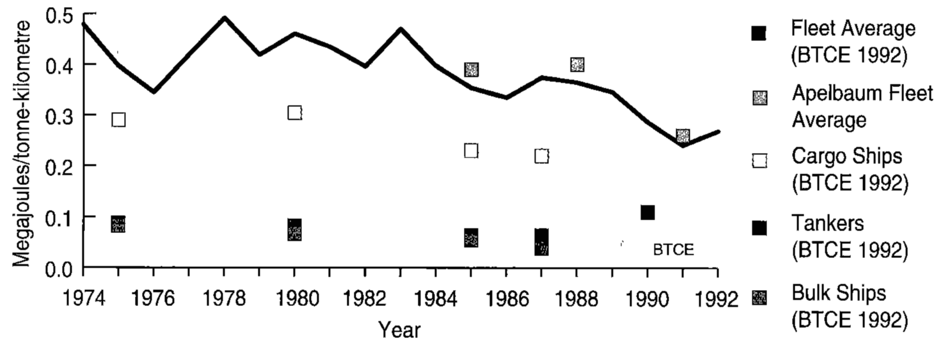
Sources DTC (1993c and earlier editions); BTCE estimates.

Figure 5.6 Actual and fitted bulk coastal freight

In 1990–91, coastal shipping undertook a freight task of 93.7 billion tonne-kilometres and, allowing for the average weight of passengers and luggage, a passenger task of 53 million tonne-kilometres (Apelbaum 1993, pp. 50, 52). Passengers therefore represent approximately 0.06 per cent of the total tonne-kilometres undertaken by coastal shipping. Similar statistics for 1985 and 1988 yield percentages of 0.08 and 0.06 respectively (Apelbaum 1993, pp. 50, 52). Given that the passenger task is very small in comparison to the freight task, and its share of the total task has not changed significantly over time, it is not taken into account in the modelling of the coastal shipping task.

In contrast to international shipping, it is unlikely that ships performing the coastal task would refuel in another country. Therefore it can be assumed that the ABARE figure for the total fuel uplifted in Australia by coastal ships is equal to the amount of fuel consumed. If cabotage is removed, however, more fuel for the coastal shipping task is likely to be uplifted overseas and a model similar to the international shipping model may have to be employed. By rearranging equation (14), the fuel intensity may be calculated by dividing fuel consumption by the coastal freight task. Using the ABARE data for total fuel uplifted in Australia by coastal ships and the coastal freight task from Cosgrove and Gargett (1992, p. 236), a time series of the fuel intensity for the coastal fleet (figure 5.7) was constructed.

Fuel intensity may be calculated in two ways. The first is to convert the amount of fuel used per day into MJ/tonne-km based upon the speed and DWT of the ship. The second is to calculate the fuel intensity from aggregate fuel consumption data. In figure 5.7, the Calculated Fleet Average and



Sources BTCE (1992, pp. 4, 54); Apelbaum (1993, p. 110); BTCE estimates.

Figure 5.7 Coastal shipping fuel intensities

Apelbaum Fleet Average are derived from aggregate data, with the remainder converted from the amount of fuel used per day. This difference may be attributed to the high degree of backhauling, where ships undertake voyages without carrying cargo. Ignoring any differences due to backhauling, the calculated fleet average time series follows a similar trend to those converted from fuel consumption rates. In addition, the Calculated Fleet Average Time Series is roughly the same as the Apelbaum Fleet Average. Hence the Calculated Fleet Average is taken to be an accurate representation of the fuel intensity of Australia's coastal fleet and is used in the fuel consumption model for coastal shipping.

Assumptions

Bulk coastal freight

To project the level of bulk coastal freight activity, a series of projections of the tonnages of the seven major bulk exports are required. With the exception of the tonnage of fertilisers/minerals, the projections for tonnages shipped were calculated from equation (16).

(16) tonnage shipped = proportion shipped x tonnage produced

(tonnes) (tonnes)

where tonnage shipped is the tonnage of each commodity carried on coastal ships, tonnage produced is the tonnage of each commodity produced, and proportion shipped is the proportion of total production which is carried on coastal ships.

TABLE 5.4 ASSUMPTIONS FOR PROPORTIONS OF PRODUCTION SHIPPED BY COASTAL SHIPS

Commodity	*Assumption*
bauxite/alumina	increase by 1.29 per cent per year
petroleum products	decrease by 1.31 per cent per year
petroleum oil	decrease by 5.75 per cent per year
sugar	decrease by 3.13 per cent per year
iron ore	decrease by 3.39 per cent per year
coal/coke	decrease by 4.00 per cent per year

Source BTCE estimates.

The proportion shipped is calculated from historical data on tonnages shipped (DTC 1993c and earlier issues) and tonnages produced (ABARE 1993b). Because there have been distinct trends in the proportions of commodities transported by coastal ships between 1983 and 1993, it is reasonable to assume that these trends will continue. The projections of the proportion shipped are given in table 5.4.

The projections for tonnages produced are calculated in two stages. The first stage, from 1994 to 1999, shows ABARE projections for tonnages produced and the second stage, from 2000 to 2015, shows a continuation of the ABARE trends. The projections for the individual commodities are listed below.

Bauxite/Alumina: 1994–1999, ABARE (1993a, p. 520) projections for production of bauxite and alumina.
2000–2015, increase of 2.4 per cent per year (ABARE trend continued).

Petroleum products: 1994–1999, ABARE (1993a, p. 515) projections for refinery production, other production and imports of petroleum products in gigalitres. To convert the petroleum products projection into tonnes, a single value for the specific volume is required. ABARE (1993b, p. 259) divides petroleum products into its separate components. Using this data, a weighted average of the specific volumes was obtained for each year from 1983 to 1993. An average was taken and used as the specific volume for petroleum products.
2000–2015, increase of 1.5 per cent per year (ABARE trend continued).

Petroleum oil:	1994–1999, ABARE (1993a, p. 515) projections for crude oil and condensate production and imports. As these projections were also given in gigalitres, a specific volume was calculated using the same method used to calculate the specific volume for petroleum products. 2000–2015, increase of 0.7 per cent per year (ABARE trend continued).
Sugar:	1994–1999, ABARE (1993a, p. 492) projections for the production of sugar. 2000–2015, increase by 3.4 per cent per year (ABARE trend continued).
Iron ore:	1994–1999, ABARE (1993a, p. 525) projections for the production of iron ore. 2000–2015, increase by 1.8 per cent per year (ABARE trend continued).
Coal/coke:	1994–1999, ABARE (1993a, p. 509) projections for the production of black coal. Brown coal projections are made by continuing the historical trend of brown coal production from 1973 to 1993 (3.9 per cent per year). 2000–2015, black coal increases by 3.6 per cent per year (ABARE trend continued). Brown coal increases by 3.9 per cent per year (historical trend continued).

The projections for the tonnages of each commodity produced and the proportion of production which is transported by ship were substituted into equation (16) to calculate the projections of the tonnages of each commodity transported by ship.

The category of fertilisers/minerals covers a wide variety of materials. As data are not available for the production of many different types of fertilisers and minerals, a projection for the amount shipped was made based on the tonnages shipped between 1983 and 1993 (DTC 1993c and earlier issues). As a result the amount of fertilisers/minerals shipped was assumed to increase at the rate of 3.6 per cent per year.

The projections for the tonnages of each of the seven commodities were summed and substituted into equation (15) to project the tonnage of bulk freight transported by coastal ships from 1994 to 2015.

There has been a noticeable downward trend in fuel intensities from 1987 (figure 5.7). This can be attributed to the changeover to new vessels under the Ships Capital Grants Scheme between 1986 and 1993. Under the Ships Capital Grants Scheme, financial assistance was given to Australian shipowners to modernise their ships through either the purchase of newer, more technologically advanced ships or the modification of older ships. In the coastal fleet, this has led to substantial improvements in the fleet fuel intensity and means that most of the current fleet will serve into the next century. As a result, fuel intensity can be assumed to remain constant from now until 1999. From 2000 to 2015, the fuel intensity is assumed to decrease by 1.7 per cent per year, derived from the coastal fleet fuel intensity trend over the last 10 years.

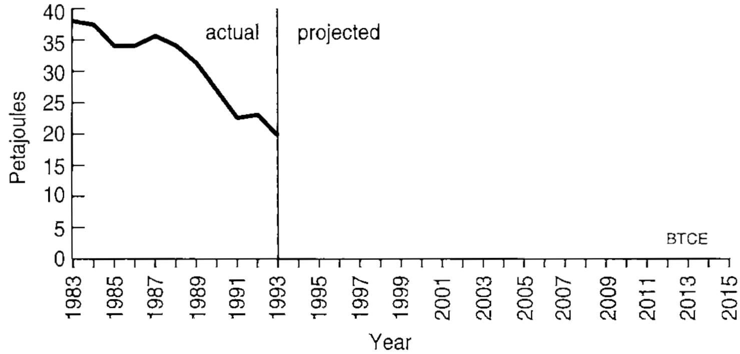
In Cosgrove and Gargett (1992, pp. 234, 236), the coastal shipping task is expressed in both tonne-kilometres and tonnes. These statistics have been calculated by multiplying port-to-port tonnages by port-to-port distances (DTC 1993c and earlier issues). Between 1971 and 1992, the average distance shipped has remained relatively constant, with an average figure of 2168 km. For projections it is assumed that the average distance for coastal shipping will remain constant at 2168 km.

Fuel consumption and emissions

By substituting the projections for the freight task, fuel intensity and average distance into equation (14), a projection for the amount of fuel consumed in coastal shipping is calculated. The results are illustrated in figure 5.8.

Coastal shipping uses four main types of fuel: automotive diesel oil, industrial diesel fuel, fuel oil and black coal. ABARE (S. Bush, pers. comm. 2 March 1994) predicts that the amount of fuel consumed as a proportion of the total fuel consumed will remain relatively constant and thus it is reasonable to proportion the total fuel consumed based on 1992 proportions.

Assuming that the proportions of fuels do not change over time, it is possible to apportion fuel consumption into automotive diesel oil, industrial diesel fuel, fuel oil and black coal and convert into greenhouse emissions using the



Sources ABARE (S. Bush pers. comm. 2 March 1994); BTCE estimates.

Figure 5.8 Fuel consumption in coastal shipping

conversion rates in table 5.5. The amounts of each fuel type and the calculated emission levels are given in appendix XI, tables XI.5 and XI.6 respectively.

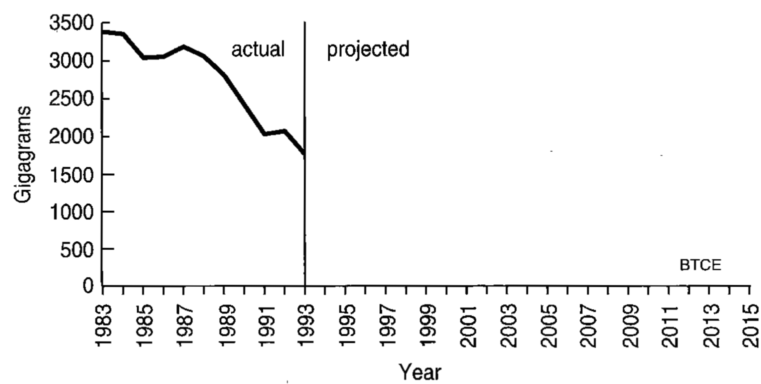
Carbon dioxide equivalent emissions from coastal shipping are projected to fall from 1763 Gg in 1992–93 to 1707 Gg in 2014–15. This reduction can be attributed to increasing fuel efficiencies coupled with a constant shipping task. Figure 5.9 illustrates the reduction in carbon dioxide equivalent emissions, while the projections for all greenhouse gases are given in appendix XI, table XI.6.

TABLE 5.5 EMISSION FACTORS FOR COASTAL SHIPPING

(g/MJ)

	Fuel			
Gas	*Automotive diesel oil*	*Industrial diesel fuel*	*Fuel oil*	*Black coal*
CH_4	0.005	0.005	0.003	0.002
N_2O	0.002	0.002	0.002	0.001
NO_X	1.52	1.52	2.00	0.31
CO	0.475	0.475	0.044	0.088
NMVOCs	0.105	0.150	0.063	0.0
CO_2	69.7	70.2	73.3	90.0

Source Appendix V.



Source BTCE estimates.

Figure 5.9 Carbon dioxide equivalent emissions from coastal shipping

CONCLUSION

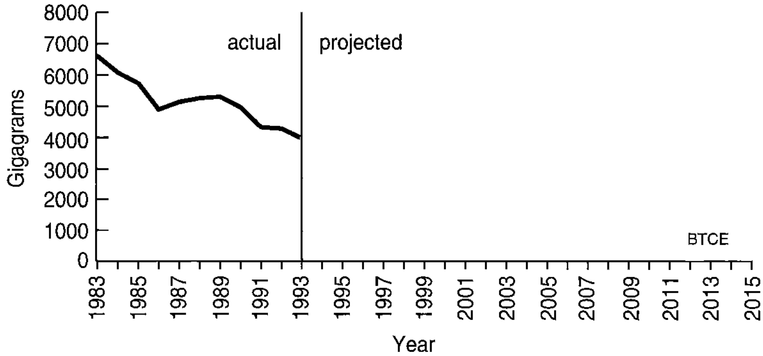
As figure 5.10 shows, the level of carbon dioxide equivalent emissions from the total Australian shipping task is projected to increase at the rate of 0.36 per cent per year, from 3972 Gg in 1992–93 to 4298 Gg in 2014–15.

While both the international and coastal shipping models are considered to be structurally sound, a lack of suitable data on the fuel intensity of ships meant that a number of assumptions had to be made. If alternative assumptions are made, then the results will change. In the international shipping model, data on fuel consumption per day, speed and DWT were converted into MJ/tkm. To make the conversion, assumptions were made regarding the proportion of the DWT dedicated to carrying freight and the extent of backhauling. In the coastal shipping model, a fleet average fuel intensity series was used despite the fuel intensity of a bulk ship being different from the fuel intensity of a non-bulk ship. While the use of assumptions will introduce errors into the results, every attempt has been made to choose assumptions which minimise inaccuracies and produce plausible estimates of greenhouse gas emissions from shipping.

The International Maritime Organisation (IMO) is in the process of drafting new regulations to reduce the levels of NO_x emissions in both international and coastal shipping. Their findings are scheduled for completion in 1995 (ANMA, N. Chambers, pers. comm. 31 May 1994).

NO_x emissions can be reduced by engine design modifications and control of the combustion process. While these modifications will reduce emissions of NO_x, they also increase the amount of fuel consumed and hence other greenhouse gas emissions (Polar Design Research Ltd 1993, pp. 42–45). The emissions projections are based on the assumption that conversion factors remain constant over time. If the IMO regulations are implemented, the emission factors for NO_x (table 5.5) would fall in the future. While such measures may reduce the levels of NO_x emissions, possible increases in fuel consumption rates could lead to increases in the CO_2 emission levels.

The IMO's new regulations are scheduled to be released in 1995. Until then, there are a number of uncertainties which preclude incorporation of the regulations into the projection assumptions. These include the methods required to reduce the gases, the emissions target and whether the regulations will apply to the current fleet as well as new ships. As the shipping sector has a relatively small share of Australian transport fuel consumption, any discrepancies in the emissions projections as a result of the new IMO regulations will be minor in comparison to the emissions from the entire Australian transport task.



Source BTCE estimates.

Figure 5.10 Carbon dioxide equivalent emissions from international and coastal shipping

CHAPTER 6 EMISSIONS FROM THE TRANSPORT SYSTEM

Estimates of emissions from the transport sector provided in this Report are generally those resulting directly from the combustion of fuel within transport engines: so-called energy 'end-use'.

For modelling purposes and for making projections of transport energy use, end-use figures are appropriate because source data are generally available only in end-use terms. However, the environmental impacts of a transport activity are often better assessed by considering the broader range of energy use associated with the activity, including both direct and indirect effects related to vehicle use. In the transport sector, a layered approach is possible. If end-use emissions from fuel used are augmented by the energy used to extract, process and distribute the fuel to the end-user, an estimate can be obtained of so-called *full fuel cycle* emission levels. It is particularly important to use full fuel cycle estimates when comparing petrol-driven road vehicles with transport modes such as electric cars or trains. Electric motors themselves emit practically no greenhouse or noxious gases, but electricity generated in a power station that uses fossil fuel would do so.

Analysis of energy use is also possible at a broader level than full fuel cycle emissions. If the energy used to manufacture cars is included, for example, then *life cycle* energy usage may be estimated. Life cycle energy usage may be more relevant than full fuel cycle comparisons if, for example, it requires more energy to produce an aluminium car than to produce a steel one, and their end-use energy usages are equivalent. From a greenhouse point of view, one car may be preferable to the other.

System cycle analysis takes into account even more indirect effects, such as the energy used in building, maintaining and operating transport infrastructure. It could include energy used in (and hence emissions related to) production of steel rails, sealing road surfaces, and operating traffic lights or railway signalling equipment.

Which level of analysis is best depends on the objective and framework of the analysis. Data availability may also be problem as the scope of the analysis is extended from strict end-use. The analysis in this chapter is intended to provide a wider perspective on the total greenhouse emissions produced by the transport sector. The following results are very approximate, and are presented as only indicative estimates of the emissions generated by indirect effects associated with transport activities.

FULL FUEL CYCLE

Full fuel cycle (FFC) emissions are those resulting from energy used solely for vehicle propulsion (end-use) and from the delivery of that energy to the end-user.

Emissions from the fuel extraction process (or *feedstock recovery*) are mostly due to the fuel used in the recovery process, but also include emissions from leaks during natural gas extraction, methane released from coal mines, and gas flaring in oilfields. OECD/IEA (1991, p. 48) estimates imply that CO_2 equivalent emissions from gas venting and flaring on oilfields are of the order of 1.5 per cent of end-use emissions from petroleum. Electricity generation in Australia relies on substantial inputs of coal, and methane vented from coal mines contributes in the order of 6 Gg of CO_2 equivalent emissions per megajoule of electricity end-use (based on Wilkenfeld 1991, p. 77).

Emissions from *fuel production* are primarily CO_2 (from energy consumed in the fuel conversion processes). Some non-CO_2 gases are also released, including NMVOCs and CH_4 leaked from petroleum refineries and CO and NO_x emitted from electric power stations. Based on NGGIC emission factors (1994a, pp. 12, 23) and emission data for Melbourne refineries (Carnovale et al. 1991, p. 105), non-CO_2 emissions account for around 3 per cent of total CO_2 equivalent emissions from power stations and 8 per cent from refineries.

Various Australian studies have adopted FFC analysis. Apelbaum (1993, p. 75) presents average full fuel cycle conversion factors relating to the production of petroleum products (leaded and unleaded petrol, diesel and LPG). The factors allow for fuel extraction, feedstock transportation, refinery fuel use and refinery product transportation (but losses due to refuelling at service stations were not taken into account). For 1990–91 the full fuel cycle factor was calculated to be 1.082 (meaning that end-use fuel consumption should be increased by 8.2 per cent to give an estimate of full fuel cycle energy consumed). For 1975–76 the full fuel cycle factor was estimated as 1.097. Wilkenfeld (1991, p. 63) estimated that end-use CO_2 emissions of petroleum fuels should be increased by 9.2 per cent, for 1989, to allow for refinery energy use.

The Department of Minerals and Energy (DME 1990) undertook a study of emissions resulting from motor vehicles in New South Wales. In terms of carbon dioxide equivalents, emissions from the fuel supply (fuel recovery, production and distribution) were estimated as equivalent to 16.6 per cent of the emissions due to vehicle operation (that is, end-use emissions).

The BTE (1980) undertook a detailed study into the level of indirect (that is, apart from end-use) fuel consumption in all modes of transport for the year 1975–76. It was estimated that approximately 101 PJ of energy were consumed in the refining, manufacture and delivery of fuel in 1975–76. End-use fuel consumption for the total transport sector in 1975–76 was 715 PJ (Bush et al. 1993, p. 112). Full fuel cycle consumption for 1975–76 would therefore have been 14 per cent greater than end-use fuel consumption.

Various BTCE studies and ABARE data on energy consumption by refineries (Bush et al. 1993, p. 103) yield an approximate difference between FFC and end-use energy consumption (and therefore CO_2 emissions) of 11.4 per cent for petroleum fuels. Because CO_2 emissions account for around 85 per cent of CO_2 equivalent emissions from energy end-use in the transport sector, refineries increase CO_2 equivalent emissions from petroleum fuels by around 9.7 per cent.

The *distribution* component of FFC includes energy losses from the transmission of electricity, fugitive emissions from pipelines and tankers, energy used to compress or liquefy gaseous fuels, and spillages at petrol stations.

Sources of evaporative fuel losses at service stations include refuelling motor vehicles, the filling of underground tanks, and underground tank breathing (Carnovale et al. 1991, p. 80). Based on NGGIC (1994b, pp. 11, 23) data on emissions from fuel supply, fugitive releases of NMVOCs and CH_4 from service stations and fuel distribution account for around 0.4 per cent as much CO_2 equivalent emissions as vehicle end-use.

Combining the above factors gives an estimated difference between FFC and end-use CO_2 equivalent emissions of 12.4 per cent for petroleum fuels; comprising 1.5 for venting and flaring, 0.8 for refinery non-CO_2 emissions, 9.7 for refinery CO_2 emissions and 0.4 for evaporative fuel losses.

Electricity is used by many railways for the movement of urban passengers (and some government freight). On an end-use basis, electricity does not emit greenhouse gases. However, the generation of electricity does. Emission levels will depend upon the primary fuel used (mostly coal and natural gas), and the efficiency with which electricity is generated from the primary fuel (which varies from State to State). Derived from figures contained in Apelbaum (1993, p. 155), for every petajoule (PJ) of energy consumed by electric trains and trams, approximately 3 PJ of primary energy are required to generate the electricity needed. Using data provided by Armour and Jordan (1992, p. 7), NGGIC (1994a) and the Victorian Public Transport Corporation (pers. comm.

October 1994), the BTCE estimates that 273 grams of CO_2 are emitted per megajoule of end-use electricity consumed. Chapter 3 (dealing with rail projections) details the calculation.

Allowing for methane leaks from coal mining and non-CO_2 emissions from power stations, results in an estimated FFC emission rate of 287 grams of CO_2 equivalent emissions per megajoule of electricity end-use by railways.

Table 6.1 details end-use and full fuel cycle fuel consumption levels for major classes of transport modes for the year 1992–93.

LIFE CYCLE AND SYSTEMS CYCLE

Life cycle emissions are those associated with vehicle energy consumption and the energy used to manufacture vehicles. Included are end-use (or tailpipe) emissions, fuel supply emissions (part of full fuel cycle emissions), and the manufacture, maintenance, repair and disposal of vehicles. Inclusion of energy used in the construction, maintenance and repair of transport infrastructure provides estimates of system-wide emissions.

The difference between end-use and full fuel cycle has been calculated above. This section deals briefly with the additional emissions due to vehicle manufacture, maintenance, repair and disposal (life cycle), and furthermore the provision of transport infrastructure (systems cycle).

In the Department of Minerals and Energy (DME 1990) study of emissions resulting from motor vehicles in New South Wales, carbon dioxide equivalent emissions from vehicle manufacture and disposal were found to contribute 2.11 million tonnes (DME 1990, p. ii): an extra 12.6 per cent add-on to end-use emissions. The OECD/IEA (1991, p. 48) have estimated that by the year 2005

TABLE 6.1 END-USE AND FULL FUEL CYCLE FUEL CONSUMPTION FOR AUSTRALIAN DOMESTIC TRANSPORT, 1992–93

(PJ)

Sector	*End-use*	*Full fuel cycle*
Air transport	55.9	62.3
Road transport	815.9	908.9
Rail transport	28.8	42.6
Marine transport	32.5	36.2
Total domestic civil transport[a]	933.1	1050.0

a. Excludes pipeline transport.

Sources Bush et al. (1993); BTCE estimates.

vehicle manufacturing will add on approximately 14.4 per cent to end-use carbon dioxide equivalent emission levels for gasoline vehicles in North America. Neither the DME (1990) nor OECD/IEA (1991) studies consider all components related to transport life cycles.

The BTE (1980) study into the level of indirect fuel consumption in all modes of transport for the year 1975–76 was more detailed. It estimated that, in 1975–76, approximately 12.8 PJ of primary energy were used in vehicle construction and assembly and for all repair to vehicles other than the motor car; 52.3 PJ were used for the extraction and processing of materials for vehicle components; 37.6 PJ were used for vehicle maintenance and motor car repair; and 19 PJ were used for the construction and maintenance of transport infrastructure. End-use fuel consumption for the total transport sector in 1975–76 was 715 PJ (Bush et al. 1993, p. 112). An addition to end-use fuel consumption of approximately 17 per cent is therefore required to take account of life cycle and system cycle effects not included in the full fuel cycle.

The BTE (1980) study split the energy consumed by each transport associated task by mode. Table 6.2 details the split and the calculated add-on for each mode in 1975–76. For illustrative purposes, and in the absence of more recent information, it is assumed that the factors would not have changed between 1975–76 and 1992–93.

To adjust total transport end-use energy consumption to system cycle energy consumption, the end-use data should therefore be increased by approximately 30 per cent (that is, the sum of the full fuel cycle effect of about 13 per cent and the extra add-on of 17 per cent for the life and systems cycles). To derive separate estimates for the transport modes, the factors contained in table 6.2 can be used in conjunction with the full fuel cycle factors given in the previous section.

Note that the use of recycled materials has not been taken account of in the BTE (1980) calculation of the energy required for the production of materials used in vehicle manufacture. However, with the exception of aluminium, the energy requirements for manufacturing products from recycled materials are of the same order as those for manufacturing from raw materials. Since aluminium generally accounts for only a small proportion of vehicle mass, allowing for the use of recycled materials in vehicle manufacture would not significantly alter the results obtained (in table 6.2). Assuming that recycling reduced the energy for production of input material by 30 per cent would change the total add-on of 17 per cent to 15 per cent.

Table 6.3 details end-use and system cycle fuel consumption levels for all modes of transport for the year 1992–93.

Table 6.4 details the carbon dioxide equivalent emissions for 1992–93 resulting from end-use fuel consumption, full fuel cycle fuel consumption and system cycle fuel consumption. System cycle emissions for Australian domestic transport total around 97 million tonnes of CO_2 equivalents for 1992–93.

TABLE 6.2 APPROXIMATE ENERGY CONSUMED BY INDUSTRIES SERVING TRANSPORT, 1975–76

(PJ)

Mode	*Construction & assembly*[a]	*Production of input material*	*Maintenance & repair (vehicles)*	*Infrastructure construction & maintenance*	*End-use fuel consumption*	*Per cent add-on to end-use*
Motor vehicles	8.5	43.3	37.6	14.8	515.50	20
Ships & boats	1.3	2.3	n.a.	1.0	96.80	5
Locomotive & rolling stock	1.6	3.5	n.a.	2.4	29.90	25
Aircraft	1.3	2.9	n.a.	0.7	71.50	7
Other transport equipment	0.1	0.3	n.a.	n.a.	1.30	35
Total	12.8	52.3	37.6	18.9	715.00	17

n.a. not available (see a below)

a. Includes energy used in repair to all vehicles except motor vehicles.

Sources Bush et al. (1993, p. 112); BTE (1980, pp. 118–126); BTCE estimates.

TABLE 6.3 END-USE AND SYSTEM CYCLE FUEL CONSUMPTION FOR AUSTRALIAN DOMESTIC TRANSPORT, 1992–93

(PJ)

Sector	*End-use*	*System cycle*
Air transport	55.9	66.1
Road transport	815.9	1074.0
Rail transport	28.9	49.9
Marine transport	32.5	37.7
Total domestic civil transport[a]	933.1	1227.7

a. Excludes pipeline transport.

Sources Bush et al. (1993); BTCE estimates.

TABLE 6.4 CARBON DIOXIDE EQUIVALENT EMISSIONS FOR END-USE, FULL FUEL CYCLE AND SYSTEM CYCLE FOR AUSTRALIAN TRANSPORT, 1992–93

(Gg)

Sector	*End-use*	*Full fuel cycle*	*System cycle*
Air transport	4002	4498	4771
Road transport	63795	71706	84612
Rail transport	1974	3855	4345
Marine transport	3125	3513	3660
Total domestic civil transport[a]	72896	83571	97388

a. Excludes pipeline transport.

Source BTCE estimates.

CHAPTER 7 CONCLUSION

The National Greenhouse Response Strategy (endorsed by all Australian governments in 1992) aims to reduce greenhouse gas emissions in Australia to below 1988 levels within a decade. The BTCE has been commissioned to estimate the costs of potential abatement measures in the Australian transport sector.

In order to evaluate abatement measures, it is necessary to establish a 'base case' projection of greenhouse gas emissions to provide a reference point into the future. Estimates can then be made of the effect and cost associated with each measure. This study provides the first step by providing base case projections.

Because the atmospheric effects of greenhouse gas emissions pose long-term problems, long-term abatement measures need to be considered, as well as more immediate policies. Equally, the longer-term effects of short-term policies need to be assessed. The BTCE chose therefore to analyse measures and emissions to the year 2015.

Long-term projections require relatively simple models that represent the major forces that cause emissions to grow over time. Models for road (cars and trucks), rail, sea and air transport have been presented in the body of this Report. Their structure has deliberately been made very simple, so as to promote an intuitive understanding of the results achieved. Each model reflects forces that affect sectoral activity, fuel intensity and emission intensity (mass of CO_2 equivalent emissions per unit of fuel consumed).

Future passenger car travel is likely to be influenced by a marked slowing in the projected growth in the number of cars per person, along with slower population growth. New car fuel and emission intensities are likely to be reduced by the scheduled implementation of automobile industry product plans. As old cars are replaced, the average fuel intensity of the fleet tends to decrease. The net result of these forces is a projected *decline* in greenhouse emissions from the Australian car fleet over the next two decades.

Emissions from trucks, on the other hand, are likely to continue to grow quite strongly, in line with expected growth in the Australian economy. Expected growth in freight activity over the next two decades is of the order of 4 per cent per annum: a doubling time of about 18 years. The limited potential for reductions in the fuel intensities of truck engines restricts the scope for achieving reductions in emissions through the introduction of new vehicles. Emissions from trucks are projected to be one of the two fastest-growing emission categories in the transport sector to the year 2015.

The other fast-growing area is likely to be air transport. BTCE projections suggest that annual growth in greenhouse emissions for domestic aviation is likely to be around 3 per cent. Some decline in fuel intensities is possible over the period to 2015, but the low densities of many of the domestic routes somewhat limits the potential effectiveness of measures such as encouraging increased aircraft size. International aviation (to and from Australia) is expected to grow more strongly with annual growth in greenhouse emissions around 5 per cent.

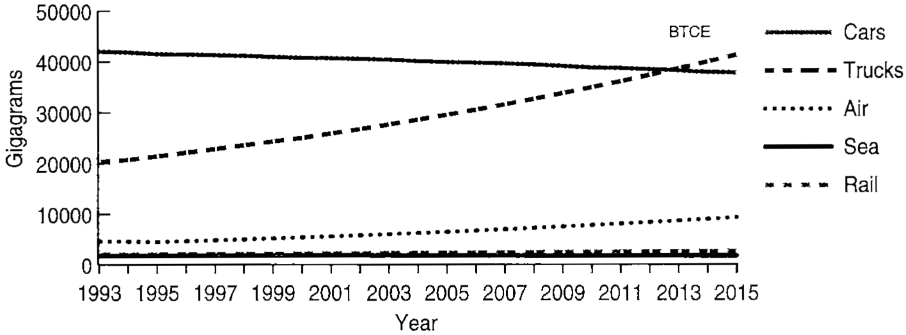
Rail and shipping are unlikely to be major contributors to growth in emissions, partly because of their smaller size and partly due to lower expected growth in activity.

Due care needs to be taken in interpreting the results of long-term models such as those used by the BTCE in this Report. Long-term models will not necessarily predict variables such as fuel usage accurately for each year. The value of such models lies more in providing estimates of the order of magnitude of changes over time. For example, additional air travel generated by the year 2000 Olympic Games is not specifically allowed for in the projections. Such perturbations are better estimated using specifically designed short- or medium-term models, and then adjusting the 'base case' results of long-term projections accordingly.

A summary of base case projections of greenhouse gas emissions from Australian domestic transport can be seen in figure 7.1. Emissions from cars (the largest source of emissions in the early 1990s) decline over the period to 2015. On the other hand, emissions from trucking and domestic air transport grow rapidly so that by about 2015 each is a major source of emissions. Rail and sea transport remain minor contributors. Emissions generated from fuel uplifted in Australia by international ships and aircraft are not included in figure 7.1, but are provided in figure 7.2. Data on emissions from bunker fuel supplied to international craft are reported separately in table 7.1, as recommended by IPCC guidelines (IPCC/OECD, 1994 p. 1.11).

On the basis of these results, future work on greenhouse gas abatement to be conducted by the BTCE will focus on cars, trucks and aircraft—although the rail and sea sectors will not be ignored. It is the BTCE's aim over the course of the coming year to identify a least-cost set of abatement measures in the transport sector.

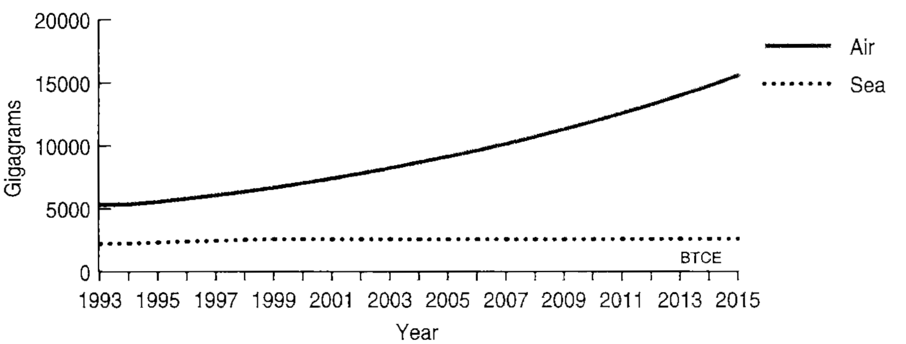
It is essential to note that a least-cost set of measures in the transport sector may not necessarily offer the most efficient, least-cost set of options for Australian governments to meet the targets established in the National Greenhouse Response Strategy. Comparable information on the costs of reducing greenhouse emissions in other sectors (such as agriculture, forestry or energy transformation) would be required before governments were in a position to pursue a least-cost approach from a national perspective. In the absence of cost information for other sectors, it should therefore not be assumed that introducing measures to reduce greenhouse gas emissions from the transport sector will necessarily be the best option for Australia.



Note Projections are of end-use emissions.

Source BTCE estimates.

Figure 7.1 Projections of carbon dioxide equivalent emissions from Australian domestic transport



Note Projections are of end-use emissions.
Emission estimates are based on fuel uplifted from Australia.

Source BTCE estimates.

Figure 7.2 Projections of carbon dioxide equivalent emissions from fuel uplifted in Australia by international transport

TABLE 7.1 PROJECTIONS OF GREENHOUSE GAS EMISSIONS FROM AUSTRALIAN TRANSPORT ENERGY END-USE, 2014–15

	Emissions (Gg)							
Sector	CO_2	NO_x	CH_4	*NMVOC*	*CO*	N_2O	CO_2 *equivalent*	*Per cent change in CO_2 equivalent emissions (1992–93 to 2014–15)*
Total transport	100881.4	628.9	22.8	314.1	1806.6	5.7	112620	41
Domestic	83833.4	515.9	22.6	312.8	1792.0	5.2	94479	31
International	17048.0	113.0	0.2	1.3	14.6	0.5	18141	141
Road transport	71517.3	397.0	21.9	304.2	1657.2	4.8	80880	27
Passenger cars	34192.0	112.3	6.1	110.6	412.0	3.7	37734	–10
Trucks	35702.8	271.5	15.0	181.5	1200.1	1.1	41243	103
Buses	1402.5	12.8	0.6	3.1	12.1	0.0	1568	18
Motorcycles	220.0	0.4	0.2	9.0	33.0	0.0	334	0
Air transport[a]	23691.1	91.3	0.5	4.5	125.7	0.7	24817	150
Domestic	8760.8	34.0	0.4	3.6	114.7	0.3	9267	100
International	14930.3	57.3	0.1	0.9	11.0	0.4	15550	193
Rail transport	2134.5	52.3	0.2	3.8	17.8	0.1	2626	31
Marine transport[a]	3538.5	88.3	0.2	1.6	5.9	0.1	4298	8
Coastal[b]	1420.8	32.6	0.1	1.2	2.3	0.0	1707	–3
International	2117.7	55.7	0.1	0.4	3.6	0.1	2591	17

a. Includes military transport fuel use.

b. Does not include small craft (such as pleasure boats or fishing vessels).

Notes 1. Since figures are for energy end-use, rail does not include emissions resulting from the generation of electricity for trains and trams.
2. International refers to emissions from bunker fuel uplifted in Australia by international transport.

Source BTCE estimates.

APPENDIX I THE PHYSICAL AND CHEMICAL ASPECTS OF TRANSPORT RELATED AIR POLLUTANTS

The primary air pollutants generated by transport activities are carbon dioxide (CO_2), carbon monoxide (CO), nitrous oxide (N_2O), other nitrogen oxides (NO_x), methane (CH_4), non-methane volatile organic compounds (NMVOCs), sulphur oxides (SO_x), chlorofluorocarbons (CFCs), lead, photochemical oxidants (primarily ozone, O_3), particulate matter (including smoke) and traces of a range of toxic compounds (such as benzene and cadmium). NMVOCs consist primarily of non-methane hydrocarbons (NMHCs), with a small proportion of other organic substances such as aldehydes. Most substances in transport emissions exhibit significant interactions and a variety of environmental impacts, both greenhouse and non-greenhouse.

The occurrence of reactions involving emissions and the effects of emissions on the regions surrounding their points of release are complicated by their dependence on the weather (such as winds dispersing or mixing pollutants), sunlight levels (for the formation of photochemical pollutants) and local geography (such as the presence of surrounding hills).

The major sources, sinks, environmental effects and basic chemical interactions of transport emissions are outlined below. A basic schematic summary of transport emissions and their interactions is provided in figure I.1.

When considering issues relating to vehicle emissions (such as the use of alternative fuels or modal change), all pollutant gases and all their major environmental impacts should be covered - not just CO_2 emissions and not just the greenhouse effect.

Carbon dioxide

Sources and sinks: Natural systems emit large quantities of CO_2, through the decomposition of organic matter, the respiration of plants and animals, and

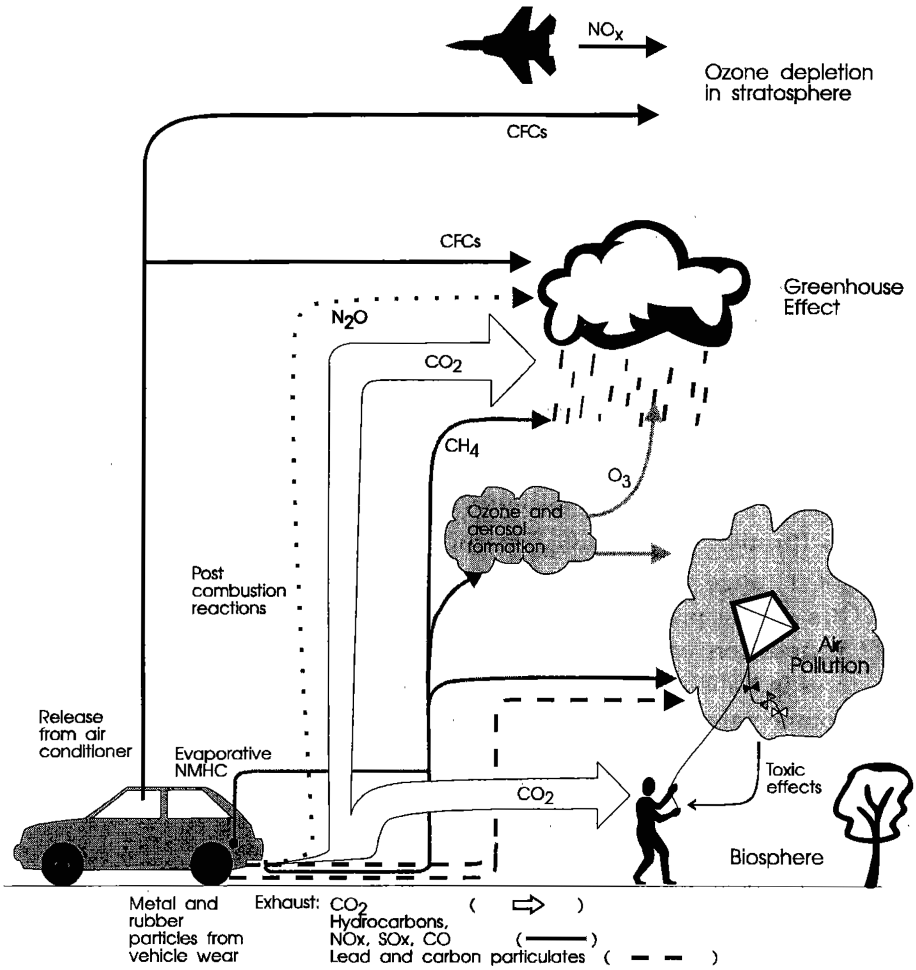


Figure I.1 Summary of gaseous emissions from transport

releases from oceans. These emissions are roughly balanced by the absorption of CO_2 by the world's oceans, soils and vegetation.

The net additions of CO_2 to the atmosphere come primarily from the combustion of fossil fuels, which are basically composed of hydrocarbons. Transport accounts for approximately a quarter of fossil fuel consumption. Other important human-related sources of CO_2 are land use changes (mainly tropical deforestation), wood fires and cement production. The resultant atmospheric concentration depends on the level of CO_2 uptake by the carbon sinks (detailed knowledge of which is still relatively uncertain).

Atmospheric CO_2 concentrations are currently increasing at a rate of around 0.5 per cent per year (NGAC 1992), which implies that around 45 per cent of man-made CO_2 emissions remain in the atmosphere. This percentage could worsen as global warming progresses, due to feedback processes. The oceans currently comprise the major CO_2 sink; but as they become warmer, CO_2 is not dissolved as easily and their net CO_2 uptake declines.

It is still not certain whether the Australian landmass (that is, its soils and ecosystems) is currently a net source or net sink for carbon dioxide. The level of annual vegetation growth probably makes the continent a net sink, but these gains are roughly balanced by the effects of deforestation and bushfires. Net vegetation production in Australia involves, on average, an annual carbon uptake of the order of 3 tonnes per hectare. In comparison, around 3 tonnes of carbon is emitted (as CO_2) per annum by the average petrol consumption of just two cars. The National Greenhouse Gas Inventory (NGGIC 1994c, p. 13) has Australian land use change and forestry as accounting for net emissions of about 131 million tonnes of CO_2 in 1990 (emissions of 156 million tonnes from forest clearing and on-site burning, a sink of 17 million tonnes through grassland conversion and a sink of 8 million tonnes through forest management).

Environmental impacts: Carbon dioxide is non-toxic, but is the major contributor to the enhanced greenhouse effect.

Photochemical oxidants

Sources and sinks: Photochemical air pollution (commonly called smog) occurs primarily in urban areas as the result of a series of complex reactions between emissions of volatile organic compounds, nitrogen oxides and carbon monoxide. This formation of a variety of reactive irritant compounds (or oxidants) occurs most readily in areas with high motor vehicle densities, plentiful sunlight, and local weather patterns that do not rapidly disperse vehicle emissions.

Photochemical pollution is comprised of many different compounds, such as formaldehyde, hydrogen peroxide, and the harsh irritant PAN (peroxyacetyl nitrate) (Streeton 1990). Yet the major element of smog volumes, constituting up to 90 per cent, is ozone (O_3).

The basic tropospheric ozone precursors are the nitrogen oxides: nitric oxide (NO) and nitrogen dioxide (NO_2). Both of these, particularly NO, are emitted in significant quantities by motor vehicles. The NO oxidises slowly in the air to NO_2. In the presence of sunlight, the NO_2 then undergoes dissociation to NO and O:

$NO_2 + \text{energy} \rightarrow NO + O.$

The atomic oxygen formed then reacts with the abundant molecular oxygen to form ozone:

$O + O_2 \rightarrow O_3.$

In air uncontaminated by volatile organic compounds the ozone then rapidly oxidises the NO to NO_2 again:

$O_3 + NO \rightarrow NO_2 + O_2.$

The net effect in this case is that the ozone produced is degraded by NO, while the concentration of NO_2 remains fairly constant.

In urban air contaminated by motor vehicle emissions of volatile organic compounds (or CO), however, alternative reactions occur, of the form:

$RH + O_2 + NO \rightarrow NO_2 + RH\text{-}O,$

where RH is any reactive volatile organic compound (or CO). This allows for the regeneration of NO_2 without the destruction of ozone. There is therefore a progressive build-up of both NO_2 and ozone concentrations.

This set of interactions serves to make ozone control very involved. For example, under some conditions it is possible for an increase in NO_x emissions to result in a decrease in ozone formation, because of the ozone destroying action of NO. For this reason, vehicle emission standards aimed at ozone reduction have often targeted volatile organic compound emissions, since a reduction in volatile organic compound levels will always reduce ozone formation. Reducing emissions of all the ozone precursors simultaneously (as is accomplished by three-way catalytic convertors in automobiles) is the best way of ensuring O_3 production is slowed.

O_3 is a very short-lived molecule, and is readily destroyed by sunlight. In contrast to the depletion of stratospheric ozone, tropospheric ozone concentrations in the Northern Hemisphere have grown by 10 per cent in the last decade (while Southern Hemisphere levels have shown slight increases).

Environmental impacts: Ozone is a potent greenhouse gas.

Ozone causes eye irritation, impaired lung function, reduced resistance to infections, and aggravation of asthma and bronchitis. Photochemical oxidants damage vegetation, causing crop loss and contributing to deforestation. They also degrade structural materials, paints, rubber and fabrics.

Carbon monoxide

Sources and sinks: Carbon monoxide arises primarily from the incomplete combustion of hydrocarbons, with the main sources being wood fires, automotive emissions and power generation. In urban areas, up to 90 per cent of CO emissions are due to motor vehicles.

CO is a relatively unreactive molecule; and though susceptible to oxidation (to CO_2) by atmospheric oxygen, the reaction is extremely slow. This reaction requires an initial supply of energy (known as the activation energy) to proceed. In the lower atmosphere, the oxidation of CO to CO_2 is accelerated by the action of very reactive molecules called *hydroxyl radicals*. Atmospheric hydroxyl radicals (OH) are generally formed through the dissociation of water vapour (H_2O) by sunlight (where this process is itself facilitated by ozone and nitrogen oxide emissions).

The intense reactivity of OH serves to lower the required activation energy for CO oxidation. CO is also removed from the atmosphere by micro-organisms in the soil and by diffusion into the stratosphere, where the more intense radiation can supply the activation energy needed for oxidation to CO_2. These processes result in CO emissions having a relatively short lifetime (or residency) in the atmosphere — around half a year.

In the Northern Hemisphere, where the major portion of world fuel combustion occurs, atmospheric CO concentrations are rising by roughly 1 per cent per year. However, CO concentrations in Australia are fairly stable, and CO emissions have actually declined in recent years due to the increasing use of emission control technology for motor vehicles.

Environmental impacts: Though not radiatively active, CO is considered an indirect greenhouse gas, since it:

- eventually oxidises to CO_2,
- aids the production of ozone, and
- scavenges (or uses up) the OH radicals.

Reaction with the hydroxyl radical is the major pathway for removing methane from the atmosphere, and the reaction with CO is thought to be considerably boosting the lifetime of methane emissions in the atmosphere.

CO interferes with the absorption of oxygen by red blood cells, impairing perception and muscle response. It also promotes respiratory and circulatory problems, and is associated with reduced worker productivity. High levels of CO inhalation are fatal.

Nitrogen oxides

Sources and sinks: The major source of nitrogen oxides (NO and NO_2) is fossil fuel combustion, where they are formed from the nitrogen and oxygen present in the air and in the fuel. Natural sources (such as release from soils) are generally negligible in comparison. As with CO emissions, up to 90 per cent of urban concentrations of NO_x are accounted for by motor vehicle emissions.

Nitrogen oxides are removed from the air by absorption onto surfaces and by the action of plants. As with CO emissions, the increasing use of catalytic convertors in motor vehicles has contributed to a gradual decline in the level of NO_x emissions over the last few years.

Environmental impacts: Nitrogen oxides are not radiative, but are considered indirect greenhouse gases since they are the major ozone precursors.

Nitrogen dioxide causes lung damage, and increased susceptibility to respiratory infections and asthma. High levels of NO_2 are potentially fatal. Nitrogen dioxide also damages plants and various materials (particularly textiles), contributes to acid rain, and causes a brown pollutant haze (reducing visibility).

Methane

Sources and sinks: The main anthropogenic sources of CH_4 are fossil fuel combustion, release from coal mining and natural gas distribution, fermentation in ruminant livestock (such as cattle), wood fires, and release from rice paddies and landfills. There are also considerable natural sources of methane (around a third of total emissions), primarily from wetland bacteria and termite mounds.

As mentioned previously, the main sink for methane emissions is the photochemical oxidation by hydroxyl radicals (forming CO_2 and H_2O). Methane oxidising bacteria in soils are another major sink. The mean atmospheric residence time for CH_4 emissions has been increasing for several decades (due to reduction of the OH sink by carbon monoxide) and is currently around 11 years. This effect has resulted in strong growth of methane concentrations, currently around 0.8 per cent per annum (IPCC 1994, p. 17), and helps explain present levels of atmospheric methane being nearly double those of pre-automobile times.

Environmental impacts: Methane is a very effective direct greenhouse gas (absorbing infra-red radiation 30 times more strongly than CO_2, on a molecule for molecule basis), and also has indirect greenhouse impacts. These comprise its oxidation to CO_2 and water vapour, and its action (like all hydrocarbons) as an ozone precursor.

Non-methane volatile organic compounds (NMVOCs)

Sources and sinks: NMVOCs, which consist primarily of non-methane hydrocarbon (NMHC) emissions, have a variety of sources: through the incomplete combustion of fossil fuels (primarily by motor vehicles); through fuel evaporation (from motor vehicles, petrol stations and refineries); from industry (such as petrochemical manufacturing); and from paint or solvent vapours. Close to half of urban hydrocarbon emissions come from motor vehicles.

NMVOC emissions generally have no sinks in the biosphere, but are oxidised in the air (in reactions involving the production of ozone), eventually forming CO_2 and water.

Environmental impacts: NMVOCs are indirect greenhouse gases through their production of tropospheric ozone and their eventual oxidation to CO_2.

Small molecule hydrocarbons cause drowsiness and symptoms akin to hay-fever. Heavy-molecular compounds contribute to cancers and lung disease. Some hydrocarbons damage fruit.

Nitrous oxide

Sources and sinks: Motor vehicles are a minor source of nitrous oxide (N_2O), with most emissions coming from natural sources (such as bacterial action in tropical soils) and fertilised crop production. In the transport sector, N_2O arises from (post-combustion) reactions between vehicle exhaust gases and atmospheric nitrogen. Ironically, this conversion is aided by the action of catalytic convertors.

N_2O has few sinks, and dissociates slowly in the atmosphere under the action of sunlight, with an atmospheric lifetime of around 120 years (IPCC 1994). The atmospheric concentration of nitrous oxide is increasing at around 0.25 per cent per year (IPCC 1994, p. 17).

Environmental impacts: Nitrous oxide is a very strong (direct) greenhouse gas.

Sulphur oxides

Sources and sinks: Emissions of sulphur oxides (principally sulphur dioxide, SO_2) generally arise from the oxidation of sulphur impurities in fossil fuels. Motor vehicle exhaust emissions account for around 15 per cent of urban SO_x

levels, with the major sources being petrol refineries and heavy industrial applications.

When there is a high level of dust or smoke in the air, sulphur dioxide produces a harmful airborne suspension of particles which includes droplets of sulphuric acid (called an *acid aerosol*). SO_x emissions (and their reactive products) reside in the atmosphere for only weeks, before being removed from the air by rain, absorption by vegetation or consumption by soil bacteria.

Environmental impacts: SO_2 causes coughing and aggravates asthma, bronchitis and lung disease. Sulphur oxides are the main precursors of acid rain; which damages vegetation, metals, buildings, textiles and waterways.

Chlorofluorocarbons (and related compounds)

Sources and sinks: CFCs are man-made compounds which have seen considerable industrial use for several decades (as solvents, refrigerator fluids, spray can propellants and foaming agents) due to their inherent stability and safety. One of the major emission sources of CFCs has been the release from the servicing and disposal of motor vehicle air-conditioners.

Being such stable compounds, they have long atmospheric lifetimes and no natural sinks. CFCs diffuse slowly (over several years) into the stratosphere. The high radiation levels there photochemically decompose the CFCs, releasing chlorine. The chlorine then reacts strongly with the stratospheric ozone, forming the so-called *ozone holes*.

Concern over ozone depleting substances prompted the signing of an international agreement in Montreal during 1987. This became known as the *Montreal Protocol,* and called for countries to reduce CFC consumption to 50 per cent of 1986 levels. Australia enacted the Ozone Protection Act in 1989, which legislates for a 95 per cent reduction in CFC use by 1996. International negotiations are currently under-way dealing with the proposed acceleration of CFC phase-out targets and the inclusion of other compounds. Some of the substances now being used as CFC alternatives are only marginally less ozone-depleting themselves, and many are still potent greenhouse gases.

Environmental impacts: Several CFC species are very effective greenhouse gases.

As noted, CFCs are major stratospheric ozone-depletors, contributing to ultraviolet radiation damage. Even if all CFC production halted today, it could be decades before stratospheric ozone levels recover because the CFC emissions released over much of the last decade have yet to reach the stratosphere.

Lead

Sources and sinks: Airborne lead particles result mainly from the combustion of leaded gasoline (since lead compounds are added to boost engine performance), smelters and battery factories.

The introduction of unleaded petrol is a significant advance in the control of lead emissions, but they will remain a problem for many years. Even by the year 2000, about a quarter of cars could still be using leaded petrol. Also, lead concentrations in the air, though falling, are reducing less quickly than projected. It is possible that this is due to the saturation of roads (and their surrounds) with lead over the years, which is then stirred up by traffic.

Environmental impacts: Lead impairs blood circulation, and can cause neurological and kidney disorders. It also lowers the learning ability of children. Lead accumulates in body tissues, and is hazardous even after exposure ends.

High levels of airborne lead can poison catalytic convertor systems, increasing the output of other noxious vehicle emissions.

Particulates

Sources and sinks: Fine particulate matter (airborne particles) generally consists of grains of carbon (released from fuel combustion) which have absorbed other (often toxic) compounds. These particulates are generated primarily as diesel vehicle exhausts. Other vehicle particulates consist of rubber or various metals; and come from the wear of tyres, brake linings and engine components. Motor vehicles account for around half of urban particulate pollution, with the rest being due to waste burning and metal industries. Of the particulates from road transport, about 80 per cent come from heavy diesel vehicles.

Fine particles can remain suspended in the air for considerable periods of time and any that are below 10 microns (one hundredth of a millimetre) in size (abbreviated as PM10) can penetrate the lower airways of humans (and are termed *respirable*).

Environmental impacts: Particulates contribute to respiratory diseases, lung cancer and infant mortality. Suspended particulates help the formation of acidic or carcinogenic aerosols by absorbing other vehicle emissions (such as sulphur dioxide).

Exhaust smoke reduces visibility, stains buildings and can damage vegetation.

Toxic substances

A number of very toxic substances are emitted by transport vehicles. These are generally members of the pollutant groups listed in this appendix: such as benzene and formaldehyde, which are NMVOCs; or heavy metals such as chromium and cadmium, emitted as respirable particulates.

APPENDIX II CONVERSION FACTORS FOR GREENHOUSE GASES

The *natural greenhouse effect* maintains the earth's temperature at a level suitable for sustaining life. Human activities cause substantial net emissions of greenhouse gases. Over the past decade, the evidence has become conclusive that the atmospheric concentrations of various greenhouse gases have been steadily increasing. These increases have been linked to increases in global temperatures, through the so-called *enhanced* greenhouse effect.

Carbon dioxide (CO_2) is the major greenhouse gas emission from human activities, but the contributions of other gases are important, even in the transport sector. The warming effect of a greenhouse gas depends on its atmospheric concentration and reactivity, infra-red absorption capability, and average residency time in the atmosphere. These factors vary considerably among gases. To represent the total greenhouse effect of emissions of several different gases from an activity, or to compare the greenhouse (or *radiative forcing*) effect of emissions of different gases, emissions are stated in terms of CO_2 equivalents. This is done on the basis of the *global warming potential* (GWP) for each gas. The GWP is an index, defined to be the warming effect over a given period (usually taken as 100 years) due to an emission of a particular gas, relative to that of an equal mass of carbon dioxide.

Representative GWP values have been calculated for the main greenhouse gases by the Intergovernmental Panel on Climate Change (IPCC). Due to the varying lifetime of greenhouse gases, GWP figures depend on the assumed time period over which the effects of emissions are considered. The IPCC (1990, 1992, 1994) has estimated global warming potential factors which range over various time horizons, including 20 years, 100 years and 500 years. Estimated values for the direct GWP components given in IPCC 1994 are presented in table II.1. Indirect GWP values were calculated by the IPCC in 1990, and revised values of these (reported in IEA 1992) are also presented in table II.1. Due to the present incomplete understanding of the complex chemical processes involved in the indirect effects, numerical values for indirect GWPs were not given in the more recent IPCC reports (IPCC 1992, 1994).

The set of GWPs given in table II.1 does not therefore explicitly represent the current IPCC position, but is an indicative scenario for global warming based on various IPCC results. Though the IPCC is reasonably confident that the GWP values for direct effects are of the right order, the current uncertainty surrounding the indirect effects hampers quantitative analysis on the total greenhouse contribution of transport emissions. Rather than omit such analysis, the BTCE has used the GWP scenario given in table II.1, on the understanding that the results derived need to be suitably qualified.

TABLE II.1 GLOBAL WARMING POTENTIALS OF ATMOSPHERIC GASES RELATIVE TO CARBON DIOXIDE, FOR DIFFERENT TIME HORIZONS

Type of greenhouse gas	*Atmospheric concentration in 1992 (parts per million by volume)*	*Estimated atmospheric lifetime (years)*	*Global warming potential*		
			Time horizon (years)		
			20	*100*	*500*
Direct					
Carbon dioxide	355	50–200	1	1	1
Methane[a]	1.7	12–17	62	24.5	7.5
Nitrous oxide	0.3	120	290	320	180
CFC-12[b]	0.0005	102	7 900	8 500	4 200
Indirect (ozone precursors)					
Carbon monoxide	0.1–40	0.4	5	1	0.0
Nitrogen oxides	0.01–0.2	<1	30	8	3
NMVOCs	0.2–0.5	<1	28	8	3

NMVOCs non-methane volatile organic compounds

a. The methane global warming potential (GWP) includes its direct effect and indirect effects due to the production of tropospheric ozone and stratospheric water vapour.

b. CFC-12 is the main chlorofluorocarbon used in transport vehicle air-conditioners.

Sources IPCC (1990, 1992, 1994 p. 28); IEA (1992 p. 32).

APPENDIX III THE AUSTRALIAN TRANSPORT TASK

The Australian transport task consists of a diverse range of services and activities, with greatly differing scales of operation and levels of patronage. Investigation of trends in Australian transport emission levels requires information on the underlying trends in transport task levels. Accurate estimation of transport emissions also requires detailed knowledge of the modal composition, vehicle types, vehicle utilisation levels and fuel consumption in the transport sector. This appendix provides time series estimates of aggregate transport activity for each of the main components of the Australian transport task. Time series for transport fuel consumption are given in appendix IV.

The data presented in the following tables refer to all separate passenger and freight movements, regardless of how many modes were involved in transporting the passengers or commodities from origin to final destination. That is, transport task figures are calculated on the basis of 'unlinked' trips. Unlinked refers to the recording separately of every segment (undertaken by a distinct mode of transport) of each trip, as opposed to a 'linked' trip, which refers to a complete journey from origin to destination, possibly involving several modes. When comparing the BTCE unlinked data to any series on linked trips, note that if a multi-modal linked trip has to be assigned to a single mode, it is generally allocated to the mode for the longest segment of the journey.

Data within the Report are generally given separately for 'urban' and 'non-urban' transport. Urban transport refers to passengers or freight moved wholly within cities of population greater than 40 000 (in the relevant year). Non-urban transport refers to all other passenger or freight movements, which include those within rural areas, between different urban areas, between different rural areas and between urban and rural areas.

GROWTH IN THE NUMBER OF ROAD VEHICLES

Over the last two decades the total stock of Australian road vehicles has approximately doubled, with passenger cars accounting for around 80 per cent of the fleet (table III.1). In 1993, the fleet included close to 10.6 million vehicles. Between 160 and 170 billion (10^9) kilometres are currently travelled each year by the Australian vehicle fleet, with cars accomplishing close to 80 per cent of this total (table III.2).

TABLE III.1 ESTIMATED NUMBER OF ROAD VEHICLES BY VEHICLE TYPE, 1970–71 TO 1992–93

(thousands of vehicles)

	Vehicle type							
Year ending June	*Car*	*Motor cycle*	*LCV*	*Rigid truck*	*Articulated truck*	*Other truck*	*Bus*	*Total*
1971	3 997.4	164.9	611.6	286.9	32.0	10.0	17.1	5 119.9
1972	4 222.3	197.6	644.1	288.0	33.1	12.0	17.4	5 414.5
1973	4 332.2	210.4	665.1	284.3	33.6	13.8	17.8	5 557.0
1974	4 731.6	274.5	723.4	295.5	36.6	18.5	18.1	6 098.3
1975	4 983.6	289.1	773.1	302.3	39.0	24.7	18.5	6 430.3
1976	5 107.8	293.4	805.0	302.1	39.7	29.2	18.9	6 596.1
1977	5 347.1	295.0	892.7	298.6	41.8	34.1	19.6	6 928.9
1978	5 461.8	292.4	948.4	286.1	42.4	35.6	20.3	7 086.8
1979	5 652.5	288.2	1 012.3	277.7	43.9	35.5	21.1	7 331.3
1980	5 794.0	310.6	1 014.8	296.0	44.7	30.3	21.8	7 512.3
1981	6 016.0	352.3	1 044.8	319.5	45.1	23.4	22.5	7 823.5
1982	6 290.2	390.8	1 094.4	352.6	46.6	18.5	23.2	8 216.3
1983	6 479.5	401.9	1 137.4	336.8	46.2	19.2	25.6	8 446.6
1984	6 683.1	398.4	1 179.5	340.7	48.3	20.3	28.0	8 698.4
1985	6 925.9	389.2	1 221.4	341.1	49.6	21.0	30.4	8 978.7
1986	7 106.1	374.5	1 244.6	336.0	49.8	21.7	31.8	9 164.4
1987	7 227.2	351.6	1 252.3	327.1	48.2	23.2	33.2	9 262.9
1988	7 381.6	323.3	1 258.2	325.3	48.7	23.1	34.6	9 394.9
1989	7 573.7	316.6	1 291.8	329.4	50.1	19.0	36.6	9 617.1
1990	7 797.3	304.0	1 316.4	329.0	51.0	16.7	37.7	9 851.9
1991	8 011.8	284.6	1 346.4	330.8	52.1	14.1	38.8	10 078.7
1992	8 190.8	292.4	1 414.1	374.4	51.7	16.3	41.4	10 381.3
1993	8 327.8	291.7	1 450.1	383.7	52.0	15.8	43.2	10 564.3

LCV Light commercial vehicle

Note Annual vehicle numbers from ABS motor vehicle registrations data are not fully comparable over time due to changes in definition of the various vehicle types during the last 20 years. BTCE estimates have been adjusted using SMVU data on fleet characteristics to allow for inconsistencies between various years.

Sources ABS (1993a, 1993b, 1992b, 1989a, 1986b, 1983, 1981a, 1981b, 1978, 1973); BTCE estimates based on ABS SMVU (1993a and earlier); ABS *Motor Vehicle Census* (1992b and earlier); ABS *Motor Vehicle Registrations* (1994a and earlier); CBCS (1973, p. 29); ABS (1981a); Cosgrove & Gargett (1992); BTCE (1994a) Indicators Database.

TABLE III.2 ANNUAL VEHICLE KILOMETRES TRAVELLED BY ROAD VEHICLE TYPE, 1970–71 TO 1992–93

(10^9 kilometres)

Year ending June	Vehicle type							
	Car	Motor cycle	LCV	Rigid truck	Articulated truck	Other truck	Bus	Total
1971	63.81	1.01	9.84	4.56	1.72	0.14	0.58	81.67
1972	66.13	1.10	10.26	4.52	1.77	0.17	0.59	84.54
1973	68.06	1.20	10.81	4.51	1.79	0.20	0.61	87.18
1974	72.60	1.30	11.80	4.60	1.82	0.27	0.62	93.00
1975	76.82	1.40	12.68	4.68	1.88	0.36	0.63	98.45
1976	79.04	1.64	13.67	4.83	2.01	0.42	0.63	102.23
1977	82.71	1.68	14.94	4.71	2.15	0.44	0.64	107.28
1978	85.85	1.73	16.13	4.64	2.27	0.46	0.65	111.73
1979	87.72	1.77	17.17	4.67	2.61	0.46	0.66	115.05
1980	88.77	1.90	16.93	5.26	2.79	0.39	0.69	116.73
1981	90.28	2.00	17.44	5.83	2.80	0.30	0.73	119.39
1982	95.71	2.18	18.47	6.73	3.00	0.24	0.77	127.10
1983	96.21	2.20	18.12	6.00	2.99	0.22	0.87	126.62
1984	100.58	2.25	19.60	5.93	3.23	0.23	0.97	132.80
1985	105.67	2.28	21.63	6.10	3.59	0.24	1.07	140.58
1986	109.49	2.10	21.43	5.98	3.60	0.24	1.15	143.99
1987	112.32	2.00	21.84	6.02	3.68	0.26	1.22	147.35
1988	116.78	1.92	23.30	6.43	3.84	0.26	1.29	153.82
1989	121.70	2.00	23.62	6.46	4.06	0.27	1.35	159.46
1990	124.58	1.92	22.93	6.55	4.10	0.24	1.38	161.68
1991	122.57	1.61	22.81	6.11	3.96	0.20	1.36	158.62
1992	124.88	1.65	23.22	6.39	4.19	0.23	1.45	162.02
1993	128.04	1.65	24.18	6.75	4.42	0.22	1.51	166.77

LCV Light commercial vehicle

Note Utilisation estimates (vehicle kilometres travelled) have been based on triennial ABS SMVU data, interpolated using fuel sales series (from ABARE) and vehicle population statistics (from ABS). Data on bus usage is limited, and the bus estimates are very approximate.

Sources ABS (1993a, 1993b, 1992b, 1989a, 1986b, 1983, 1981a, 1981b, 1978, 1973); CBCS (1973); Apelbaum (1993, pp. 17, 22); Cosgrove & Gargett (1992); BTCE estimates based on ABS SMVU (1993a and earlier), ABS *Motor Vehicle Census* (1992b and earlier); ABS *Motor Vehicle Registrations* (1994a and earlier); Adena & Montesin (1988, p. 140); ABARE (1991); Bush et al. (1993, p. 112); BTCE (1994a) Indicators Database; Hensher (1989); Wilkenfeld (1991, p. 151).

Comparing growth trends of the different vehicle types is complicated by discontinuities in the basic data series (annual motor vehicle registration data compiled by the Australian Bureau of Statistics [ABS]) due to changes in data coverage, methods of collection and vehicle classification. The BTCE has sought to derive consistent time series on fleet composition (given in table III.1) using published and unpublished data from the ABS *Survey of Motor Vehicle Use* (ABS 1993a and earlier). The ABS has conducted the *Survey of Motor Vehicle Use* (SMVU) approximately triennially over the last 20 years. Figures for years between surveys have been interpolated using annual percentage changes in the different vehicle stocks, derived from ABS (1994a and earlier) vehicle registration data.

The vehicle types most affected by revisions to the vehicle classification categories are rigid trucks and buses, and the statistics presented for these vehicle types are necessarily very approximate. Note that 'other trucks' are special purpose vehicles, such as fire engines or mobile cranes, having little or no freight carrying capacity. The vehicle categories used in this Report are defined in the glossary.

DOMESTIC FREIGHT

The movement of freight within Australia comprises a collection of activities as diverse in character as in geographical location, including the long-haul movement of domestic raw materials for secondary industry (primarily iron ore, oil and coal) by coastal sea freight, the carriage of primary products from inland mines and farms to coastal city markets and export ports by railway, and the urban and inter-city distribution of non-bulk goods by road transport.

The composition of the Australian road freight task for 1970–71 to 1992–93 is shown in table III.3. Articulated trucks perform the greatest share (83 per cent) of the non-urban road freight task (which totalled 67.4 billion tonne-kilometres in 1992–93), while the urban task (31.1 billion tonne-kilometres in 1992–93) is more evenly split between rigid and articulated trucks (with 42 and 48 per cent respectively). Light commercial vehicles (LCVs) account for a major part (68 per cent) of total kilometres travelled by commercial vehicles, but represent a minor component of the total road freight task in terms of tonne-kilometres (where tonne-kilometres are calculated as the product of the weight of the freight by the distance carried).

Based on SMVU data (ABS 1993a, p 21; 1993b), bulk commodities account for around 27 per cent of the total road freight task (with around 24 billion bulk tonne-kilometres out of 88.2 billion tonne-kilometres in 1990–91). Bulk freight by rail accounts for around 70 per cent of government rail freight tonne-kilometres (tkm) and most of private rail freight, giving an overall bulk freight share of 80 per cent of total rail tkm (Apelbaum 1993, pp 37–40; BTCE 1994a). Air freight is almost exclusively non-bulk and coastal sea freight is predominantly bulk (92 per cent of total tkm).

TABLE III.3 AUSTRALIAN ROAD FREIGHT TASK BY VEHICLE TYPE AND AREA OF OPERATION, 1970–71 TO 1992–93

(10^9 tonne-kilometres)

Year ending June	Light commercial vehicle			Rigid truck			Articulated truck		
	Urban	Non-urban	Total	Urban	Non-urban	Total	Urban	Non-urban	Total
1971	0.75	0.62	1.37	5.41	5.21	10.62	3.00	12.20	15.20
1972	0.81	0.63	1.44	5.44	5.16	10.61	3.45	13.16	16.61
1973	0.88	0.65	1.53	5.51	5.15	10.67	3.87	13.92	17.79
1974	1.00	0.69	1.68	5.70	5.25	10.95	4.34	14.71	19.05
1975	1.11	0.72	1.82	5.89	5.33	11.22	4.94	15.80	20.75
1976	1.24	0.75	1.99	6.16	5.51	11.67	5.74	17.30	23.04
1977	1.38	0.82	2.20	6.27	5.85	12.12	6.28	18.96	25.23
1978	1.54	0.88	2.41	6.48	6.23	12.71	6.76	20.46	27.21
1979	1.67	0.93	2.60	6.85	6.80	13.64	7.90	24.00	31.90
1980	1.60	0.98	2.59	7.34	7.18	14.52	8.90	26.31	35.22
1981	1.62	1.08	2.70	7.68	7.52	15.20	9.39	27.12	36.51
1982	1.66	1.21	2.88	8.48	7.77	16.24	10.49	29.76	40.25
1983	1.65	1.21	2.86	8.19	7.37	15.55	10.67	30.69	41.36
1984	1.80	1.34	3.15	8.76	7.74	16.49	11.84	34.32	46.16
1985	2.01	1.51	3.52	9.69	8.43	18.12	13.44	39.23	52.66
1986	2.22	1.53	3.75	10.37	8.21	18.58	13.73	40.32	54.05
1987	2.51	1.61	4.12	11.35	8.12	19.46	14.34	41.83	56.17
1988	2.94	1.74	4.68	12.86	8.27	21.13	15.21	44.52	59.72
1989	2.90	1.83	4.73	12.93	8.73	21.66	15.54	48.13	63.67
1990	2.84	1.88	4.73	13.15	8.84	21.99	15.08	49.53	64.61
1991	2.86	1.89	4.75	12.16	8.39	20.55	14.01	48.90	62.91
1992	2.93	1.94	4.81	12.46	8.97	21.43	14.22	52.74	66.97
1993	3.05	2.02	5.07	13.17	9.47	22.64	14.93	55.89	70.82

Note Figures refer to unlinked freight movements. Urban figures refer to freight moved wholly within cities of population greater than 40 000. Non-urban figures refer to all other freight movements.

Sources ABS (1993a, 1993b, 1986b, 1983, 1981b, 1978, 1973); Apelbaum (1993, p. 30); Cosgrove & Gargett (1992, p. 235); BTCE (1991a, 1991b); BTE (1980, 1975); BTCE estimates.

The total domestic freight task by transport vehicles (that is, excluding pipelines) was about 290 billion tkm for 1992–93 (table III.4), of which about 67 per cent is due to bulk commodities and 33 per cent to non-bulk. The estimates can be extended to cover freight transport by both mobile and stationary engines by including major pipeline transport (that is, pipelines involved in the transmission of fuels between points of extraction and the distribution system—data on the freight task due to the urban piped distribution of water and gas is not available). Major oil and gas pipelines account for around 6 per cent of the total domestic freight task undertaken by mobile and stationary engines (Apelbaum 1993, pp. 53–60). In 1990–91, the oil pipeline network transported 18.9 Mt of oil, accounting for a task of 6.7 billion tkm (Apelbaum 1993, p. 55), and the natural gas (NG) pipeline network transported 12.2 Mt of gas, accounting for a task of 10.5 billion tkm. Scaling by the growth in oil and NG between 1990–91 and 1992–93 gives an estimated fuel pipeline task of 18 billion tkm for 1992–93. The result is an estimated total domestic freight task (including pipelines) of 308 billion tkm for 1992–93, of which 69 per cent is bulk and 31 per cent is non-bulk.

TABLE III.4 THE AUSTRALIAN DOMESTIC FREIGHT TASK (EXCLUDING PIPELINES), 1970–71 TO 1992–93

(10^9 tonne-kilometres)

Year ending June	Mode								
	Road			Rail			Sea	Air	Total
	Urban	Non-urban	Total	Government	Private	Total			
1971	9.1	18.1	27.2	25.2	13.8	39.0	72.0	0.09	138.3
1972	9.7	19.0	28.7	25.4	16.6	42.0	83.2	0.09	154.0
1973	10.2	19.7	29.9	26.6	20.0	46.6	89.5	0.09	166.1
1974	11.0	20.7	31.7	28.3	26.5	54.8	96.1	0.11	182.7
1975	11.9	21.9	33.8	29.8	30.2	60.0	101.2	0.11	195.1
1976	13.1	23.6	36.7	30.8	26.3	57.1	104.6	0.11	198.5
1977	13.9	25.7	39.6	32.0	27.3	59.3	102.3	0.11	201.3
1978	14.7	27.6	42.3	31.5	28.4	59.9	105.1	0.11	207.5
1979	16.4	31.8	48.2	33.4	25.6	59.0	104.7	0.11	212.0
1980	17.8	34.5	52.3	35.4	27.8	63.2	105.1	0.11	220.7
1981	18.6	35.8	54.4	37.4	28.9	66.3	110.3	0.11	231.1
1982	20.6	38.8	59.4	38.0	27.4	65.4	97.8	0.12	222.7
1983	20.5	39.3	59.8	34.0	25.0	59.0	80.9	0.12	199.8
1984	22.4	43.4	65.8	40.1	23.3	63.4	94.3	0.14	223.6
1985	25.1	49.2	74.3	44.2	28.4	72.6	96.3	0.14	243.4
1986	26.3	50.1	76.4	48.2	29.2	77.4	101.8	0.14	255.7
1987	28.2	51.6	79.8	49.6	30.3	79.9	95.2	0.13	255.0
1988	31.0	54.5	85.5	50.5	31.0	81.5	93.6	0.14	260.7
1989	31.4	58.7	90.1	51.9	28.7	80.6	90.7	0.14	261.6
1990	31.1	60.3	91.4	54.4	32.5	86.9	94.2	0.08	272.6
1991	29.0	59.2	88.2	54.8	35.3	90.1	93.8	0.12	272.2
1992	29.6	63.6	93.3	56.7	35.1	91.7	96.4	0.13	281.5
1993	31.1	67.4	98.5	59.4	35.8	95.2	96.0	0.14	289.9

Note Figures refer to unlinked freight movements. Urban figures refer to freight moved wholly within cities of population greater than 40 000 in the relevant year. Non-urban figures refer to all other freight movements.

Sources Apelbaum (1993, pp. 30, 37, 40, 49, 50); ABS (1993a, 1991b, 1986b, 1983, 1981a, 1981b, 1978, 1973); CBCS (1973); BTCE (1991a, 1991b, 1989); BTE (1982, 1980, 1975); DTC (1991a, 1991b); Cosgrove & Gargett (1992, p. 234); BTCE (1994a) Indicators Database; BTCE estimates.

URBAN PASSENGER

Australia is highly urbanised, with ten urban localities accounting for about 70 per cent of the population (ABS 1991a). But the larger Australian cities are generally decentralised, typically evolving by the gradual extension of outer residential areas. This type of development, which frequently involves large distances between residential and work locations, has resulted in considerable dependence being placed on private cars for urban commuting, and correspondingly limited reliance on public transit systems.

Table III.5 presents estimates for motorised urban travel (from 1970–71 to 1992–93), in which the dominance of the private automobile is evident. In 1992–93, the car accounted for about 87 per cent of almost 158 billion urban (motorised) passenger-kilometres (pkm) while the public transport share was less than 8 per cent (with bus at 3 per cent, rail at 4.6 per cent and ferry at 0.2 per cent). Passenger-kilometres are calculated as the product of the number of passengers by the distance travelled.

Non-motorised travel (walking and cycling) forms a significant proportion of the total number of trips undertaken in urban areas, but accounts for only a small share of total urban passenger-kilometres. Between 2 and 4 per cent of urban trips are by bicycle. Since the average trip length for urban cycling is only 2.5 km (Adena & Montesin 1988, pp. 131–132), bicycle trips account for less than 1 per cent of total urban pkm. Bicycle travel is approximately evenly split between children travelling 2 km at a time, generally to school, and adults travelling about 3.5 km a time (Wigan 1994a, p. 5).

Most journeys involve some walking. For example, a journey to work may consist of the following trip segments (a component of a journey undertaken by a distinct mode): car trip to parking lot, walk to bus terminal, bus trip to inner-city bus stop, walk to work location. On the basis of the number of urban trip segments, walking accounts for a considerable share (up to 20 per cent of total trips). Around 6 per cent of journeys to work are undertaken solely on foot. However, the average trip length for walking is less than 1 km, and pedestrians account for less than 2 per cent of total urban passenger-kilometres (Adena & Montesin 1988, p. 132).

Although distances are typically short for walking trips, the slow average speed of 4.7 km/h for pedestrians (Wigan 1994b, p. 8) can result in walking accounting for a substantial portion of the total time spent travelling. For Australians aged in their mid-20s, time spent walking is around 10 per cent of daily travel time, while for 9- to 15- year-olds and those over 65 walking accounts for around 20 per cent (Wigan 1994b, p. 12).

Time series data are not readily available for non-motorised travel, but it does appear that the transport shares of walking and cycling have declined slightly over the last 20 years. Between 1970 and 1980, non-motorised journeys to

TABLE III.5 AUSTRALIAN URBAN (MOTORISED) PASSENGER TASK, 1970–71 TO 1992–93

(10^9 passenger-kilometres)

	Mode							
	Road					Rail[b]	Ferry	Total
Year ending June	Car[a]	Light commercial vehicle	Truck	Bus	Motor-cycle			
1971	66.50	2.21	0.41	3.50	0.66	7.32	0.16	80.76
1972	69.85	2.57	0.42	3.51	0.72	6.61	0.16	83.84
1973	71.79	3.01	0.42	3.66	0.78	6.23	0.15	86.04
1974	76.34	3.60	0.44	3.80	0.85	6.30	0.15	91.48
1975	80.54	4.13	0.44	3.89	0.91	6.01	0.18	96.10
1976	82.62	4.71	0.44	3.91	1.07	5.96	0.19	98.91
1977	88.07	5.21	0.41	3.97	1.05	5.86	0.18	104.76
1978	91.14	5.59	0.39	4.00	1.09	5.71	0.15	108.06
1979	92.84	6.10	0.36	4.06	1.11	5.67	0.14	110.27
1980	93.36	5.69	0.39	4.19	1.20	6.13	0.13	111.09
1981	94.67	5.59	0.42	4.16	1.29	6.29	0.15	112.57
1982	100.06	5.62	0.44	4.19	1.36	6.46	0.17	118.30
1983	100.29	5.44	0.42	4.17	1.40	6.30	0.18	118.19
1984	104.53	5.85	0.39	4.15	1.43	6.35	0.19	122.89
1985	113.88	6.38	0.37	4.26	1.47	6.43	0.20	132.99
1986	117.76	6.24	0.38	4.34	1.43	6.97	0.20	137.32
1987	123.33	6.32	0.37	4.43	1.40	7.18	0.23	143.25
1988	131.32	6.75	0.37	4.51	1.35	7.47	0.24	152.03
1989	134.53	6.61	0.34	4.66	1.41	7.67	0.24	155.48
1990	136.34	6.52	0.31	4.55	1.35	7.47	0.26	156.82
1991	133.72	6.65	0.26	4.62	1.06	7.52	0.26	154.11
1992	134.52	6.41	0.26	4.96	1.09	7.52	0.25	155.04
1993	137.49	6.52	0.27	4.72	1.09	7.18	0.25	157.55

a. Includes taxis. In 1990–91, taxis comprised around 1.7 per cent of the urban car task.

b. Includes trams. Between 1970–71 and 1992–93, the tram passenger task was of the order of 0.6 billion pkm per year, that is, around 8 per cent of the urban rail task.

Note Figures refer to unlinked passenger trips. Urban figures refer to travel wholly within cities of population greater than 40 000 each year.

Sources Apelbaum (1993, pp. 25, 26, 35, 36, 52); Adena & Montesin (1988); Cosgrove & Gargett (1992); ABS (1993a, 1991b, 1989a, 1986b, 1983, 1981a, 1981b, 1978, 1973); CBCS (1973); BTCE (1991a, 1991b); BTE (1980, 1975); NELA (1988); Newman & Kenworthy (1990); RIC (1990); BTCE (1994a) Indicators Database; BTCE estimates.

work accomplished solely by walking or cycling decreased from 7.5 per cent of total work journeys to 5.4 per cent for Sydney, and from 10.4 to 5.7 per cent work accomplished solely by walking or cycling decreased from 7.5 per cent of total work journeys to 5.4 per cent for Sydney, and from 10.4 to 5.7 per cent for Melbourne (Newman & Kenworthy 1989). Data from the Transport Study Group of NSW (STSG 1985; Itorralba & Balce 1992) imply that non-motorised travel share for Sydney declined from 20 per cent of morning peak trips in 1971 to 15 per cent in 1981, but did not reduce any further (and possibly rose slightly) by 1991.

Adjusting the BTCE estimates for the motorised urban passenger task (157.6 billion pkm in 1992–93, from table III.5) upward by 2.7 per cent (derived from Adena and Montesin 1988), to allow for non-motorised travel, gives an estimate of 162 billion pkm for the total urban passenger task in 1992–93, with modal shares of: car 84.9 per cent, LCV 4.0 per cent, truck 0.2 per cent, bus 2.9 per cent, motorcycle 0.7 per cent, rail 4.4 per cent, ferry 0.2 per cent, walking 1.9 per cent, and bicycle 0.8 per cent. Although non-motorised travel has a minor share of total urban passenger-kilometres, its share is similar to (or greater than) that of urban taxis, motorcycles or buses.

NON-URBAN PASSENGER

Estimates of the Australian motorised non-urban passenger task are presented in table III.6. The dominance of private car travel is again apparent, with 61.3 per cent of 1992–93 non-urban (motorised) passenger-kilometres being performed by cars. After cars, the main segments of the 1992–93 task were due to air travel (19 per cent), buses and coaches (11 per cent), and light commercial vehicles (5.5 per cent).

Data reported by Adena and Montesin (1988, pp. 140, 148) imply that non-motorised transport accounts for about 2.6 per cent of day-to-day (that is, not long distance) travel in non-urban areas (1.3 per cent by walking and 1.3 per cent by bicycle). Interstate travel accounts for about 20 per cent of non-urban motor vehicle kilometres travelled. Therefore, if we assume that the remaining 80 per cent of non-urban road travel (around 67 billion pkm for 1992–93) approximates non-urban day-to-day travel, we have an estimated non-motorised task of 1.8 billion pkm in non-urban travel for 1992–93. The total (motorised and non-motorised) non-urban passenger task for 1992–93 is thus around 108.2 billion pkm.

INTERNATIONAL FREIGHT

Between 1970–71 and 1992–93 Australia's international freight task increased by approximately 186 per cent in tonne-kilometre terms (details of the

TABLE III.6 AUSTRALIAN NON-URBAN (MOTORISED) PASSENGER TASK, 1970–71 TO 1992–93

(10^9 passenger-kilometres)

	Mode								
	Road					Rail	Air[a]	Sea[b]	Total
Year ending June	Car	Light commercial vehicle	Truck	Bus	Motor-cycle				
1971	41.87	2.63	0.43	3.1	0.46	6.1	5.20	0.54	60.33
1972	42.00	2.93	0.44	3.2	0.49	5.0	5.61	0.54	60.21
1973	42.98	3.29	0.44	3.2	0.54	5.0	6.16	0.54	62.15
1974	45.71	3.76	0.46	3.2	0.58	3.8	7.34	0.54	65.39
1975	48.22	4.12	0.46	3.2	0.63	3.2	7.93	0.54	68.30
1976	49.47	4.50	0.46	3.3	0.74	2.6	7.74	0.55	69.36
1977	49.52	4.76	0.44	3.3	0.79	2.7	7.46	0.54	69.51
1978	51.25	4.84	0.42	3.3	0.82	2.7	8.15	0.54	72.02
1979	52.20	4.98	0.40	3.3	0.83	2.7	8.58	0.54	73.53
1980	53.02	4.84	0.45	3.7	0.89	2.6	9.49	0.54	75.53
1981	53.76	5.01	0.50	4.2	0.91	3.0	9.57	0.55	77.50
1982	56.82	5.22	0.54	4.7	1.00	2.9	10.06	0.55	81.79
1983	56.95	5.13	0.49	6.1	1.02	3.0	9.25	0.55	82.49
1984	59.36	5.50	0.45	7.6	1.05	2.9	9.81	0.55	87.22
1985	57.26	6.04	0.41	9.0	1.03	3.0	10.59	0.61	87.94
1986	59.49	5.55	0.38	9.9	0.88	2.7	11.47	0.57	90.94
1987	57.61	5.26	0.34	10.9	0.80	2.7	12.28	0.49	90.38
1988	55.83	5.23	0.31	11.8	0.77	2.9	13.57	0.40	90.81
1989	60.16	5.45	0.31	12.5	0.79	2.9	14.15	0.40	96.66
1990	62.47	5.60	0.30	12.9	0.76	2.5	10.41	0.41	95.35
1991	61.27	5.93	0.23	12.3	0.72	2.5	15.66	0.39	99.00
1992	63.75	5.75	0.23	11.4	0.74	2.3	20.24	0.38	104.79
1993	65.16	5.84	0.24	11.7	0.74	2.2	20.15	0.38	106.41

a. Includes general aviation. The strong decline in 1989–90 air travel was due to the airline pilots' dispute.

b. Cruises and Bass Strait ferries.

Note Figures refer to unlinked trips. Non-urban figures refer to all passenger movements except those wholly within cities of population greater than 40 000 each year.

Sources Apelbaum (1993, pp. 25, 36, 49, 52, 166); ABS (1993a, 1991b, 1989a, 1986b, 1983, 1981a, 1981b, 1978, 1973); CBCS (1973); BTCE (1991a, 1991b); Cosgrove & Gargett (1992); BTE (1980, 1975); DTC (1991b); NELA (1988); Transport Tasmania (1990); BTCE (1994a) Indicators Database; BTCE estimates.

calculation of international tonne-kilometres from import and export tonnages are given in chapter 5).

Shipping is by far the dominant carrier for both exports and imports in terms of tonne-kilometres performed. In 1992–93, the export freight task was more than 10 times the level of imports (see table III.7). For import tonne-kilometres in 1992–93, bulk commodities accounted for 78.5 per cent and non-bulk for 21.5 per cent, while for exports bulk comprised 97 per cent and non-bulk 3 per cent. The bulk share of total international shipping for 1992–93 (4331 billion tkm) is therefore about 95.4 per cent.

Air freight is carried mainly on scheduled passenger services and the goods are typically high value, small volume and perishable in nature (BTCE 1991a). Unlike sea freight, import and export levels carried by air are of similar proportions. Between 1971 and 1993, total international air freight in tonne-kilometres increased by more than 14 times.

INTERNATIONAL PASSENGER MOVEMENTS

In contrast to international freight, international passenger movements are undertaken almost exclusively by air (table III.8). The number of passenger-kilometres travelled to and from Australia in 1992–93 was over 6 times greater than in 1970–71 (details of the calculation of international passenger-kilometres from passenger arrivals and departures are given in chapter 4). Since net immigration (permanent international arrivals minus permanent international departures, typically less than 1 per cent) is relatively small compared with total international arrivals and departures, passenger flows into and out of Australia, by both sea and air transport, are roughly equivalent (figures III.1 and III.2).

Foreign tourism to Australia is the fastest growing sector of the aviation market. Since the 1970s, growth in the number of foreign arrivals has averaged 11 per cent per annum, while that of Australian residents departing on overseas trips has been lower at 5.7 per cent per annum (time series provided in appendix X).

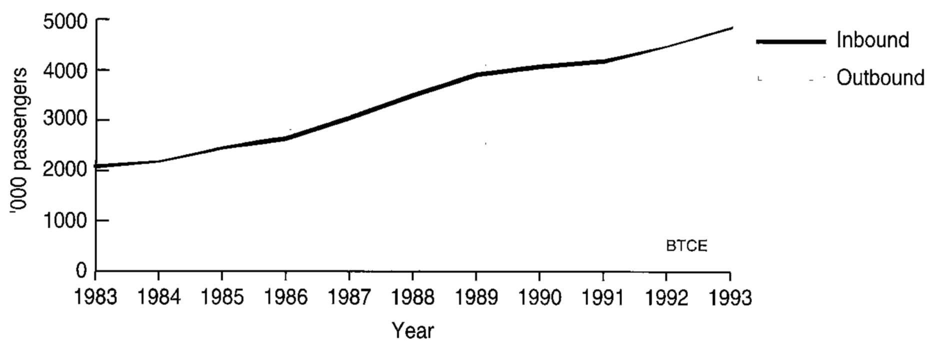
Passenger-kilometres due to international sea travel are very small compared to air (at less than 0.4 per cent of total international pkm for 1993), declining significantly since the 1970s.

TABLE III.7 INTERNATIONAL FREIGHT TASK TO AND FROM AUSTRALIA, 1970–71 TO 1992–93

(10^9 tonne-kilometres)

Year ending June	Air			Sea			
	Imports	*Exports*	*Total*	*Imports*	*Exports*	*Total*	*Total*
1971	0.15	0.10	0.24	231.23	1282.69	1513.92	1514.16
1972	0.16	0.13	0.29	210.65	1383.00	1593.66	1593.94
1973	0.22	0.16	0.38	217.80	1694.23	1912.04	1912.42
1974	0.35	0.20	0.55	248.99	1926.03	2175.02	2175.57
1975	0.41	0.25	0.66	236.44	2110.28	2346.73	2347.39
1976	0.47	0.28	0.75	212.95	1998.50	2211.46	2212.21
1977	0.49	0.29	0.78	221.98	2110.71	2332.69	2333.47
1978	0.54	0.35	0.89	234.48	2105.14	2339.63	2340.52
1979	0.66	0.46	1.12	236.35	2113.20	2349.55	2350.67
1980	0.70	0.52	1.22	274.70	2398.44	2673.14	2674.36
1981	0.68	0.52	1.21	289.08	2284.97	2574.05	2575.26
1982	0.86	0.65	1.50	278.31	2257.64	2535.94	2537.44
1983	0.86	0.73	1.59	256.99	2193.15	2450.14	2451.72
1984	1.04	0.81	1.84	244.07	2682.33	2926.40	2928.25
1985	1.12	0.93	2.05	250.99	3161.93	3412.92	3414.97
1986	0.99	1.09	2.08	220.04	3128.98	3349.03	3351.11
1987	0.97	1.25	2.22	254.22	3096.12	3350.34	3352.56
1988	1.10	1.19	2.29	299.94	3472.08	3772.02	3774.31
1989	1.50	1.22	2.72	378.54	3399.98	3778.52	3781.24
1990	1.54	1.30	2.84	356.55	3559.40	3915.95	3918.78
1991	1.53	1.36	2.89	362.66	3883.94	4246.60	4249.49
1992	1.58	1.48	3.06	323.12	3929.64	4252.76	4255.82
1993	1.68	1.78	3.46	369.27	3961.35	4330.62	4334.09

Sources ABS (1991c and earlier); BTCE (1994a) Indicators Database; BTCE estimates based on Apelbaum (1993, pp. 64, 67, 68, 161, 169); BTCE (1993c, 1988); CBCS (1973); DTC (1993b and earlier).



Source DTC (1993 and earlier).

Figure III.1 International air passengers to and from Australia

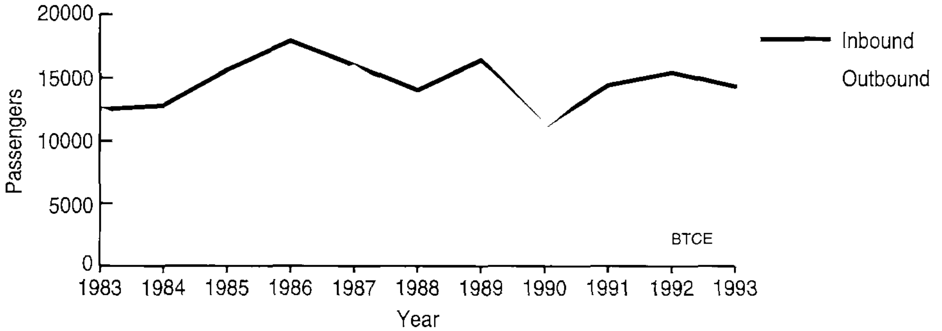
TABLE III.8 INTERNATIONAL PASSENGER TASK TO AND FROM AUSTRALIA, 1970–71 TO 1992–93

(10^9 passenger-kilometres)

Year ending June	*Air*	*Sea*	*Total*
1971	11.02	1.94	12.96
1972	14.77	1.60	16.37
1973	17.54	1.32	18.86
1974	20.87	1.19	22.06
1975	23.08	0.82	23.90
1976	26.38	0.64	27.02
1977	26.58	0.60	27.18
1978	29.15	0.42	29.57
1979	34.36	0.53	34.89
1980	34.88	0.47	35.35
1981	32.24	0.21	32.45
1982	33.05	0.15	33.20
1983	32.04	0.20	32.24
1984	33.50	0.19	33.69
1985	37.12	0.29	37.41
1986	39.12	0.32	39.44
1987	44.03	0.29	44.32
1988	50.66	0.21	50.87
1989	57.55	0.26	57.81
1990	59.50	0.18	59.68
1991	60.86	0.24	61.10
1992	63.40	0.27	63.67
1993	70.45	0.25	70.70

Note 1. Figures refer to both inward and outward travel.
2. Passenger flows into and out of Australia, by both sea and air transport, are roughly equivalent, so arrivals or departures can be roughly estimated by dividing the value provided by two.

Sources BTCE (1994a) Indicators Database; BTCE estimates based on Apelbaum (1993, pp. 64, 70, 161, 170); BTCE (1993c, 1988); CBCS (1973); DTC (1993b and earlier).



Source ABS (1993c).

Figure III.2 International sea passengers to and from Australia

APPENDIX IV AUSTRALIAN TRANSPORT FUEL CONSUMPTION

This appendix provides time series estimates of transport fuel consumption by each mode of transport in performing the Australian transport task outlined in appendix III. Fuel consumption is measured in petajoules (PJ) of energy consumed in order to take account of each transport mode using different types of fuel with different energy contents. The energy consumption figures provided are 'end-use'; that is, energy use resulting solely from vehicle operation. The figures do not contain energy consumption involved in the fuel refining process, electricity generation or electricity transmission losses.

Different fuels are consumed by each transport mode. For example, the main fuel consumed by passenger cars is automotive gasoline, commonly called petrol. However, small amounts of automotive diesel oil, liquefied petroleum gas (LPG) and compressed natural gas (CNG) are also used. In the case of trucks, diesel is the main fuel consumed although small quantities of petrol, LPG and CNG are also consumed. The major fuel used for rail transport is automotive diesel oil (ADO). However, industrial diesel fuel (IDF) and electricity are also used. Electricity consumed by rail is used mainly for the movement of urban rail passengers. However, a small amount is also used for the movement of government freight (Apelbaum 1993, p. 100). International aviation uses aviation turbine fuel (avtur). The domestic aviation market consumes both aviation gasoline (avgas) and aviation turbine fuel (avtur). Aviation gasoline is used primarily by the general aviation market (consisting of commuter and charter services, private and training flights, and aerial agricultural work) while aviation turbine fuel is used primarily by scheduled airline services. Sea transport consumes mainly fuel oil, although small quantities of automotive diesel oil and industrial diesel fuel are also used.

Times series estimates for Australian domestic transport energy consumption for each transport mode are provided in table IV.1. Due to a lack of detailed data, the time series in the appendix do not separate out miliary fuel use, do not include pipelines and only include marine fuel use due to coastal shipping (that is, pleasure craft, fishing boats and urban ferries are excluded).

TABLE IV.1 AUSTRALIAN DOMESTIC TRANSPORT ENERGY CONSUMPTION BY MODE, 1970–71 TO 1992–93

(petajoules)

Year ending June	Mode				
	Road	Air	Sea	Rail	Total
1971	392.8	25.9	34.5	21.5	474.7
1972	409.1	27.9	40.0	23.0	500.0
1973	426.3	30.9	43.0	26.0	526.2
1974	455.2	36.4	45.9	27.7	565.2
1975	483.5	39.9	40.1	29.1	592.6
1976	507.3	40.3	36.1	29.9	613.6
1977	537.4	41.5	42.9	29.9	651.7
1978	560.7	44.2	51.6	30.3	686.8
1979	587.9	43.6	43.8	30.9	706.2
1980	597.6	45.3	48.3	30.8	722.0
1981	607.1	45.1	47.9	30.8	730.9
1982	641.4	48.1	38.7	30.6	758.8
1983	630.7	46.7	38.0	28.2	743.6
1984	657.4	46.4	37.4	30.4	771.6
1985	691.5	47.5	34.0	32.1	805.1
1986	703.6	50.8	34.1	31.2	819.7
1987	717.6	52.8	35.6	32.4	838.4
1988	752.6	56.4	34.1	32.3	875.4
1989	780.4	55.9	31.3	30.5	898.1
1990	791.5	45.7	27.0	30.2	894.4
1991	778.5	56.4	22.6	30.0	887.5
1992	796.0	61.1	25.9	29.3	912.3
1993	815.9	63.9	20.1	28.8	928.7

Notes 1. End-use figures (that is, energy consumption resulting solely from vehicle operation).
2. Figures include energy consumption by military transport.
3. Energy use for bunkers, pipelines, fishing and pleasure craft, and ferries is excluded.

Sources Bush et al. (1993); ABARE (S. Bush pers. comm. 1994); Apelbaum (1993); BTCE estimates.

For 1992–93, the BTCE has calculated the following detailed sectoral estimates of Australian transport energy consumption (adjusting for the above exclusions):

- 937 PJ for domestic civil transport and 14.7 PJ for military transport;
- domestic civil transport energy use composed of 55.9 PJ for domestic aviation (6 per cent), 815.9 PJ for the road sector (87 per cent), 32.5 PJ for the maritime sector (3.5 per cent), 28.8 PJ for rail transport (3.1 per cent) and 3.8 PJ for pipelines (0.4 per cent);

- Australian bunker fuel use by international air transport of 72.5 PJ and by international sea transport of 24.8 PJ.

ROAD

Energy consumption by road vehicles doubled between 1970–71 and 1992–93. A breakdown of energy consumption by vehicle type is provided in table IV.2. Cars, the largest energy consumption item, accounted for around 64.5 per cent of total energy consumption in 1992–93. Cars are followed by trucks (rigid, articulated, other and light commercial vehicles) with 32.9 per cent, buses with 2.2 per cent and motorcycles with 0.4 per cent.

TABLE IV.2 ENERGY CONSUMPTION BY ROAD VEHICLES, 1970–71 TO 1992–93

(petajoules)

Year ending June	Vehicle type							Total
	Cars	Motor-cycles	LCVs	Rigid trucks	Articulated trucks	Other trucks	Buses	
1971	268.01	2.05	39.55	45.78	29.64	0.71	7.04	392.78
1972	278.68	2.23	42.01	47.38	30.78	0.85	7.16	409.08
1973	289.30	2.43	45.31	48.90	31.98	0.98	7.34	426.25
1974	308.72	2.63	50.19	51.51	33.34	1.32	7.48	455.19
1975	326.78	2.83	55.07	54.03	35.35	1.76	7.65	483.47
1976	339.65	3.32	60.19	56.36	38.04	2.07	7.70	507.33
1977	356.03	3.40	67.20	57.60	42.31	3.00	7.81	537.35
1978	369.22	3.50	73.36	57.94	45.69	3.13	7.90	560.74
1979	380.59	3.46	79.14	60.30	53.27	3.13	8.03	587.91
1980	382.86	3.71	76.85	65.76	57.36	2.64	8.45	597.62
1981	387.18	3.91	77.01	69.88	57.66	2.60	8.85	607.09
1982	404.77	4.19	80.97	77.62	62.04	2.52	9.28	641.39
1983	403.12	4.22	79.28	69.59	61.82	2.34	10.33	630.71
1984	417.90	4.32	85.01	69.60	66.69	2.48	11.42	657.42
1985	432.24	4.53	93.33	72.33	74.17	2.36	12.58	691.54
1986	444.37	4.18	93.13	71.49	74.64	2.39	13.39	703.58
1987	452.68	3.98	94.91	72.70	76.50	2.56	14.23	717.56
1988	472.38	3.95	102.22	76.37	80.15	2.55	15.01	752.63
1989	495.96	4.04	104.21	75.35	82.88	2.63	15.31	780.38
1990	511.41	3.88	103.01	72.68	82.07	2.31	16.17	791.54
1991	511.60	3.21	106.88	61.84	77.36	1.58	16.00	778.47
1992	519.18	3.34	108.79	65.01	80.83	1.82	17.06	796.03
1993	526.59	3.33	113.20	68.74	84.30	1.76	18.00	815.92

Note End-use figures (that is, energy consumption resulting solely from vehicle operation).

Sources Apelbaum (1993); Cosgrove & Gargett (1992); BTCE estimates based on ABS SMVU (1993a and earlier); Bush et al. (1993); BTCE (1994a); Indicators Database; Hensher (1989); and Wilkenfeld (1991).

DOMESTIC FREIGHT

Table IV.3 provides energy consumption data for the Australian road freight transport sector between 1970–71 and 1992–93. In 1992–93, total energy consumption by road freight transport was around 266 PJ. The urban and non-urban split of energy consumption by freight transport vehicles is fairly even, with non-urban accounting for about 53 per cent.

Light commercial vehicles (LCVs) are responsible for 42 per cent of total energy consumption by road freight transport. In particular, LCVs account for over half of the total urban energy consumption. However, as noted in appendix III, LCVs represent a minor component of the total road freight task in terms of tonne-kilometres.

Articulated trucks account for around 32 per cent of total road freight energy consumption, but four-fifths of this energy consumption occurs in non-urban areas. Rigid trucks account for around 26 per cent of total energy used, and just over half of rigid truck energy consumption occurs in urban areas.

Energy use by all domestic freight transport between 1970–71 and 1992–93 is presented in table IV.4. In 1992–93, it is estimated that 309 PJ of energy was consumed by Australian freight transport (excluding pipelines). Around 86 per cent of this total can be attributed to energy use by the road freight sector. Rail and sea freight transport each account for around 7 per cent. Air freight transport is excluded from the table because freight is generally carried on passenger services.

Table IV.4 excludes the energy consumed by freight transport via pipelines. However, Apelbaum (1993, p. xvii), has estimated that in 1990–91 energy expended in the movement of gas or liquids in pipelines was around 3.5 PJ. If pipelines were to be included in the 1991 freight energy use total, they would account for around 1.2 per cent of energy used in freight transport.

URBAN PASSENGER

Outlined in table IV.5 is the consumption of energy by urban passenger transport between 1970–71 and 1992–93. Cars comprise the largest consumer of energy (97 per cent), followed by buses (2 per cent) and rail (1 per cent). Between 1970–71 and 1992–93, energy use by cars doubled while buses increased their energy use by almost 50 per cent. The dominance of energy consumption by cars in the urban area reflects the large number of passenger-kilometres travelled relative to other modes (table III.5 provides the number of urban passenger-kilometres travelled per year for each mode).

TABLE IV.3 ENERGY CONSUMPTION BY AUSTRALIAN ROAD FREIGHT VEHICLES, 1970–71 TO 1992–93

(petajoules)

Year ending June	*Articulated*			*Rigid*			*LCVs*			*Total*		
	Urban	*Non-urban*	*Total*	*Urban*	*Non-urban*	*Total*	*Urban*	*Non-urban*	*Total*	*Urban*	*Non-urban*	*Total*
1971	5.85	23.79	29.64	23.31	22.47	45.78	21.57	17.98	39.55	50.7	64.2	115.0
1972	6.39	24.39	30.78	24.30	23.07	47.38	23.58	18.43	42.01	54.3	65.9	120.2
1973	6.96	25.02	31.98	25.28	23.62	48.90	26.15	19.17	45.31	58.4	67.8	126.2
1974	7.60	25.74	33.34	26.83	24.68	51.51	29.73	20.46	50.19	64.2	70.9	135.0
1975	8.42	26.93	35.35	28.36	25.67	54.03	33.45	21.62	55.07	70.2	74.2	144.5
1976	9.47	28.56	38.04	29.77	26.59	56.36	38.91	22.67	60.19	78.2	77.8	154.6
1977	10.52	31.79	42.31	29.80	27.80	57.60	42.14	25.06	67.20	82.5	84.6	167.1
1978	11.34	34.35	45.69	29.53	28.41	57.94	46.70	26.66	73.36	87.6	89.4	177.0
1979	13.19	40.09	53.27	30.26	30.03	60.30	50.72	28.42	79.14	94.2	98.5	192.7
1980	14.50	42.85	57.36	33.24	32.51	65.76	47.63	29.22	76.85	95.4	104.6	200.0
1981	14.83	42.83	57.66	35.30	34.58	69.88	46.18	30.84	77.01	96.3	108.2	204.6
1982	16.17	45.87	62.04	40.51	37.11	77.62	46.88	34.09	80.97	103.6	117.1	220.6
1983	15.95	45.87	61.82	36.63	32.96	69.59	45.75	33.53	79.28	98.3	112.4	210.7
1984	17.11	49.59	66.69	36.95	32.65	69.60	48.76	36.25	85.01	102.8	118.5	221.3
1985	20.70	53.46	74.17	40.32	32.01	72.33	50.38	42.95	93.33	111.4	128.4	239.8
1986	18.96	55.68	74.64	39.90	31.60	71.49	55.13	37.99	93.13	114.0	125.3	239.3
1987	19.53	56.98	76.50	42.38	30.32	72.70	57.88	37.03	94.91	119.8	124.3	244.1
1988	23.84	56.31	80.15	48.89	27.47	76.37	59.83	42.39	102.22	132.6	126.2	258.7
1989	20.23	62.65	82.88	44.99	30.37	75.35	63.89	40.32	104.21	129.1	133.3	262.4

TABLE IV.3 (cont.)   ENERGY CONSUMPTION BY AUSTRALIAN ROAD FREIGHT VEHICLES, 1970–71 TO 1992–93

(petajoules)

Year ending June	*Articulated*			*Rigid*			*LCVs*			*Total*		
	Urban	*Non-urban*	*Total*	*Urban*	*Non-urban*	*Total*	*Urban*	*Non-urban*	*Total*	*Urban*	*Non-urban*	*Total*
1990	19.15	62.92	82.07	43.46	29.22	72.68	61.96	41.06	103.01	124.6	133.2	257.8
1991	20.33	57.03	77.36	37.13	24.71	61.84	60.31	46.58	106.88	117.8	128.3	246.1
1992	17.17	63.66	80.83	37.81	27.20	65.01	65.40	43.39	108.79	120.4	134.3	254.6
1993	17.77	66.53	84.30	39.98	28.76	68.74	68.05	45.15	113.20	125.8	140.4	266.2

Notes 1. End-use figures (that is, energy consumption resulting solely from vehicle operation).
2. 'Other trucks' are not included since they do not carry freight.

Sources ABS (1993a, 1993b, 1992b, 1986b, 1983, 1981a, 1978, 1973); Apelbaum (1993); Cosgrove & Gargett (1992); BTCE (1991a, 1991b); BTE (1980, 1975); BTCE estimates.

TABLE IV.4 AUSTRALIAN DOMESTIC FREIGHT ENERGY CONSUMPTION (EXCLUDING PIPELINES) 1970–71 TO 1992–93

(petajoules)

Year ending June	*Road*		*Rail*	*Sea*	*Total*
	Urban	*Non-urban*			
1971	50.73	64.24	n.a.	34.50	n.a.
1972	54.28	65.89	n.a.	40.00	n.a.
1973	58.39	67.81	n.a.	43.00	n.a.
1974	64.16	70.88	n.a.	45.90	n.a.
1975	70.23	74.23	n.a.	40.10	n.a.
1976	78.15	77.83	n.a.	36.10	n.a.
1977	82.47	84.65	n.a.	42.90	n.a.
1978	87.57	89.42	23.65	51.60	252.24
1979	94.17	98.54	24.50	43.80	261.01
1980	95.38	104.59	24.29	48.30	272.55
1981	96.31	108.25	24.01	47.90	276.46
1982	103.57	117.06	23.87	38.70	283.20
1983	98.34	112.36	21.59	38.00	270.28
1984	102.82	118.48	23.92	37.40	282.63
1985	111.40	128.43	25.59	34.00	299.42
1986	113.99	125.27	24.76	34.10	298.12
1987	119.79	124.33	26.02	35.60	305.73
1988	132.56	126.17	25.75	34.10	318.59
1989	129.11	133.34	23.74	31.30	317.48
1990	124.57	133.20	23.79	27.00	308.56
1991	117.78	128.31	23.49	22.60	292.17
1992	120.38	134.25	22.97	25.90	303.51
1993	125.80	140.44	22.73	20.10	309.07

n.a. Not available

Notes 1. End-use figures (that is, energy consumption resulting solely from vehicle operation).

2. Air transport is excluded from this table as air freight is generally carried on passenger services.

Sources Apelbaum (1993); ABS (1993a, 1991b, 1986b, 1983, 1981a, 1981b, 1978, 1973); CBCS (1973); BTCE (1991a, 1991b, 1989); BTE (1982, 1980, 1975); DTC (1991a, 1991b); Cosgrove & Gargett (1992, p. 234); BTCE (1994a) Indicators Database; BTCE estimates.

NON-URBAN PASSENGER

Energy consumption estimates for non-urban passenger transport by vehicle type is provided in table IV.6. Cars again dominate energy consumption, accounting for around 67 per cent of total non-urban passenger energy consumption in 1992–93. Air transport was also significant, accounting for around 27 per cent. The remaining modes include bus (5 per cent) and rail

(1 per cent). However, changes over time reveal a slightly different picture. Over the period from 1977–78 to 1992–93, the greatest growth in energy consumption by non-urban passenger vehicles occurred in bus transport: deregulation of the bus industry in the early 1980s was responsible for a substantial spurt in growth which has now considerably levelled off. Air transport increased by about 45 per cent, cars increased by about 26 per cent and rail transport decreased by approximately 15 per cent.

TABLE IV.5 ENERGY CONSUMPTION BY URBAN PASSENGER TRANSPORT, 1970–71 TO 1992–93

(petajoules)

Year ending June	*Mode* Car	Bus	Rail	Total
1971	171.37	4.63	n.a.	n.a.
1972	181.14	4.67	n.a.	n.a.
1973	188.32	4.87	n.a.	n.a.
1974	200.96	5.08	n.a.	n.a.
1975	212.72	5.22	n.a.	n.a.
1976	221.10	5.27	n.a.	n.a.
1977	236.78	5.39	n.a.	n.a.
1978	245.55	5.46	3.89	254.90
1979	253.11	5.57	3.80	262.48
1980	253.78	5.77	4.03	263.58
1981	256.65	5.78	4.07	266.50
1982	268.30	5.86	4.10	278.26
1983	267.21	5.89	3.92	277.02
1984	277.01	5.93	3.88	286.82
1985	298.03	6.11	3.85	307.99
1986	306.39	6.27	4.03	316.69
1987	319.59	6.44	4.00	330.03
1988	342.55	6.60	4.01	353.16
1989	354.61	6.83	4.08	365.52
1990	363.10	6.67	3.93	373.70
1991	363.24	6.77	3.91	373.92
1992	364.99	7.27	3.91	376.17
1993	370.20	6.92	3.73	380.85

n.a. Not available

Notes 1. End-use figures (that is, energy consumption resulting solely from vehicle operation).

2. Motorcycles and ferries excluded. In 1991 motorcycles in the urban area consumed 1.9 PJ and energy consumption for urban ferries was 0.4 PJ (Apelbaum 1993, pp. 78, 108).

Sources Apelbaum (1993); Adena & Montesin (1988); Cosgrove & Gargett (1992); ABS (1993a, 1991b, 1989a, 1986b, 1983, 1981a, 1981b, 1978, 1973); CBCS (1973); BTCE (1991a, 1991b); BTE (1980, 1975); NELA (1988); Newman & Kenworthy (1990); RIC (1990); BTCE (1994a) Indicators Database; BTCE estimates.

TABLE IV.6 ENERGY CONSUMPTION BY NON-URBAN PASSENGER TRANSPORT, 1970–71 TO 1992–93

(petajoules)

	Mode				
Year ending June	*Car*	*Bus*	*Rail*	*Air*	*Total*
1971	96.64	2.41	n.a.	n.a.	n.a.
1972	97.54	2.48	n.a.	n.a.	n.a.
1973	100.98	2.46	n.a.	n.a.	n.a.
1974	107.76	2.40	n.a.	36.4	n.a.
1975	114.06	2.44	n.a.	39.9	n.a.
1976	118.55	2.43	n.a.	40.3	n.a.
1977	119.25	2.42	n.a.	41.5	n.a.
1978	123.67	2.44	2.76	44.2	173.07
1979	127.48	2.46	2.60	43.6	176.14
1980	129.08	2.68	2.48	45.3	179.54
1981	130.53	3.07	2.72	45.1	181.42
1982	136.46	3.42	2.63	48.1	190.61
1983	135.91	4.44	2.69	46.7	189.74
1984	140.89	5.49	2.60	46.4	195.38
1985	134.21	6.47	2.66	47.5	190.84
1986	137.98	7.12	2.41	50.8	198.31
1987	133.09	7.79	2.38	52.8	196.06
1988	129.82	8.41	2.54	56.4	197.17
1989	141.35	8.48	2.68	55.9	208.41
1990	148.31	9.50	2.48	45.7	205.99
1991	148.36	9.23	2.60	56.4	216.59
1992	154.20	9.79	2.42	61.1	227.51
1993	156.40	11.08	2.34	63.9	233.72

n.a. Not available

Notes 1. End-use figures (that is, energy consumption resulting solely from vehicle operation).

2. Air energy consumption is from scheduled airline services.

3. Motorcycles and sea transport are excluded. In 1991, motorcycles in non-urban areas consumed 1.3 PJ (Apelbaum 1993 pp. 78, 108).

4. In 1991, the passenger task due to urban ferries (see notes on table IV.5) was of similar size to that of non-urban sea transport (coastal cruises and Bass Strait ferries) (Apelbaum 1993, p. 52).

Sources Apelbaum (1993); ABS (1993a, 1991b, 1990, 1989a, 1986b, 1983, 1981a, 1981b, 1978, 1973); CBCS (1973); BTCE (1991a, 1991b); Cosgrove & Gargett (1992); BTE (1980, 1975); DTC (1991b); NELA (1988); BTCE (1994a) Indicators Database; BTCE estimates.

INTERNATIONAL FREIGHT

The attribution problems involved in allocating responsibility for consumption of bunker fuel among various countries is still subject to debate. The tables containing data on international freight and passenger energy consumption (tables IV.7 and IV.8) record fuel uplifted, both in Australia and overseas, in the performance of the international passenger and freight movements both into and out of Australia.

A breakdown of estimates for energy consumption from international sea freight transport to and from Australia is provided in table IV.7. Energy consumption by international air freight transport is excluded, as the data are unable to be separated from energy consumed by the international passenger task. In 1992–93, around 12 per cent of the energy required to complete Australia's international sea freight transport task was uplifted in Australia. Most of the energy consumed (about 88 per cent) was uplifted outside Australia.

INTERNATIONAL PASSENGER

Estimates of energy consumption resulting from international passenger movements to and from Australia are provided in table IV.8. Total energy used by international passenger transport increased from around 116 PJ in 1970–71 to 254 PJ in 1992–93, an increase of around 120 per cent. The majority of energy consumed for international air passenger transport (70 per cent) was uplifted from outside Australia. Energy consumption by international sea passenger transport is small.

TABLE IV.7 ENERGY CONSUMPTION FROM INTERNATIONAL SEA FREIGHT MOVEMENTS TO AND FROM AUSTRALIA, 1970–71 TO 1992–93

(petajoules)

	Sea		
Year ending June	*Uplifted in Australia*	*Uplifted outside Australia*	*Total fuel uplifted*
1971	75.2	n.a.	n.a.
1972	66.9	n.a.	n.a.
1973	60.7	n.a.	n.a.
1974	55.4	n.a.	n.a.
1975	62.4	n.a.	n.a.
1976	59.3	n.a.	n.a.
1977	49.2	n.a.	n.a.
1978	48.7	n.a.	n.a.
1979	34.7	n.a.	n.a.
1980	36.2	n.a.	n.a.
1981	30.5	n.a.	n.a.
1982	30.2	n.a.	n.a.
1983	36.2	230.3	266.5
1984	30.5	198.5	229.0
1985	30.2	251.0	281.2
1986	20.6	196.4	217.0
1987	21.9	193.4	215.3
1988	24.8	193.0	217.8
1989	28.0	214.0	242.0
1990	28.6	211.9	240.5
1991	28.8	231.8	260.6
1992	24.9	198.9	223.7
1993	24.8	199.2	224.0

n.a. Not available

Notes 1. End-use figures (that is, energy consumption resulting solely from vehicle operation).

2. Air transport is not included in the table as freight and passenger energy consumption data cannot be differentiated (since air freight is generally carried on passenger services).

Sources ABS (1991c and earlier); BTCE (1994a) Indicators Database; BTCE estimates based on Apelbaum (1993); BTCE (1993c, 1988); CBCS (1972); DTC (1993b and earlier).

TABLE IV.8 ENERGY CONSUMPTION FROM INTERNATIONAL PASSENGER MOVEMENTS TO AND FROM AUSTRALIA, 1970–71 TO 1992–93

(petajoules)

	Air			*Sea*		
Year ending June	*Uplifted in Australia*	*Uplifted outside Australia*	*Total fuel uplifted*	*Uplifted in Australia*	*Uplifted outside Australia*	*Total fuel uplifted*
1971	n.a	n.a	n.a	n.a	n.a	n.a
1972	n.a	n.a	n.a	n.a	n.a	n.a
1973	n.a	n.a	n.a	n.a	n.a	n.a
1974	n.a	n.a	n.a	n.a	n.a	n.a
1975	n.a	n.a	n.a	n.a	n.a	n.a
1976	n.a	n.a	n.a	n.a	n.a	n.a
1977	n.a	n.a	n.a	n.a	n.a	n.a
1978	34.16	81.34	115.50	n.a	n.a	n.a
1979	33.62	80.05	113.67	n.a	n.a	n.a
1980	35.07	83.51	118.58	n.a	n.a	n.a
1981	34.95	83.21	118.16	n.a	n.a	n.a
1982	37.49	89.27	126.76	n.a	n.a	n.a
1983	36.50	86.90	123.40	1.06×10^{-4}	5.67×10^{-4}	6.72×10^{-4}
1984	36.41	86.70	123.11	9.73×10^{-5}	5.36×10^{-4}	6.33×10^{-4}
1985	41.00	97.62	138.62	1.01×10^{-4}	7.35×10^{-4}	8.36×10^{-4}
1986	41.82	99.57	141.39	6.67×10^{-5}	5.68×10^{-4}	6.35×10^{-4}
1987	44.16	105.15	149.31	6.60×10^{-5}	5.17×10^{-4}	5.83×10^{-4}
1988	49.95	118.92	168.87	6.99×10^{-5}	4.75×10^{-4}	5.45×10^{-4}
1989	57.67	137.30	194.97	7.36×10^{-5}	4.89×10^{-4}	5.63×10^{-4}
1990	62.99	149.97	212.96	7.91×10^{-5}	5.07×10^{-4}	5.86×10^{-4}
1991	65.53	156.01	221.54	6.79×10^{-5}	4.79×10^{-4}	5.46×10^{-4}
1992	69.52	165.52	235.04	6.93×10^{-5}	4.85×10^{-4}	5.55×10^{-4}
1993	75.15	178.92	254.07	6.84×10^{-5}	4.82×10^{-4}	5.51×10^{-4}

n.a. Not available

Note End-use figures (that is, energy consumption resulting solely from vehicle operation).

Sources BTCE (1994a) Indicators Database; BTCE estimates based on Apelbaum (1993, pp. 64, 70, 161, 170); BTCE (1993c, 1988); DTC (1993b and earlier).

APPENDIX V ESTIMATING EMISSIONS FROM TRANSPORT

Methodology

Current international standards for the compilation of greenhouse gas inventories are based on Intergovernmental Panel on Climate Change (IPCC) guidelines (IPCC/OECD 1994) for calculating greenhouse gas emissions from mobile sources.

The BTCE methodology follows the IPCC guidelines and allows for the estimation of both direct and indirect greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), oxides of nitrogen other than nitrous oxide (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), sulphur oxides (SO_x) and fluorocarbon (FC) species.

Transport emission activities included in the methodology are: domestic air transport, international air transport (relating to Australian sales of aviation bunker fuel), passenger cars (subdivided by vehicle age), trucks (subdivided by gross vehicle mass, see Glossary), buses, motorcycles, railways, domestic marine transport (including coastal shipping, ferries, recreational boating and commercial fishing), and international shipping (relating to Australian sales of marine bunker fuel). To improve the accuracy of transport emission estimates, fuel consumption by non-transport mobile sources, which is generally included in ABARE estimates of transport fuel use, have been allowed for. Such sources include miscellaneous off-road vehicles (unregistered trail bikes and recreation vehicles, competition vehicles, and forklifts), mobile utility engines (such as lawn-mowers, chainsaws, portable generators, and mobile compressors), and military vehicles. Emissions due to major oil and gas pipeline transmission are also addressed.

The methodology presented in this appendix deals solely with end-use emissions. That is, emissions from transport energy production, such as refining automotive gasoline or generating electricity for electric railways, are not included here. The extension of end-use emission estimates to include such indirect emissions are dealt with in chapter 6. The *Workbook for Fuel*

Combustion Activities (excluding Transport) (NGGIC 1994a) and *Workbook for Fuel Production, Transmissions, Storage and Distribution* (NGGIC 1994b) also address these issues.

Greenhouse gas emissions from mobile sources consist of the gaseous products of engine fuel combustion (*exhaust emissions*) and gas leakage from vehicles (*fugitive emissions*), essentially comprising:

- CO_2 emissions due to the oxidation of fuel carbon content during fuel combustion;
- CH_4, N_2O, NO_x, CO, NMVOCs, and SO_x emissions resulting from incomplete fuel combustion, reactions between air and fuel constituents during fuel combustion and post-combustion reactions; and
- fugitive emissions of FCs, due to vehicle air-conditioner refrigerant release, and of NMVOCs, due to fuel evaporation.

The estimation of mobile source emissions is complex, since emission levels depend on a large number of factors, including:

- class of vehicle and type of pollution control equipment fitted;
- type of fuel consumed and the average rate of fuel consumption;
- condition of vehicle (such as vehicle age and level of maintenance); and
- operating characteristics (such as driver behaviour, weather conditions, road type and traffic levels).

Calculation of non-CO_2 greenhouse gas emissions from the combustion and evaporation of fuels in mobile engines is carried out by converting activity data (either fuel consumption or distance travelled) to an emission estimate through multiplication by a conversion rate or *emission factor*. Emission factor units are expressed as grams of gas emitted per megajoule of energy used (g/MJ) or grams emitted per vehicle kilometre travelled (g/km).

Carbon dioxide emissions from the combustion of fuels are estimated by converting energy consumption for each mobile engine type to an amount of CO_2 through multiplication by an emission factor (g/MJ) and an oxidation factor. The oxidation factor represents the proportion of fuel oxidised during combustion. One minus the factor represents the proportion of fuel that is converted into solid products (such as soot).

The estimation methods used ensure that the total carbon content of the fuel is accounted for as CO_2 emissions and solid products. Even though a portion of the carbon in the fuel is released as CH_4, CO and NMVOC emissions under actual engine operating conditions, the IPCC prefers CO_2 emissions to be reported as if all the carbon which is oxidised produces CO_2. As well as making the estimation of CO_2 emissions more straightforward, the primary reason for the slight double counting is that carbon emitted as CH_4, CO or NMVOCs eventually converts to CO_2 in the atmosphere. The conversion occurs over a relatively short period compared to the lifetime of CO_2 in the atmosphere (greater than 100 years). To derive an estimate of actual CO_2 emissions for a given year (for example, as an input to a detailed atmospheric model), the carbon contained in the CH_4, CO and NMVOC emissions should be subtracted from the CO_2 emissions.

Fluorocarbon emissions from the transport sector are estimated by multiplying the number of vehicles with air-conditioners by an average leakage rate (in grams of FC emitted per vehicle per year).

All emission factors relating to energy consumption are given in terms of gross calorific value (GCV), rather than the OECD standard of net calorific value (NCV), since the Australian Bureau of Agricultural and Resource Economics (ABARE) reports energy use in terms of GCV. ABARE figures (Bush et al. 1993) are the primary source of data on Australian energy consumption by sector. Emission factors given in NCV terms (such as those provided by OECD 1991) are reduced by 5 per cent for solid or liquid fuels and 10 per cent for gaseous fuels to provide compatibility with the GCV energy data (as suggested by OECD 1991).

The emission factors reproduced in tables V.3 to V.7 effectively represent national average default values which are to be used whenever more specific figures are unavailable. Emission factors have been calculated on the basis of Australian vehicle characteristics wherever possible. Where data specific to Australian conditions have not been available, emission factors have been derived from the default estimates given in *Estimation of Greenhouse Gas Emissions and Sinks* (OECD 1991). The methodology presented is consistent in approach with the emission estimation methods prepared for the IPCC (OECD 1991).

Assumptions

Incomplete combustion of fuel is assumed to result in the production of solids, such as ash, rather than greenhouse gases.

The sulphur content of the fuel is assumed to oxidise completely during fuel combustion. The products are reported in terms of weight of SO_2. Similarly, for mass calculations (involving molecular weights), assume NO_x emissions have the empirical formula NO_2.

In order to calculate on-road consumption from data on annual automotive gasoline sales (available from ABARE), it is assumed that 1 per cent of sales is consumed in small marine craft. Farrington (1988) contains analysis which implies that fuel use by small marine craft operating in the airsheds of Australian coastal cities is of the order of 1 per cent of automotive gasoline use. This figure is supported by data provided by Australian port authorities, pleasure boating clubs (personal communications) and the Australian Bureau of Statistics (ABS 1989).

A further 1 per cent of annual automotive gasoline sales is assumed to be consumed by unregistered off-road motor vehicles, military vehicles and small mobile utility equipment (such as lawn-mowers). Data given by Farrington (1988) suggest that such use of automotive gasoline could account for around 1 per cent of total consumption. Advice from motor traders, recreational vehicle clubs, the Department of Defence, lawn-mower manufacturers and gardening services also supports this figure. Based on the limited data available, it is assumed that the 1 per cent (of total automotive gasoline consumption allocated to miscellaneous sources) is composed of 0.1 per cent due to unregistered vehicles, 0.1 per cent due to military vehicles and 0.8 per cent due to utility engines.

Off-road recreational vehicles are assumed to have emission factors (g/MJ) equivalent to those for gasoline passenger cars without emission control measures (derived from OECD 1991, table 2-20). Small marine craft emission factors (g/MJ) for CH_4 and N_2O are also assumed to be equivalent to those for gasoline passenger cars without emission control measures.

Military vehicles using automotive gasoline are assumed to have emission factors (g/MJ) equivalent to those for gasoline light duty trucks, and those using ADO are assumed equivalent to heavy duty ADO trucks with moderate emission control (derived from OECD 1991).

Ships using natural gas are assumed to have emission factors (g/MJ) equivalent to those of heavy duty road vehicles using natural gas (derived from OECD 1991, table 2-27). Ships and trains using coal are assumed to have emission factors (in g/MJ) equivalent to those for an industrial coal-fired boiler (derived from OECD 1991, table 2-10).

Emission factors for non-CO_2 gases (g/km) generated by LPG goods vehicles are assumed to be proportional (according to fuel consumption) to those for LPG passenger cars. That is, emission factors for LPG light trucks are calculated by increasing those for LPG cars by the percentage difference between the average fuel consumption rates of the light truck and car fleets.

CNG consumption for road transport is subdivided into vehicle categories according to fleet composition data provided by the Australian Gas Association (AGA). It is assumed that, for each CNG vehicle type, the average fuel consumption rate and annual kilometres travelled per vehicle display the same relative relationship as that for road vehicles using ADO. That is, if an

ADO heavy truck consumes four times as much fuel per kilometre and travels five times as far per annum as an ADO car, then a CNG heavy truck is assumed to have four times the fuel consumption and five times the annual utilisation of a CNG car.

Emission factors for N_2O (g/km) from heavy duty road vehicles using CNG and LPG are assumed to be similar to those for heavy duty gasoline vehicles (OECD 1991).

Emission factors for N_2O (g/MJ) for piston engined aircraft are assumed to be similar to those for gasoline passenger cars without emission control measures (OECD 1991). A value for N_2O emissions from jet aircraft could not be found in the literature. For the purposes of this inventory, the jet emission factor for N_2O (in g/MJ) has been assumed to be similar to that of high-speed diesel engines. The CH_4 emission factor for Avtur use was derived by assuming that CH_4 emissions from Australian jet aircraft comprise the same percentage of volatile organic compound emissions as jet emissions reported in OECD 1991.

Algorithms

To complete the subsequent algorithms, reference should be made to tables V.1 and V.2. Table V.1 summarises mobile source categories, fuel types and greenhouse gas emission species. The notation of the algorithms relies on the values of the appropriate subscripts (*h, i, j, k or l*) given in table V.1. Table V.2 describes the purpose of each algorithm.

The emission level of a greenhouse gas from a mobile fuel combustion engine, using a specified fuel type, is calculated by:

(1) $$E(l)_{hijk} = A^m{}_{hijk}\ F(l)^m{}_{hijk} \qquad \text{for } m = 1 \text{ or } 2 \text{ and } l = 1 \text{ to } 8$$

where

$E(l)_{hijk}$ is the emission of greenhouse gas l in gigagrams (Gg), from a mobile source of category i and class j (within sector h), using fuel type k;

$A^m{}_{hijk}$ is the activity level, where m=1 refers to energy consumption in petajoules (PJ) and m=2 refers to distance travelled in terametres (Tm); and

$F(l)^m{}_{hijk}$ is the emission factor, in units of grams of gas l emitted per megajoule of energy use (g/MJ) for m=1, and grams of gas l emitted per kilometre travelled (g/km) for m=2.

TABLE V.1 SUMMARY OF MOBILE SOURCE CATEGORIES, FUEL TYPES AND GREENHOUSE GAS EMISSION SPECIES

Mobile sources: Sector	(h)	Category	(i)	Class	(j)	Fuel type	(k)	Greenhouse gas	(l)
Air transport[a,d]	1					Automotive gasoline	1	CO_2	1
		Domestic aviation	1		1	ADO	2	CH_4	2
						LPG	3	N_2O	3
		International aviation	2		1	Avgas	4	NO_x	4
						Avtur	5	CO	5
Road transport[a,b,c]	2					IDF	6	NMVOCs	6
		Passenger cars	1			Fuel oil	7	SO_x	7
				Post-1985	1	Natural gas	8	FCs	8
				1981–1985	2	Black coal	9		
				1976–1980	3				
				Pre-1976	4				
		Light goods vehicles	2		1				
		Medium goods vehicles	3		1				
		Heavy goods vehicles	4		1				
		Buses	5		1				
		Motorcycles	6		1				
Rail transport[a,c]	3		1		1				
Marine transport[a,d]	4								
		Domestic marine	1						
				Small craft	1				
				Ferries[a]	2				
				Fishing[e]	3				
				Shipping	4				
		International marine	2		1				
Military transport[d]	5								
		Air	1		1				
		Land	2		1				
		Water	3		1				
Other mobile sources	6								
		Off-road recreational vehicles	1		1				

Note Annual national energy consumption for mobile engines can be obtained from ABARE (Bush et al. 1993); with supplementary activity data available from: a. Apelbaum (1993), b. ABS (1993a), c. Cosgrove & Gargett (1992), d. Department of Defence (N. Martin, pers. comm. 9 May 1994) and e. ACS (1991).

TABLE V.2 DESCRIPTIONS OF ALGORITHMS

Algorithm	*Purpose*
(1)	Calculates emissions of a specified greenhouse gas from combustion of a particular fuel in a particular sector and source category.
(2)	Calculates emissions of a specified greenhouse gas from a particular sector and source category by summing over fuel types.
(3)	Calculates emissions of a specified greenhouse gas from a particular sector by summing over source categories.
(4)	Calculates emissions of a specified greenhouse gas from transport (mobile sources) by summing over sectors.
(5)	Calculates total activity for a specified fuel type in a particular source category by summing over classes.
(6)	Calculates total activity for a specified fuel type in a particular sector by summing over source categories.
(7)	Calculates total activity for a specified fuel type for all mobile sources by summing over sectors.
(8)–(35)	Assign activity levels to sectors and categories based on energy consumption data.
(36)	Converts activity levels from litres of fuel to petajoules.
(37)	Apportions road transport fuel use among vehicle categories.
(38)	Converts activity data from petajoules to terametres (that is, calculates vehicle distance travelled from fuel use).
(39)–(42)	Group petrol passenger car proportions of total distance travelled by vehicle age into age classes.
(43)	Calculates the average rate of fuel consumption for petrol passenger cars.
(44)	Apportions energy use by petrol passenger cars among vehicle age classes.
(45)	Converts activity data from petajoules to terametres for petrol passenger cars.
(46)	Calculates CO_2 emissions using fuel consumption figures.
(47)	Calculates fugitive FC emissions from vehicle air-conditioners.
(48)	Calculates exhaust and evaporative NMVOC emissions from road transport.
(49)	Calculates other exhaust emissions from road transport.

The required form of the equation (whether m equals 1 or 2) for a particular calculation depends on the units of the emission factor generally used for that calculation. Emission factors for non-CO_2 gases from road vehicles are usually derived in terms of g/km. So the estimation of non-CO_2 greenhouse gases from road vehicles is based on equation (1) with m=2. Alternately, CO_2 emissions and non-CO_2 emissions from off-road engines are generally estimated by using equation (1) with m=1.

Once the emissions from each mobile engine type has been estimated, they may be summed to derive total emission levels by category and sector:

(2) $$E(l)_{hi} = \sum_j \sum_k E(l)_{hijk}$$

(3) $$E(l)_h = \sum_i E(l)_{hi}$$

where

$E(l)_{hi}$ is the emission of greenhouse gas l (in Gg), from mobile source category i (within sector h); and

$E(l)_h$ is the total emission of greenhouse gas l (in Gg) from sector h.

Then summing over the sectors (from h = 1 to 6) gives:

(4) $$E(l) = \sum_h E(l)_h \qquad \text{for } l = 1 \text{ to } 8$$

where $E(l)$ is the total emission of greenhouse gas l (in Gg) from mobile sources.

For example:

Suppose that air transport (h=1) NO_x emissions (l = 4) in 1990–91 consisted of 0.33 Gg due to domestic air transport (i, j =1) avgas (k=4) use, 8.59 Gg due to domestic (i,j=1) avtur (k=5) use, and 16.38 due to international airline (i=2, j=1) avtur (k=5) use. Then

$E(4)_{1,1} = E(4)_{1,1,1,4} + E(4)_{1,1,1,5} = 0.33 + 8.59 = 8.92$ Gg NO_x
$E(4)_{1,2} = E(4)_{1,2,1,5} = 16.38$ Gg NO_x; and

$E(4)_1 = E(4)_{1,1} + E(4)_{1,2} = 8.92 + 16.38 = 25.30$ Gg NO_x.

The first step in the emission inventory methodology is to collect or derive activity level and emission factor data in as much detail as practicable. The emission factors given in this report have been derived, as far as possible, to be representative of average national operating conditions. If emissions are to be estimated using activity data on a more detailed basis than is covered by the Report (for example, disaggregated by time of day or type of road), then more specific emission factors should be sought. If emission factors specific to a particular set of operating conditions are unavailable, the national default values (given in tables V.3 to V.7) should be used.

Many of the default emission factors are approximate or uncertain, and it must be stressed that, before attempting an inventory compilation, the most up-to-date factors be sought. Emission levels (particularly for evaporative losses) can vary significantly with ambient temperatures; and the use of average emission factors, though valid for calculating annual emissions, will not capture seasonal variations in those levels.

The default emission factors relate to current fleet characteristics and vehicle technology, so are very approximate when used to calculate past or future levels of transport emissions. Similarly, due to the differing compositions (by age, size and condition) of the various fleets, data averages for particular mobile classes (such as average emission factors or rates of fuel consumption) are not suitable for making comparisons between the technical capabilities of different engine types. For example, figures showing the average rate of fuel consumption of Australian passenger cars using ADO as higher than that of petrol cars (ABS 1993a) should not be taken to imply that petrol cars are intrinsically more fuel efficient than diesel cars. In fact, when a particular model of car is available as either petrol or diesel fuelled, generally the diesel version is considerably more fuel efficient. The average rates of fuel consumption are biased by the diesel car fleet being older and larger, on average, than the petrol car fleet.

Where possible, emission factors in this appendix have been given to three significant figures. Because of the wide range in magnitude and accuracy of the factors, precision to a variable number of decimal places has been used in tables V.3 to V.7.

Activity levels

Default methods for estimating national activity levels are detailed below, using algorithms to apportion total annual fuel consumption by fuel type (k) for mobile sources (denoted by $A^{m=1}{}_{k}$), supplied by ABARE (Bush et al. 1993), between the various mobile categories (i).

TABLE V.3 NON-CO_2 EMISSION FACTORS FOR OFF-ROAD MOBILE SOURCES

	Emission factor ($F(l)^{m=1}{}_{hijk}$) (g/MJ)					
Source (h, i, j) and fuel type (k)	*CH_4 (l=2)*	*N_2O (l=3)*	*NO_x (l=4)*	*CO (l=5)*	*NMVOCs (l=6)*	*SO_x (l=7)[a]*
Aircraft						
(*h*=1, *i*=1) & (*h*=5, *i*=1)						
Avgas (*k*=4)	0.057	0.0009	0.076	22.8	0.513	0.013
Avtur (*k*=5)[b]	0.0011	0.002	0.27	0.079	0.010	0.013
(*h*=1, i=2)						
Avtur (*k*=5)[b]	0.0004	0.002	0.26	0.050	0.004	0.013
Rail (*h*=3)						
ADO (*k*=2)	0.006	0.002	1.71	0.580	0.124	0.083
IDF (*k*=6)	0.006	0.002	1.71	0.580	0.124	0.204
Coal (*k*=9)	0.002	0.001	0.30	0.088	0.0	0.37
Marine						
(*h*=4, *i*=1,2) & (*h*=5, *i*=3)						
Petrol (*k*=1)	0.030	0.0009	0.35	19.61	5.83	0.013
ADO (*k*=2)	0.005	0.002	1.52	0.475	0.105	0.083
IDF (*k*=6)	0.005	0.002	1.52	0.475	0.105	0.204
Fuel oil (*k*=7)[c]	0.003	0.002	2.00	0.044	0.063	1.35
CNG (*k*=8)	0.243	0.001	0.243	0.095	0.029	0.0004
Coal (*k*=9)	0.002	0.001	0.31	0.088	0.0	0.37
Military land vehicles						
(*h*=5, *i*=2)						
Petrol (*k*=1)	0.026	0.0009	0.418	4.24	0.67	0.013
ADO (*k*=2)	0.01	0.002	0.86	0.60	0.124	0.083
Other mobile (*h*=6)						
Unregistered vehicles (*i*=1)						
Petrol (*k*=1)	0.030	0.0009	0.37	7.0	1.08	0.013

Sources OECD (1991), adjusted into GCV terms; with supplementary information from a. AIP (R. Corinaldi, pers. comm. 4 February 1994), AGA (K Lyall, pers. comm. 9 February 1994), ALPGA (L. Borgas, pers. comm. 15 February 1994), b. BTCE estimates based on Department of Transport (J. Streeter, & P. Hoss, pers. comm. 15 February 1994), Federal Airports Administration (1991) and Qantas (B. Bourke, pers. comm. 6 May 1994), c. Lloyds' Register of Shipping (1990).

TABLE V.4 CO_2 EMISSION FACTORS AND LIQUID FUEL ENERGY DENSITIES BY FUEL TYPE

Fuel type	(k)	Proportion of fuel oxidised[a] (P_k)	CO2 emission factor[a,b] ($F1_k$) (g/MJ)	Energy density[c] (D_k) (MJ/L)
Automotive gasoline	1	0.99	66.0	34.2
Automotive diesel oil	2	0.99	69.7	38.6
Liquefied petroleum gas	3	0.99	59.4	25.7
Aviation gasoline	4	0.99	68.0	33.1
Aviation turbine fuel	5	0.99	67.8	36.8
Industrial diesel fuel	6	0.99	70.2	39.6
Fuel oil	7	0.99	73.3	40.8
Natural gas	8	1.00	51.3	..
Black coal	9	0.99	90.0	..

.. not applicable

Notes 1. Values are expressed in GCV terms.

2. Figures for automotive gasoline refer to both leaded and unleaded forms.
3. Coal energy densities vary from mine to mine. New South Wales black coal has an average energy density of around 23 MJ/kg. Victorian brown coal has an energy density of around 10 MJ/kg. The energy density of natural gas is around 39 MJ/m^3.

Sources a. NGGIC (1994a), b. ADIPG (1991), c. Bush et al. (1993).

TABLE V.5 NON-CO_2 EMISSION FACTORS FOR NATURAL GAS ROAD VEHICLES

Vehicle type (i) for sector h=2 and fuel type k=8	Emission factor $(F(l)^{m=1}{}_{2ij8})$ (g/MJ)					
	CH_4 (l=2)	N_2O (l=3)	NO_x (l=4)	CO (l=5)	NMVOCs (l=6)	SO_x (l=7)[a]
Light vehicles (i = 1, 2)[b]	0.261	0.001	0.19	0.11	0.02	0.0004
Heavy vehicles (i = 3,4,5)[c]	0.101	0.001	1.2	0.2	0.01	0.0004

Sources a. AGA (K. Lyall, pers. comm. 9 February 1994), b. OECD (1991), c. De Maria (1992).

TABLE V.6 NON-CO_2 EXHAUST EMISSION FACTORS FOR ROAD VEHICLES (USING FUELS OTHER THAN NATURAL GAS)

	Emission factor $(FE(l)_{2ijk})$ (g/km)					
Vehicle type (i, j) for sector h=2 and fuel type k	*CH_4 (l=2)*[a, b]	*N_2O (l=3)*[a, c]	*NO_x (l=4)*	*CO (l=5)*	*NMVOCs (l=6)*	*SO_x (l=7)*[d]
Cars (*i*=1)						
Petrol (*k*=1)						
Post-1985 (*j*=1)	0.10	0.025	1.23	7.81	0.50	0.024
1981–1985 (*j*=2)	0.15	0.0037	1.70	28.93	2.38	0.055
1976–1980 (*j*=3)	0.18	0.0037	1.87	37.15	2.88	0.056
Pre-1976 (*j*=4)	0.21	0.0037	2.15	37.84	3.33	0.056
ADO (*k*=2)	0.01	0.010	1.03	1.08	0.53	0.420
LPG (*k*=3)	0.087	0.0079	1.94	21.60	1.69	0.034
Light trucks (*i*=2)						
Petrol (*k*=1)	0.14	0.012	1.76	23.58	1.97	0.050
ADO (*k*=2)	0.01	0.014	1.18	1.11	0.53	0.394
LPG (*k*=3)	0.089	0.008	1.98	21.99	1.72	0.035
Medium trucks (*i*=3)						
Petrol (*k*=1)	0.174	0.006	4.65	57.80	4.13	0.094
ADO (*k*=2)	0.02	0.017	3.10	1.82	0.99	0.633
LPG (*k*=3)	0.13	0.011	2.82	24.00	2.46	0.050
Heavy trucks (*i*=4)						
Petrol (*k*=1)	0.21	0.009	4.66	121.3	6.09	0.153
ADO (*k*=2)	0.07	0.025	15.29	7.86	2.78	1.412
LPG (*k*=3)	0.22	0.020	4.83	24.00	4.21	0.085
Buses (*i*=5)						
Petrol (*k*=1)	0.15	0.005	3.91	48.61	3.47	0.079
ADO (*k*=2)	0.03	0.025	4.90	2.88	1.56	1.000
LPG (*k*=3)	0.12	0.011	2.76	24.00	2.41	0.049
Motorcycles (*i*=6)						
Petrol (*k*=1)	0.15	0.002	0.21	19.27	4.58	0.026

Note The emission factors for NO_x, CO and NMVOCs (scaled to allow for the presence of exhaust carbonyls as well as hydrocarbons) are based on an air emissions inventory compiled by the Environment Protection Authority of Victoria (Carnovale et al. 1991), adjusted using data on average fleet characteristics from the *Survey of Motor Vehicle Use Australia* (ABS 1993a). These average emission factors relate to dynamometer drive cycles used to test compliance with Australian vehicle regulatory standards. The tests include allowances for the variation of exhaust emissions with speed, acceleration and cold engine starts, and the results have been averaged to be representative of national driving conditions. The passenger car CH_4 and N_2O emission factors are derived from Australian (Weeks et al. 1993) and US (Hoekman 1992) vehicle test data.

Sources BTCE estimates based on Carnovale et al. (1991) and ABS (1993), with supplementary information from a. OECD (1991), b. Hoekman (1992), c. Weeks et al. (1993) and d. AIP (R. Corinaldi, pers. comm. 4 February 1994).

TABLE V.7 EVAPORATIVE EMISSION FACTORS FOR ROAD VEHICLES USING AUTOMOTIVE GASOLINE

Vehicle type (i, j) *For sector h=2 and* *fuel type k=1*		*Emission factor (g/km)* *Hot soak and diurnal emissions*[a] *(FH_{ij})*	*Running losses*[b] *(FR_{ij})*
Cars (*i*=1)			
Post-1985	(*j*=1)	0.33	0.14
1981–1985	(*j*=2)	1.04	0.25
1976–1980	(*j*=3)	1.13	0.25
Pre-1976	(*j*=4)	2.48	0.29
Light trucks	(*i*=2)	1.13	0.19
Medium trucks	(*i*=3)	2.24	0.26
Heavy trucks	(*i*=4)	2.75	0.29
Buses	(*i*=5)	2.24	0.20
Motorcycles	(i=6)	0.76	0.0

Note The emission factors for running losses are very uncertain and are based on limited US data. European tests (Morgan et al. 1993) on a range of cars (with fuel injection systems and fitted with three-way catalytic converters) found negligible running losses during higher speed driving, significant NMVOC losses during idling, and substantial car-to-car variations in losses obtained. One vehicle (with a carburettor fuel system and fitted with a large carbon canister) showed no running losses under any of the driving cycles tested.

Sources a. Carnovale et al. (1991), where pre-1970 cars (within car age class *j*=4) exhibit crankcase losses as well as hot soak and diurnal emissions.
b. BTCE estimates based on OECD (1991).

Similar to equations (2) and (3), totals and subtotals of activity levels by fuel type are defined in terms of the source activity levels, $A^m{}_{hijk}$ from equation (1), by:

(5) $$A^m{}_{hik} = \sum_j A^m{}_{hijk}$$

(6) $$A^m{}_{hk} = \sum_i A^m{}_{hik}$$

(7) $$A^m{}_{k} = \sum_h A^m{}_{hk}$$

where

> $A^m{}_{hik}$ is the total activity level of mobile category i in sector h using fuel type k,
> $A^m{}_{hk}$ is the total activity level of all categories in sector h using fuel type k, and
> $A^m{}_k$ is the total activity level of all categories in all sectors using fuel type k.

In the following equations, activity levels taken directly from ABARE data (Bush et al. 1993; Bush, S., pers. comm. 1994) are presented in bold type (for example, $\boldsymbol{A^{m=1}{}_{2,2}}$ is ABARE's estimate of road transport ADO use).

The main adjustments made [by equations (8) to (37)] to ABARE energy consumption estimates allow for off-road and military fuel use. The operations of the Australian Defence Force are not separated from the ABARE figures for transport fuel use, and off-road fuel use by such sources as pleasure boating, trail-bikes and lawn-mowers is not separated from on-road use. To allow for military transport fuel use, subtract from the ABARE energy consumption figures for transport: 0.1 per cent of automotive gasoline, 0.5 per cent of road ADO, 3.5 per cent of Avgas, 8.0 per cent of Avtur, 40 per cent of marine ADO, and 0.05 per cent of marine fuel oil consumption (based on Department of Defence [Martin, N. 1994, pers. comm., 9 May]). ABARE's figure for total road transport use of automotive gasoline is reduced by a further 1.9 per cent to allow for miscellaneous off-road uses (1 per cent for small marine craft, 0.1 per cent for unregistered motor vehicles and 0.8 per cent for lawn-mowers).

Energy activity levels (m=1) are derived (in PJ) using:

for air transport

(8) $$A^1{}_{1,1,4} = \boldsymbol{A^1{}_{1,1,4}} - A^1{}_{5,1,4}$$

(9) $$A^1{}_{1,1,5} = \boldsymbol{A^1{}_{1,1,5}} - A^1{}_{5,1,5}$$

(10) $$A^1{}_{1,2,5} = \boldsymbol{A^1{}_{1,2,5}}$$

for road transport

(11) $$A^1{}_{2,1} = 0.98\boldsymbol{A^1{}_{2,1}}$$

(12) $$A^1{}_{2,2} = \boldsymbol{A^1{}_{2,2}} - A^1{}_{5,2,2}$$

(13) $$A^{1}_{2,3} = \boldsymbol{A^{1}_{2,3}}$$

(14) $$A^{1}_{2,8} = \boldsymbol{A^{1}_{2,8}}$$

for rail transport

(15) $$A^{1}_{3,2} = \boldsymbol{A^{1}_{3,2}}$$

(16) $$A^{1}_{3,6} = \boldsymbol{A^{1}_{3,6}}$$

(17) $$A^{1}_{3,9} = \boldsymbol{A^{1}_{3,9}}$$

for marine transport

(18) $$A^{1}_{4,1,1,1} = 0.01\boldsymbol{A^{1}_{2,1}}$$

(19) $$A^{1}_{4,1,2,2} = 0.4$$

(20) $$A^{1}_{4,1,3,2} = 0.17\boldsymbol{AAFF_{k=2}}$$

(21) $$A^{1}_{4,1,4,2} = \boldsymbol{A^{1}_{4,1,2}} - A^{1}_{5,3,2}$$

(22) $$A^{1}_{4,1,4,6} = \boldsymbol{A^{1}_{4,1,6}}$$

(23) $$A^{1}_{4,1,4,7} = \boldsymbol{A^{1}_{4,1,7}} - A^{1}_{5,3,7}$$

(24) $$A^{1}_{4,1,4,8} = \boldsymbol{A^{1}_{4,1,8}}$$

(25) $$A^{1}_{4,1,4,9} = \boldsymbol{A^{1}_{4,1,9}}$$

(26) $$A^{1}_{4,2,2} = \boldsymbol{A^{1}_{4,2,2}}$$

(27) $$A^{1}_{4,2,6} = \boldsymbol{A^{1}_{4,2,6}}$$

(28) $$A^{1}_{4,2,7} = \boldsymbol{A^{1}_{4,2,7}}$$

for military transport

(29) $A^1{}_{5,1,4} = 0.035\mathbf{A^1{}_{1,4}}$

(30) $A^1{}_{5,1,5} = 0.08\mathbf{A^1{}_{1,5}}$

(31) $A^1{}_{5,2,1} = 0.001\mathbf{A^1{}_{2,1}}$

(32) $A^1{}_{5,2,2} = 0.005\mathbf{A^1{}_{2,2}}$

(33) $A^1{}_{5,3,2} = 0.4\mathbf{A^1{}_{4,2}}$

(34) $A^1{}_{5,3,7} = 0.0005\mathbf{A^1{}_{4,7}}$; and

for other mobile sources

(35) $A^1{}_{6,1,1} = 0.001\mathbf{A^1{}_{2,1}}$

where

$\mathbf{AAFF}_{k=2}$ is the ABARE estimate of ADO consumption by the agriculture, forestry and fishing sectors.

Note that due to limited data, equation (19) consists of only a value rather than an algorithm. Since activity levels for ferries are small compared with other source categories and fairly static over time, the levels are assumed to remain constant at the 1990–91 values (given by Apelbaum 1993).

Any fuel consumption figure (for fuel type *k*) provided in litres is converted into energy terms (petajoules) using the energy density of fuel type *k* (D_k, given in table V.4), by:

(36) $A^{m=1}{}_{hijk} = 10^{-9} L_{hijk}\ D_k$

where

$A^{m=1}{}_{hijk}$ is the fuel consumption in petajoules, of fuel type *k*, by engine type *i,j* in sector *h*, as in equation (5);
L_{hijk} is the fuel consumption in litres; and
D_k is the energy density of fuel type *k* (in MJ/L).

For example:

Suppose that in 1990–91 Australian railways (h=3, i=1, j=1) consumed 596 ML of ADO (k=2). To estimate ADO consumption in energy terms by railways, use equation (36) with $L^1_{3,1,1,2}$ = 5.96 x 10^8 L, and D_2 = 38.6 MJ/L (from table V.4).

$A^1_{3,1,1,2} = (5.96 \times 10^8) \times (38.6 \times 10^{-9}) = 23.0$ PJ for 1990–91.

Road vehicles are the dominant mobile sources of greenhouse gas emissions. For this reason, the road sector is examined in greater detail than other mobile source sectors, with more categories (and more specific emission rates).

The proportion of total consumption of each fuel (k), due to each vehicle type (i) for the road transport sector (h=2), has been calculated from *Survey of Motor Vehicle Use, Australia* (ABS 1993a), Apelbaum (1993) and AGA (pers. comm.) data for 1990–91. *The Survey of Motor Vehicle Use* (SMVU) has been conducted approximately triennially over the last 20 years. The proportions (presented in table V.8) can be re-estimated for any survey year and are assumed to remain constant over intervening years.

TABLE V.8 PROPORTION OF TOTAL ROAD FUEL CONSUMPTION BY VEHICLE AND FUEL TYPE

	Proportion of fuel consumption[a] (Q_{ik})			
Vehicle type (i) (for sector h=2)	*Automotive gasoline (k=1)*	*ADO (k=2)*	*LPG (k=3)*	*CNG (k=8)*
Cars (i=1)	0.840	0.086	0.738	0.11
Light trucks (i=2)	0.140	0.127	0.200	0.1
Medium trucks (i=3)	0.009	0.115	0.033	0.11
Heavy trucks(i=4)	0.003	0.592	0.026	0.04
Buses (i=5)	0.002	0.080	0.003	0.62
Motorcycles (i=6)	0.006	0.0	0.0	0.0

a. Based on vehicle fleet compositions for 1990–91.

Sources ABS (1993a); Apelbaum (1993); BTCE estimates based on AGA (Lyall, K. 1994, pers. comm., 9 February) and ABS unpublished data (from SMVU).

The proportions are applied to annual total transport energy consumption by fuel type, $A^{m=1}{}_{2k}$ [from equations (11) to (14)], to obtain the annual energy consumption for each vehicle category (i), using:

(37) $$A^{m=1}{}_{2ik} = A^{m=1}{}_{2k}\ Q_{ik} \qquad \text{for } k = 1,2,3,8 \text{ and } i = 1 \text{ to } 6$$

where

Q_{ik} is the proportion of fuel type k consumed by vehicle type i.

For example:

Suppose that in 1990–91 Australian road transport consumed 590 PJ of automotive gasoline (k=1). Then to estimate the consumption in buses (i=5) use equation (37) with $Q_{5,1}$ = 0.002 (from table V.8).

$A^{1}{}_{2,5,1}$ = 590 x 0.002 = 1.18 PJ for 1990–91.

Vehicle distances travelled (apart from those for petrol passenger cars, which are derived in the next section) are calculated from the energy consumption levels derived in equation (37) using:

(38) $$A^{m=2}{}_{2ik} = A^{m=1}{}_{2ik} / (R_{ik}\ D_k) \qquad \text{for } k = 1,2,3,8 \text{ and } (i,k)\ \ (1,1)$$

where

$A^{m=2}{}_{2ik}$ is the distance travelled (in Tm) by vehicle type i, using fuel type k; and
R_{ik} is the average rate of fuel consumption (in L/km, given in table V.9) for vehicle type i, using fuel type k.

For example:

Suppose that in 1990–91 Australian buses (i=5) consumed 1.0 PJ of automotive gasoline (k=1). To estimate vehicle kilometres travelled by automotive gasoline buses, use equation (38) with $A^{1}{}_{2,5,1}$ = 1.0 PJ, $R_{5,1}$ = 0.178 L/km (from table V.9), and D_1 = 34.2 MJ/L (from table V.4):

$A^{2}{}_{2,5,1}$ = 1.0 / [0.178 x 34.2] = 0.164 Tm in 1990–91.

As in the case of the fuel proportions (table V.8), rates of fuel consumption (table V.9) are assumed to change little from year to year, and can be re-estimated using the ABS *Survey of Motor Vehicle Use* for any particular survey year.

Passenger cars

Passenger cars (using automotive gasoline) are further categorised by age of vehicle. They are split according to year of manufacture into the following classes:

(j=1) post-1985
(j=2) 1981–1985
(j=3) 1976–1980
(j=4) pre-1976.

As well as allowing for vehicle deterioration with age, dividing the car fleet in this manner is a proxy for differences in emissions control technology. The pre-1976 group essentially has no emissions control, the 1976–1980 and 1981–1985 groups use a variety of non-catalytic control (such as exhaust gas recirculation), and the post-1985 group uses catalytic control. Although Australian cars manufactured between 1976 and 1985 have essentially the same level of emission control (and are not subdivided according to Australian Design Rules), they have been split into the 1976–1980 and

TABLE V.9 AVERAGE RATES OF FUEL CONSUMPTION FOR ROAD VEHICLES BY VEHICLE AND FUEL TYPE

	Rate of fuel consumption[a] *(R_{ik}) (L/km)*		
Vehicle type (i) (for sector h=2)	*Automotive gasoline (k=1)*	*ADO (k=2)*	*LPG (k=3)*
Cars (i=1)	..[b]	0.131	0.166
Light trucks (i=2)	0.137	0.123	0.169
Medium trucks (i=3)	0.212	0.198	0.241
Heavy trucks (i=4)	0.344	0.450	0.413
Buses (i=5)	0.178	0.312	0.236
Motorcycles (i=6)	0.058	..	..

.. Not applicable

a. Based on vehicle fleet compositions for 1990–91.

b. Since cars comprise the major mobile emission category, the average fuel consumption rate for cars (using automotive gasoline) is derived on a year-by-year basis, using equation (42), rather than assumed constant at the 1990–91 value (0.120 L/km).

Sources ABS (1993a); BTCE estimates based on Apelbaum (1993) and ABS unpublished data (from SMVU).

1981–1985 groups to allow for vehicle aging. Around 80 per cent of post-1985 petrol cars are fitted with three-way catalytic converters, and most of the remainder are fitted with oxidation (or two-way) catalysts (based on data from FCAI [King, W.R., pers. comm. 7 February 1994]).

Table V.10 presents the proportion of total distance travelled and the average rates of fuel consumption by petrol passenger cars, for each age class, for 1990–91 (based on unpublished ABS SMVU data). Since the proportions given in table V.10 are for 1990–91, and the actual proportions would vary considerably from year to year, they are not totally adequate for an inventory of any other year. To compile an emissions inventory for any year other than 1990–91, the proportions are recalculated using the distribution of vehicle utilisation with vehicle age (in years), given in table V.11. To calculate appropriate figures to replace those in table V.10, translate each vehicle age (relative to the inventory year) into the appropriate year of manufacture, and partition the fleet into post-1985, 1981–1985, 1976–1980 and pre-1976 year of manufacture classes. In each age class, sum the proportions of total vehicle distance travelled, according to:

(39) $$QC(Y)_{j=1} = \sum_{t=0}^{Y-1986} QA_t$$

(40) $$QC(Y)_{j=2} = \sum_{t=Y-1985}^{Y-1981} QA_t$$

(41) $$QC(Y)_{j=3} = \sum_{t=Y-1980}^{Y-1976} QA_t$$

(42) $$QC(Y)_{j=4} = \sum_{t=Y-1975}^{20} QA_t$$

where

Y is the calendar year that the inventory year ends in (national inventories are typically done using the financial year, due to national activity data being available on this basis)—for example, if the inventory is compiled for 1987–88, then Y = 1988);

$QC(Y)_j$ is the proportion of total vehicle distance travelled (by petrol cars) due to cars in age class j, during year Y; and

QA_t is the proportion of total vehicle distance travelled (by petrol cars) due to cars t years old in year Y.

TABLE V.10 PROPORTION OF VEHICLE DISTANCE TRAVELLED AND RATE OF FUEL CONSUMPTION BY VEHICLE CLASS FOR AUTOMOTIVE GASOLINE PASSENGER CARS, 1990–91

Passenger car year of manufacture class (j) for h=2 and i=1		*Proportion of total fleet kilometres[a] (QC(Y=1991)$_j$)*	*Average fuel consumption rate[a] (RC$_j$) (L/km)*
Post-1985	(*j*=1)	0.426	0.115
1981–1985	(*j*=2)	0.275	0.123
1976–1980	(*j*=3)	0.181	0.127
Pre-1976	(*j*=4)	0.118	0.127

a. Based on vehicle fleet compositions for 1990–91.

Source BTCE estimates based on unpublished ABS data (from SMVU).

TABLE V.11 PROPORTION OF VEHICLE DISTANCE TRAVELLED BY AGE OF VEHICLE FOR AUTOMOTIVE GASOLINE PASSENGER CARS, 1990–91

Passenger car age (years)	*(t)*	*Proportion of total vehicle distance[a] (QA$_t$)*
0–1	0	0.0490
1–2	1	0.0900
2–3	2	0.0824
3–4	3	0.0745
4–5	4	0.0666
5–6	5	0.0638
6–7	6	0.0609
6–8	7	0.0581
8–9	8	0.0552
9–10	9	0.0523
10–11	10	0.0483
11–12	11	0.0443
12–13	12	0.0402
13–14	13	0.0362
14–15	14	0.0321
15–16	15	0.0283
16–17	16	0.0245
17–18	17	0.0206
18–19	18	0.0168
19–20	19	0.0129
more than 20	20	0.0430

a. Based on vehicle fleet compositions for 1990–91.

Note The first proportion entry (for *t*=0) is roughly half of that implied by the trend (with decreasing *t*), since cars aged 0–1 years have on average operated for only half a year.

Source ABS unpublished data (from SMVU).

An average rate of fuel consumption for petrol cars ($R_{1,1}$, which was not provided in table V.9) appropriate to the inventory year can be calculated by:

(43) $$R_{1,1} = \sum_{j=1}^{4}[RC_j \times QC(Y)_j]$$

where

RC_j is the average rate of fuel consumption (in L/km, provided in table V.10) for vehicle age class j.

The activity levels for the age classes can then be calculated from total fuel consumption by petrol cars, $A^1{}_{2,1,1}$ estimated with equation (39), using:

(44) $$A^{m=1}{}_{2,1,j,1} = A^{m=1}{}_{2,1,1}\ QC(Y)_j\ RC_j / R_{1,1} \text{ for } j = 1 \text{ to } 4$$

and

(45) $$A^{m=2}{}_{2,1,j,1} = A^{m=1}{}_{2,1,j,1} / (RC_j\ D_1) \text{ for } j = 1 \text{ to } 4.$$

The most accurate results from equations (39) to (45) will be obtained by using SMVU data (on vehicle utilisation according to vehicle age) for a survey year close to the year for which the inventory is being done. If such figures are unavailable (since they are not published by the ABS), the average fuel consumption rates in table V.10 and the vehicle distance distribution data in table V.11 are to be taken as default values. As previously, the default values are assumed to change little from year to year.

Greenhouse gas emission estimates

Non-CO2 emissions from off-road sources and natural gas road vehicles

Non-CO_2 emissions from off-road sources are calculated using equation (1), in the form m=1, and the emission factors given in table V.3. Non-CO_2 emissions from CNG road vehicles (h=2, k=8) are also estimated using equation (1) with m = 1, where the appropriate emission factors are presented in table V.5.

For example:

Assume Australian railways (source category h=3, i=1) consumed 23 PJ of ADO (fuel type k=2) in 1990–91. To estimate NO_x emissions (gas l=4) for rail ADO consumption, use equation (1) with $F^1(4)_{3,1,1,2}$ = 1.71 g/MJ (from table V.3):

$E(4)_{3,1,1,2}$ = (23 x 1.71) = 39.33 Gg of NO_x for 1990–91.

Carbon dioxide emissions

For CO_2 emissions, from all source categories, equation (1) is slightly altered to allow for incomplete oxidation of the fuel, becoming:

$$E(l=1)_{hijk} = A^{m=1}{}_{hijk}\ (F1_k\ P_k) \qquad (46)$$

where

$F1_k$ is the CO_2 emission factor (for fuel type k) applicable to complete oxidation of fuel carbon content; and

P_k is the proportion of fuel that is completely oxidised upon combustion (given in table V.4).

For example:

Continuing the previous Australian railways source category (h=3) example, the total CO_2 emissions (l=1) for rail ADO consumption (k=2) are calculated using equation (46) with $F1_k$ = 69.7 g/MJ and P_k = 0.99 (from table V.4):

$E(1)_{3,1,1,2}$ = (23 x 69.7 x 0.99) = 1587.1 Gg of CO_2 for 1990–91.

Fugitive emissions from road vehicles

Fugitive releases of fluorocarbons from motor vehicles can be roughly estimated by two methods:

- multiplying the number of post-1990 vehicles fitted with air-conditioners by an emission rate of 35 grams of FC per annum and the number of pre-1990 vehicles fitted with air-conditioners by an emission rate of 75 grams of FC per annum (based on FCAI data [pers. comm.]).

- multiplying the annual amount of FC compounds used to fill vehicle air-conditioning systems (given in CEPA 1993) by an average leakage rate of 34 per cent (based on DME 1990).

Due to the paucity of data concerning fluorocarbon emissions, estimates of annual FC emissions for the national inventory are currently restricted to the derivation of an aggregate value for road transport. An estimate of national FC emissions from road transport is obtained by averaging the results of the two methods outlined above:

(47) $$E(l{=}8)_2 = [(N1 \times 35 + N2 \times 75) + (AFC \times 0.34)] / 2 \times 10^{-9}$$

where

> N1 is the number of vehicles in the Australian fleet manufactured after 1990;
> N2 is the number of vehicles manufactured during or before 1990; and
> AFC is the annual consumption of FCs (in grams) by the vehicle air-conditioning sector.

For example:

> Assume that 80 per cent of vehicles are equipped with air-conditioners (based on personal communications with vehicle manufacturers). In 1989–90, there were approximately 10 million registered road vehicles, giving $N2 \approx 8 \times 10^6$
> (and $N1 = 0$).
>
> Assume that 1700 tonnes of FC compounds were used in vehicle air-conditioners during 1989–90 (based on CEPA 1993)—that is, $AFC = 1.7 \times 10^9$ g.

Thus,

$$
\begin{aligned}
E(8)_2 &= (8 \times 10^6 \times 75 + 1.7 \times 10^9 \times 0.34) / 2 \times 10^{-9} \\
&= (0.6 + 0.578) / 2 \\
&\approx 0.59 \text{ Gg of FC emission for 1989–90.}
\end{aligned}
$$

NMVOC emissions from road vehicles using automotive gasoline consist of both exhaust and evaporative emissions. Evaporative NMVOC emissions from petrol-fuelled road vehicles include running losses (that is, evaporative emissions released during engine operation), hot soak losses (from evaporation of fuel at the end of each trip) and diurnal losses (resulting from vapour being expelled from fuel tanks due to ambient temperature changes).

Evaporative emissions from vehicle refuelling are not included in this appendix, but are dealt with in chapter 6.

Total NMVOC (l=6) emissions for each road (h=2) vehicle type i,j using automotive gasoline (k=1), $E(6)_{2ij1}$, are calculated from vehicle distance travelled, $A^{m=2}{}_{2ij1}$ obtained by equations (38) and (45), according to:

(48) $$E(6)_{2ij1} = A^{2}{}_{2ij1}\ (FH_{ij} + FR_{ij} + FE(6)_{2ij1}) \qquad \text{for } i = 1 \text{ to } 6$$

where

FH_{ij} is the hot soak and diurnal emission factor for vehicle i,j (table V.7);
FR_{ij} is the running emission factor for vehicle i,j (table V.7); and
$FE(6)_{2ij1}$ is the NMVOC exhaust emission factor for vehicle i,j (table V.6).

For example:

Suppose that in 1990–91 Australian gasoline (k=1) buses (i=5) travelled 0.164 Tm. To estimate total NMVOC (l=6) emissions from buses in this year use equation (48) with $A^{2}{}_{2,5,1,1}$ = 0.164 Tm, $FH_{5,1}$ = 2.24 and $FR_{5,1}$ = 0.20 (from table V.7) and $FE(6)_{2,5,1,1}$ = 3.47 (from table V. 6):

$E(6)_{2,5,1,1}$ = 0.164 x (2.24 + 0.20 + 3.47) = 0.969 Gg in 1990–91.

Non-CO_2 exhaust emissions by road vehicles (apart from those using CNG)

The remaining emissions from road vehicles are assumed to occur solely as exhaust emissions and are calculated by the following form of equation (1) with m = 2:

(49) $$E(l)_{2ijk} = A^{m=2}{}_{2ijk}\ FE(l)_{2ijk} \qquad \text{for } l = 2 \text{ to } 7 \ \&\ k = 2,3; \quad \text{for } l = 2,3,4,5,7 \ \&\ k=1.$$

where

$FE(l)_{2ijk}$ is the exhaust emission factor for gas l from vehicle type i,j using fuel type k (table V.6).

Case study: CO emission estimates for passenger cars using automotive gasoline

The following worked example of the estimation of CO emissions from passenger cars using automotive gasoline for 1989–90 is presented to illustrate the details of the inventory methodology.

Taking $A^1{}_{2,1}$ = 588.9 PJ for 1989–90 from ABARE data (Bush et al. 1993), equation (11) gives,

$$A^1{}_{2,1} = 588.9 \times 0.98 \approx 577.12 \text{ PJ}.$$

Then using (37)

$$A^1{}_{2,1,1} = 577.12 \times 0.84 \approx 484.8 \text{ PJ}.$$

Categorising by vehicle age, from equations (39) to (42) and table V.11,

$$QC(1990)_1 = 0.049 + 0.09 + 0.0824 + 0.0745 + 0.0666 = 0.3625$$
$$QC(1990)_2 = 0.0638 + 0.0609 + 0.0581 + 0.0552 + 0.0523 = 0.2903$$
$$QC(1990)_3 = 0.0483 + 0.0443 + 0.0402 + 0.0362 + 0.0321 = 0.2011$$
$$QC(1990)_4 = 0.0283 + 0.0245 + 0.0206 + 0.0168 + 0.0129 + 0.043 = 0.1461.$$

Equations (43) to (45) then give:

$$R_{1,1} = 0.115 \times 0.3625 + 0.123 \times 0.2903 + 0.127 \times 0.2011 + 0.127 \times 0.1461 \approx 0.1215 \text{ L/km}$$

$$A^1{}_{2,1,1,1} = 484.8 \times 0.3625 \times 0.115 \;/\; 0.1215 \approx 166.3 \text{ PJ}$$
$$A^1{}_{2,1,2,1} = 484.8 \times 0.2903 \times 0.123 \;/\; 0.1215 \approx 142.5 \text{ PJ}$$
$$A^1{}_{2,1,3,1} = 484.8 \times 0.2011 \times 0.127 \;/\; 0.1215 \approx 102 \text{ PJ}$$
$$A^1{}_{2,1,4,1} = 484.8 \times 0.1461 \times 0.127 \;/\; 0.1215 \approx 74 \text{ PJ}$$

$$A^2{}_{2,1,1,1} = 166.3 \;/\; (0.115 \times 34.2) \approx 42.28 \text{ Tm}$$
$$A^2{}_{2,1,2,1} = 142.5 \;/\; (0.123 \times 34.2) \approx 33.88 \text{ Tm}$$
$$A^2{}_{2,1,3,1} = 102 \;/\; (0.127 \times 34.2) \approx 23.48 \text{ Tm}$$
$$A^2{}_{2,1,4,1} = 74 \;/\; (0.127 \times 34.2) \approx 17.04 \text{ Tm}$$

CO emissions can then be calculated by using equation (49) and table V.6,

$$E(5)_{2,1,1,1} = 42.28 \times 7.81 \approx 330 \text{ Gg for 1989–90}$$
$$E(5)_{2,1,2,1} = 33.88 \times 28.93 \approx 980 \text{ Gg for 1989–90}$$
$$E(5)_{2,1,3,1} = 23.48 \times 37.15 \approx 872 \text{ Gg for 1989–90}$$
$$E(5)_{2,1,4,1} = 17.04 \times 37.84 \approx 665 \text{ Gg for 1989–90.}$$

Emissions from pipelines

There are two sources of emissions due to pipelines: leakage (primarily from low-pressure pipelines, such as those used for urban distribution of natural gas) and combustion products (from energy used for pipeline transmission). For major oil and gas pipelines, NGGIC (1994b, pp. 20–25) assumes that leakages of CO_2 and NMVOCs are negligible and derives methane leakages of around 2 Gg per annum. The main fuel used for NG pipeline transmission is NG, and assuming that pipeline (stationary) engines have similar emission characteristics to gas turbines gives the emission factors in table V.12 for pipeline combustion products.

As mentioned in appendix III, urban pipeline distribution is beyond the scope of this study. However, if the urban distribution of NG were included, CH_4 leakage would be considerable, possibly exceeding 200 Gg per annum (based on Wilkenfeld 1991, p. 76; NGGIC 1994b, p. 46).

Greenhouse Gas Emissions Inventory

The methodology presented in this appendix permits the estimation of Australian greenhouse gas emissions for each transport mode. Table V.13 provides estimates of Australian greenhouse gas emissions in 1992–93. The figures in table V.13 differ in some cases from 1992–93 values provided in modal time series tabulations (appendices VIII to XI) due to allowances made in this chapter for fuel use by defence vehicles and various off-road activities (such as pleasure boating).

TABLE V.12 PIPELINE COMBUSTION EMISSION RATES

(g/MJ)

CO_2	CO	CH_4	NO_x
51.3	0.03	0.006	0.17

Note Assumes natural gas is burnt in gas turbines to provide the energy required for product movement by pipeline.

Source NGGIC (1994a, p. 12).

TABLE V.13 GREENHOUSE GAS EMISSION INVENTORY FOR AUSTRALIAN TRANSPORT ENERGY END-USE, 1992–93

	Emission type (Gg)							
Emission source[a]	*CO_2*	*CH_4*	*N_2O*	*NO_x*	*CO*	*NMVOCs*	*SO_x*	*Total*[b] *(CO_2 equivalent)*
Mobile sources								
Domestic civil transport	61 514	20.36	2.58	404.08	3 283.36	442.54	39.18	72 896.1
Military transport	991	0.05	0.03	7.46	7.64	0.92	0.44	1 075.9
International civil transport	6 653	0.12	0.19	66.30	6.71	2.05	28.80	7 271.1
Recreational vehicles	38	0.02	0.0	0.22	4.09	0.63	0.01	49.7
Pipeline	207	2	0.0	0.5	0.1	0.0	0.0	258.0
Air transport	8 618	0.27	0.25	33.32	80.39	2.45	1.67	9 072.3
Domestic	3 752	0.24	0.11	14.47	76.77	2.16	0.73	4 002.1
Avgas	214	0.18	0.00	0.24	72.61	1.63	0.04	307.4
Avtur	3 537	0.06	0.11	14.23	4.16	0.53	0.69	3 694.7
International								
Avtur	4 866	0.03	0.15	18.85	3.63	0.29	0.94	5 070.3

TABLE V.13 GREENHOUSE GAS EMISSION INVENTORY FOR AUSTRALIAN TRANSPORT ENERGY END-USE, 1992–93 (Continued)

	Emission type (Gg)							
Emission source[a]	CO_2	CH_4	N_2O	NO_x	*CO*	*NMVOCs*	SO_x	*Total*[b] *(CO_2 equivalent)*
Road transport	53 815	19.69	2.37	306.60	3 072.72	401.57	17.20	63 795.0
Passenger cars	34 297	16.03	1.89	192.94	2 408.40	302.67	6.19	41 668.1
Petrol	31 442	15.40	1.80	176.68	2 263.80	289.78	4.51	38 392.0
Post -1985	16 500	6.22	1.61	78.98	501.47	62.62	1.54	18 800.7
1981–1985	7 777	4.29	0.10	48.10	818.57	103.72	1.56	9 948.8
1976–1980	4 735	3.07	0.06	31.20	619.84	71.18	0.93	6 269.0
Pre-1976	2 429	1.82	0.03	18.40	323.92	52.27	0.48	3 373.4
ADO	1 215	0.03	0.03	3.59	3.76	1.84	1.46	1 273.8
LPG	1 636	0.57	0.05	12.65	140.83	11.04	0.22	1 996.4
NG	5	0.03	0.00	0.02	0.01	0.00	0.00	5.9
Light trucks	7 478	2.64	0.30	40.02	447.68	62.19	3.07	8 903.3
Petrol	5 234	2.40	0.21	30.09	403.15	56.28	0.85	6 453.6
ADO	1 792	0.05	0.08	6.45	6.07	2.90	2.15	1 898.2
LPG	447	0.15	0.01	3.45	38.45	3.01	0.06	545.0
NG	6	0.03	0.00	0.02	0.01	0.00	0.00	6.5

TABLE V.13 GREENHOUSE GAS EMISSION INVENTORY FOR AUSTRALIAN TRANSPORT ENERGY END-USE, 1992–93 (Continued)

	Emission type (Gg)							
Emission source[a]	CO_2	CH_4	N_2O	NO_x	*CO*	*NMVOCs*	SO_x	*Total*[b] *(CO_2 equivalent)*
Medium trucks	2 051	0.23	0.06	13.69	53.34	8.47	2.03	2 306.4
Petrol	351	0.13	0.00	3.46	42.95	4.93	0.07	466.1
ADO	1 622	0.06	0.05	9.56	5.61	3.05	1.95	1 747.3
LPG	72	0.03	0.00	0.56	4.75	0.49	0.01	86.7
NG	5	0.01	0.00	0.12	0.02	0.00	0.00	6.3
Heavy trucks	8 543	0.42	0.09	51.62	119.14	16.20	4.49	9 242.5
Petrol	129	0.16	0.01	3.46	90.14	6.78	0.11	306.7
ADO	8 355	0.22	0.08	47.16	24.24	8.58	4.35	8 855.4
LPG	57	0.04	0.00	0.96	4.75	0.83	0.02	78.2
NG	2	0.00	0.00	0.04	0.01	0.00	0.00	2.3
Buses	1 228	0.12	0.04	7.99	11.77	3.07	1.38	1 342.6
Gasoline	60	0.02	0.00	0.59	7.36	0.90	0.01	80.3
ADO	1 133	0.04	0.03	6.68	3.92	2.13	1.36	1 219.8
LPG	6	0.00	0.00	0.04	0.38	0.04	0.00	6.8
NG	29	0.06	0.00	0.67	0.11	0.01	0.00	35.7
Motorcycles								
Gasoline	218	0.25	0.00	0.35	32.38	8.97	0.04	332.0

TABLE V.13 GREENHOUSE GAS EMISSION INVENTORY FOR AUSTRALIAN TRANSPORT ENERGY END-USE, 1992–93 (Continued)

	Emission type (Gg)							
Emission source[a]	*CO_2*	*CH_4*	*N_2O*	*NO_x*	*CO*	*NMVOCs*	*SO_x*	*Total*[b] *(CO_2 equivalent)*
Rail transport	1 602	0.14	0.05	39.67	13.46	2.88	2.18	1 974.0
ADO	1 456	0.13	0.04	36.08	12.24	2.62	1.75	1 794.4
IDF	146	0.01	0.00	3.59	1.22	0.26	0.43	179.6
Coal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Marine transport	4 132	0.38	0.10	90.78	123.50	37.69	46.93	5 325.9
Domestic	2 346	0.29	0.05	43.33	120.42	35.93	19.07	3 125.0
Gasoline								
Small craft	382	0.17	0.01	2.05	114.64	34.08	0.08	791.6
ADO								
Ferries	28	0.00	0.00	0.61	0.19	0.04	0.03	33.5
Fishing	580	0.04	0.02	12.77	3.99	0.88	0.70	699.0
Shipping	13	0.00	0.00	0.29	0.09	0.02	0.02	16.0
IDF	88	0.01	0.00	1.92	0.60	0.13	0.26	105.8
Fuel oil	885	0.04	0.02	24.40	0.54	0.77	16.47	1 095.8
NG	5	0.02	0.00	0.02	0.01	0.00	0.00	6.0
Coal	365	0.01	0.00	1.27	0.36	0.00	1.52	377.4

TABLE V.13 GREENHOUSE GAS EMISSION INVENTORY FOR AUSTRALIAN TRANSPORT ENERGY END-USE, 1992–93 (Continued)

Emission source[a]	*Emission type (Gg)*							
	CO_2	*CH_4*	*N_2O*	*NO_x*	*CO*	*NMVOCs*	*SO_x*	*Total*[b] *(CO_2 equivalent)*
Marine transport								
International	1 786	0.08	0.05	47.45	3.08	1.76	27.86	2 200.9
ADO	216	0.01	0.01	4.76	1.49	0.33	0.26	260.5
IDF	103	0.01	0.00	2.25	0.70	0.16	0.30	124.0
Fuel oil	1 467	0.06	0.04	40.44	0.89	1.27	27.30	1 816.4
Military transport	991	0.05	0.03	7.46	7.64	0.92	0.44	1 075.9
Petrol	38	0.02	0.00	0.24	2.48	0.39	0.01	46.3
ADO								
Land	71	0.01	0.00	0.88	0.62	0.13	0.09	80.5
Water	155	0.01	0.00	3.40	1.06	0.24	0.19	186.4
Avgas	8	0.01	0.00	0.01	2.63	0.06	0.00	11.1
Avtur	718	0.01	0.02	2.89	0.85	0.11	0.14	750.2
Fuel oil	1	0.00	0.00	0.03	0.00	0.00	0.02	1.5
Other sources								
Recreational vehicles								
Petrol	38	0.02	0.00	0.22	4.09	0.63	0.01	49.7
Pipeline								
NG	207	2	0.0	0.5	0.1	0.0	0.0	258.0

a. Emission sources are subdivided by sector, category, fuel type and class.

b. Excluding the effects of SO_x and FCs.

Note Road sector FC emissions are estimated to be around 0.58 Gg for 1992–93.

Source BTCE estimates.

Uncertainties

The main areas of uncertainty which would arise in estimates compiled using the methodology described in this report are covered briefly below.

Uncertainties in activity levels
Activity levels for non-CO_2 emissions from road vehicles are reported (in kilometres) by vehicle type in the triennial ABS SMVU (ABS 1993a). Uncertainty in these figures arises from both sampling and non-sampling errors (such as inaccuracies in reporting details due to respondents not having detailed records on their vehicles' use). One measure of sampling variation is the standard error, and ABS reports standard errors of between 1 and 3 per cent for most of its national average estimates. ABS assessments of non-sampling errors imply that the total uncertainty in the estimates would be considerably higher, perhaps of the order of 10 per cent. Further uncertainty is added by the need to use results from the SMVU for the years between the surveys.

The activity levels for aggregate transport modes are reported (in megajoules of energy used) in the annual ABARE *Energy Supply and Demand Projections* (Bush et al. 1993). ABARE figures are based on annual fuel sales data and the biennial Fuel and Electricity Survey. Uncertainty in total energy consumption by fuel type would be fairly small (perhaps of the order of 3 per cent) but considerable uncertainty could arise from apportioning total consumption between the various vehicle and engine types. Additional uncertainties would arise from fuel spillage and non-fuel use (such as use of petrol as a cleaner or solvent).

Activity levels for various off-road sources (for example, pleasure boats) are not readily available. Activity levels for such sources have been roughly estimated from data on numbers of units and average annual usage per unit. These activity levels are highly uncertain, probably by over 50 per cent, but their levels are small relative to total transport fuel consumption.

Uncertainties in emission conversion factors for non-CO_2 gases
Estimates of emissions of SO_2 are based on figures for the sulphur content of fuels and the assumption that there is total conversion of the sulphur content to SO_2. In the cases of ADO, automotive gasoline, avgas, avtur, and LPG, where the sulphur content is closely controlled in the refinement process, and in the case of CNG, where the sulphur content is a result of the controlled addition of odorant, the figures are fairly certain. Sulphur contents of IDF, fuel oils, and coal, on the other hand, vary significantly by source region. The figures used in this Report are from typical assays from large suppliers, but are subject to a variability of around 20 per cent.

Estimates of emissions of NMVOCs are affected by the high degree of uncertainty regarding running losses of fuel for road vehicles and the dependence of evaporative emissions on ambient temperature. The figures used in this Report for fugitive NMVOC emissions are based on US tests, and may have uncertainties of the order of 100 per cent.

Estimates of non-CO_2 emissions from jet aircraft are based on test data (conducted under United States conditions) for common engine types, at assumed cruising power levels. The emission rates for various engine types and power levels have been averaged over the composition of the Australian airline fleet and over an assumed representative flight cycle (that is, by the proportion of time spent cruising, landing or taking off). Uncertainties arise from variability between engine types, variability of flying conditions, variability of power levels used in cruising, the effects of landing and take-off, and variability in the engine age and levels of maintenance. Uncertainty in the emission factors is significant, perhaps more than 50 per cent.

Estimates of exhaust emissions of CO, NO_x and NMVOCs from road vehicles are based on emission measurements performed by Australian environment protection authorities. Apart from small experimental uncertainties in these measurements (usually performed on a dynamometer), uncertainty in these emission factors arises primarily from the variability of engine performance with vehicle age, unknown effects of vehicle maintenance, and unknown discrepancies between the vehicle usage conditions assumed for the test and those obtaining in use (particularly relating to ambient temperature). Since there is some doubt as to how exactly dynamometer testing reflects 'real world' or on-road emissions, uncertainties in the emission figures from these sources may be significant, perhaps of the order of 30 per cent.

Uncertainties in carbon dioxide emissions

CO_2 emission estimates are based on the carbon content of fuels by fuel type, assuming certain levels of combustion.

Carbon content by fuel type is fairly constant, except in the cases of coal, LPG and natural gas. Steaming coals are fairly uniform, but the compositions of LPG and CNG show considerable variation. These are not major transport fuels at present, and the uncertainty that they contribute to overall CO_2 emission estimates will not be large.

Uncertainties in fluorocarbon emissions

Estimates of FC emissions from mobile cooling systems (vehicle air-conditioners and refrigerated transport) are based on production figures supplied by CEPA and on rough estimates of the losses during operation. Uncertainties are considerable, probably of the order of 100 per cent.

APPENDIX VI EMISSIONS FROM ALTERNATIVE FUELS

Apart from an increased penetration of CNG and LPG vehicles, the base case projections given in this Report assume no alternative (to petroleum) fuel use is significant by 2015. The following tables are reproduced from BTCE Information Paper 39 (BTCE 1994b) for reference purposes.

TABLE VI.1 PROJECTED LIFE CYCLE GREENHOUSE GAS EMISSIONS FROM NORTH AMERICAN PASSENGER VEHICLES IN 2000

Fuel type	*Grams CO_2 equivalent emissions per km*	*Per cent below gasoline*
Gasoline	260	..
Reformulated gasoline	263	–1
Diesel	210	19
LPG	201	23
CNG	231	11
Methanol, from natural gas	250	4
Ethanol, from biomass	82	68
Liquid hydrogen produced by electricity from non-fossil fuel	77	70
Electricity from hydro-power	35[a]	86

a. BTCE estimate based on IEA (1993) emissions data for urban driving cycle.

Source IEA (1993 pp. 95, 96).

TABLE VI.2 RANGE OF GREENHOUSE GAS EMISSION ESTIMATES FROM USE OF ALTERNATIVE FUELS IN PASSENGER VEHICLES (COMPARED WITH REFORMULATED GASOLINE)

Fuel	*Worst: % change*	*Best: % change*
Reformulated gasoline (RFG)	+6	–4
Standard US gasoline	+3	–6
Diesel fuel	–6	–25
Methanol from coal	+75	+10
Methanol from natural gas	+12	–25
Methanol from wood	–5	–100
CNG or LNG	+35	–35
LPG	–6	–37
Ethanol from corn/coal	+80	–66
Ethanol from corn/corn stover	0	–72
Ethanol from wood	+12	–100
Hydrogen: hydride/nuclear electrolysis	–41	–80
Liquid hydrogen/nuclear hydrolysis	+10	–80
EV/coal fired	+100	–61
EV/marginal US power generation mix	+67	–43
EV/natural gas fired	+15	–73
EV/nuclear electricity generation	–81	–88
EV/wood fired electricity generation	–10	–100
EV/solar	–89	–92
Methanol from coal: fuel cell	+10	–25
Methanol from natural gas: fuel cell	–33	–50
Methanol from wood: fuel cell	–45	–100
Hydrogen from solar: fuel cell	–81	–89

EV Electric vehicle.

Note Results show a comparison of each fuel with RFG for a number of test scenarios over which RFG results also vary.

Source DeLuchi (1993).

TABLE VI.3 RANGE OF GREENHOUSE GAS EMISSION ESTIMATES FROM USE OF ALTERNATIVE FUELS IN TRUCKS (COMPARED WITH DIESEL FUEL)

Fuel	*Worst: % change*	*Best: % change*
LPG	+15	–11
CNG or LNG	+45	–13
Methanol from natural gas	+35	–6
Methanol from coal	>+100	+40
Ethanol from corn/coal	+100	–56
Ethanol from wood	+35	–100
Hydrogen: hydride/ nuclear electrolysis	–26	–85
Hydrogen: hydride from solar: fuel cell	–84	–92

Source Sinor (1992).

APPENDIX VII VARIABLE MNEMONICS FOR BTCE MODELS

ADUM	Dummy variable for the introduction of discount airfares (from 1991 onwards)
AFC	Aviation turbine fuel uplifted in Australia for international flights
AFI	Average aircraft fleet fuel intensity (derived from engineering data)
AIRDUM	Dummy variable to allow for the effects of the pilot's dispute, 1989–90
APASS	The number of Australian resident passengers travelling on the domestic air network
APASSKM	Australian resident passenger-kilometres flown on the domestic air network
AUSTFAR	General index of real urban public transport fares
AVKM	Average kilometres flown on domestic flights
AVKMIN	Average distance travelled by international air passengers arriving in Australia
AVKMOUT	Average distance travelled by international air passengers leaving Australia
BIDUM	Bicentennial year (1988Q1 to 1988Q3) dummy variable
CAPCON	Dummy variable for capacity utilisation in the Australian economy (used in international shipping model).
CBLK	Tonnage of coastal bulk freight
CCOM	Sum of the tonnages of the seven major coastal bulk commodities
CDUM	Dummy variable for decreased airfare prices to Fiji (1991Q2 onward)

CFC	Corrected rail fuel consumption (detrended for fuel efficiency improvements)
CGD	Commonwealth Games (1982) dummy variable
CGEXP	The aggregate level of coal and grain exports (tonnes)
CORC	Cochrane–Orcutt estimation procedure
CPI	Consumer price index
D_1	First quarter (of the year) dummy variable
D_2	Second quarter dummy variable
D_3	Third quarter dummy variable
DH	Durbin's h statistic
DISP	Dummy variable used to capture the rail dispute between 1989Q3 and 1990Q2
DUM	Dummy variable for low rail traffic (1979Q3 to 1980Q2)
DW	Durbin–Watson statistic
EXP	The total tonnage of six major Australian bulk exports (iron, coal, alumina, oil/petroleum products, grain and sugar)
FC	Fuel consumption
FE	Fuel efficiency
FI	Fuel intensity
FI_{GB}	The fuel intensity of trains carrying government bulk freight
FI_{GNR}	The fuel intensity of trains carrying government non-bulk freight
FI_{PASNU}	The fuel intensity of non-urban trains carrying passengers
FI_{PASU}	The fuel intensity of urban trains carrying passengers
FI_{PF}	The fuel intensity of trains carrying private freight
$FI_{year, sector}$	The average fuel intensity of (sector) in (year)
FPASS	The number of foreign passengers flying in the domestic aviation network
FPASSKM	Revenue passenger-kilometres flown by foreign passengers on the Australian domestic air network
FU	The quantity of fuel uplifted from coastal bunkers
GBT	Government bulk freight tonnes carried by rail
GBTKM	Government bulk freight tonne-kilometres travelled by rail

GNBT	Government non-bulk freight tonnes carried by rail
GNBTKM	Government non-bulk freight tonne-kilometres travelled by rail
G7GDP	Index of the sum of the real gross domestic products of the Group of Seven major OECD countries (the United States, Japan, Germany, France, Italy, Canada and the United Kingdom) in 1985 US$
IMP	The total of two major Australian non-bulk imports (fuel and chemicals in millions of dollars)
INPASS	Short-term foreign air passenger arrivals in Australia
IOP	The level of iron ore production
IPKM	International passenger-kilometres travelled to and from Australia by short-term and long-term air travellers
k	Saturation level of the logistic function
LF	Average aircraft passenger load factor
MVPER	Cars per thousand population
OLS	Ordinary Least Squares estimation
OUTPASS	Total number of short-term Australian resident departures by air
PASKMNU	Non-urban rail passenger-kilometres
PASKMU	Urban rail passenger-kilometres
PASNU	Non-urban rail passenger numbers
PASSKM	Total domestic revenue passenger-kilometres flown
PASU	Urban rail passenger numbers (includes trams in Victoria and South Australia)
PFT	Private rail freight tonnages
PFTKM	Private rail freight tonne-kilometres
RAUSPFC	Real Australian private final consumption
RGDP	Real gross domestic product
RGNE	Australian real gross national expenditure
RGNF	Australian real gross non-farm product
RHDY	Real household disposable income for the destination country
RIFARE	Weighted average of real inbound overseas airfares
RMEDF	Index of average real airfares on medium-length air routes

ROFARE	Weighted average of real outbound airfares
RROADLH	Index of real long-haul road freight rates
RTWI	The real trade weighted index of the Australian dollar exchange rate
SERDUM	Dummy variable to account for service frequency cuts in Victorian tram and train services from 1993Q3 onwards
SGNE85	Seasonally adjusted gross national expenditure (in 1984–85) prices
SKM	Seat-kilometres
t	Time
$Task_y$	Rail task of type y
tc	Total fuel uplifted in Australia by international ships
TFC	Total fuel consumed for Australia's international aviation task
tft	Total amount of fuel required to complete the international shipping task to and from Australia
3SLS	Three-stage least squares (a method of estimation)
TIPKM	Total number of seat-kilometres travelled by aircraft arriving in and departing from Australia
TOTFRT	Estimate of the total Australian road freight task in billions of tonne-kilometres
TWI	Trade weighted index of the Australian dollar exchange rate
VKT	(Average annual) vehicle kilometres travelled
XRATE	The real exchange rate between Australia and the United States quoted in US dollars per Australian dollar

APPENDIX VIII ROAD TRANSPORT DATA

TABLE VIII.1 PASSENGER CAR FLEET CHARACTERISTICS

Year	VKT (billion km)	Australian population (millions)	Vehicles per thousand persons	Number of vehicles (millions)	Average fleet L/100km
1971	63.81	13.07	305.3	4.00	12.28
1972	66.13	13.30	316.8	4.22	12.32
1973	68.06	13.51	320.1	4.33	12.43
1974	72.60	13.72	344.2	4.73	12.44
1975	76.82	13.89	358.1	4.98	12.44
1976	79.04	14.03	363.2	5.11	12.57
1977	82.71	14.19	375.8	5.35	12.59
1978	85.85	14.36	379.3	5.46	12.58
1979	87.72	14.52	388.2	5.65	12.70
1980	88.77	14.69	393.2	5.79	12.63
1981	90.28	14.92	401.9	6.02	12.57
1982	95.71	15.18	412.9	6.29	12.40
1983	96.21	15.39	419.5	6.48	12.29
1984	100.58	15.58	426.9	6.68	12.19
1985	105.67	15.79	435.7	6.93	12.10
1986	109.49	16.02	440.3	7.11	11.90
1987	112.32	16.26	441.0	7.23	11.85
1988	116.78	16.52	446.5	7.38	11.90
1989	121.70	16.81	450.2	7.57	12.00
1990	124.58	17.07	456.4	7.80	12.10
1991	122.57	17.28	463.4	8.01	12.29
1992	124.88	17.48	468.4	8.19	12.19
1993	128.04	17.67	471.1	8.33	12.08
1994	130.27	17.84	471.1	8.40	11.96
1995	132.58	18.02	474.6	8.55	11.83
1996	134.86	18.21	477.9	8.70	11.70
1997	137.10	18.40	480.8	8.85	11.58
1998	139.32	18.59	483.6	8.99	11.45
1999	141.52	18.78	486.2	9.13	11.32
2000	143.69	18.98	488.5	9.27	11.20
2001	145.82	19.17	490.8	9.41	11.08
2002	147.85	19.36	492.7	9.54	10.96
2003	149.88	19.55	494.7	9.67	10.84
2004	151.80	19.73	496.3	9.79	10.69
2005	153.71	19.92	497.9	9.92	10.57
2006	155.55	20.10	499.4	10.04	10.45
2007	157.33	20.27	500.7	10.15	10.33
2008	159.06	20.45	501.9	10.26	10.20
2009	160.76	20.62	503.1	10.37	10.05
2010	162.41	20.79	504.1	10.48	9.90
2011	164.01	20.95	505.0	10.58	9.79
2012	165.60	21.12	505.9	10.68	9.65
2013	167.15	21.28	506.8	10.78	9.51
2014	168.66	21.44	507.5	10.88	9.36
2015	170.13	21.60	508.1	10.98	9.22

Sources ABS (1991a, 1994a, 1994b, 1994d); Cosgrove & Gargett (1992); BTCE estimates.

TABLE VIII.2 PASSENGER CAR FUEL CONSUMPTION

	Fuel consumption (million litres)				Total
Year	Petrol	Diesel	LPG	CNG	PJ
1971	7828	8	0	0.0	268
1972	8133	11	4	0.0	279
1973	8437	13	11	0.0	289
1974	8996	16	16	0.0	309
1975	9517	18	24	0.0	327
1976	9886	21	29	0.0	340
1977	10363	20	33	0.0	356
1978	10743	20	40	0.0	369
1979	11066	18	56	0.0	381
1980	11087	37	88	0.0	383
1981	11180	44	122	0.0	387
1982	11651	57	160	0.0	405
1983	11567	70	188	0.0	403
1984	11938	100	224	0.0	418
1985	12225	190	265	0.0	432
1986	12516	200	335	0.0	444
1987	12687	220	400	0.0	453
1988	13186	244	467	0.1	472
1989	13736	300	569	0.2	496
1990	14055	350	670	0.3	511
1991	13854	420	838	1.0	512
1992	13964	440	955	2.3	519
1993	14067	456	1082	3.2	527
1994	14080	462	1099	4.4	528
1995	14101	464	1116	6.1	529
1996	14177	466	1134	8.5	532
1997	14243	467	1151	11.7	535
1998	14303	468	1169	16.1	538
1999	14344	469	1186	22.3	540
2000	14395	469	1203	30.7	542
2001	14430	470	1221	42.4	544
2002	14443	470	1238	58.6	546
2003	14441	470	1255	80.8	547
2004	14374	467	1273	111.6	546
2005	14338	467	1290	154.0	547
2006	14316	466	1308	170.0	547
2007	14281	465	1325	186.0	547
2008	14224	462	1342	201.9	546
2009	14117	459	1360	217.9	543
2010	14020	455	1377	233.9	540
2011	13963	453	1394	249.8	539
2012	13860	450	1412	265.8	537
2013	13741	446	1429	281.8	534
2014	13607	441	1446	297.7	530
2015	13500	480	1460	314.0	528

Note The CNG figures refer to litres of petroleum displaced by CNG use (ie give the volume of petrol with equal energy content to the level of CNG consumption forecast for each year), and are assumed negligible prior to 1988.

Sources ABS (1993a and earlier); Bush et al. (1993); BTCE estimates.

TABLE VIII.3 PASSENGER CAR EMISSIONS

	Emissions (gigagrams)						
Year	CO_2	CH_4	N_2O	NO_x	CO	NMVOCs	CO_2 equivalent
1971	17513	13	0	137	2412	389	24540
1972	18210	14	0	142	2500	403	25492
1973	18903	14	0	146	2573	415	26399
1974	20171	15	0	156	2744	443	28166
1975	21350	16	0	165	2904	469	29810
1976	22191	17	0	170	2988	482	30896
1977	23260	17	0	176	3122	491	32239
1978	24121	18	0	180	3237	495	33306
1979	24861	18	0	182	3303	492	34086
1980	25006	18	0	182	3338	483	34204
1981	25284	17	0	181	3340	478	34417
1982	26429	18	0	191	3484	492	35938
1983	26318	18	0	188	3435	480	35657
1984	27282	19	0	196	3520	487	36853
1985	28225	19	0	202	3635	496	38030
1986	29007	19	1	204	3591	485	38744
1987	29542	19	1	202	3370	449	38807
1988	30821	19	1	202	3281	437	39970
1989	32353	18	1	204	3164	414	41261
1990	33352	18	1	203	3015	395	42038
1991	33346	17	2	194	2758	357	41440
1992	33824	17	2	193	2619	337	41666
1993	34289	16	2	193	2407	306	41695
1994	34363	16	2	191	2250	284	41522
1995	34445	16	2	190	2174	276	41502
1996	34649	15	3	185	2027	259	41414
1997	34833	14	3	180	1873	242	41290
1998	35003	13	3	174	1713	224	41137
1999	35132	12	3	168	1546	205	40929
2000	35291	11	3	162	1374	185	40736
2001	35417	11	3	158	1270	176	40663
2002	35499	11	3	153	1161	166	40534
2003	35558	10	3	148	1049	156	40375
2004	35482	10	3	142	933	146	40070
2005	35502	9	4	137	813	135	39853
2006	35504	9	4	134	755	131	39741
2007	35475	9	4	131	696	126	39594
2008	35397	8	4	127	634	122	39392
2009	35201	8	4	124	571	117	39069
2010	35028	7	4	120	507	112	38763
2011	34950	7	4	119	489	112	38651
2012	34765	7	4	117	470	112	38430
2013	34543	7	4	116	451	111	38169
2014	34284	6	4	114	432	111	37869
2015	34192	6	4	112	412	111	37734

Source BTCE estimates.

TABLE VIII.4 FREIGHT VEHICLE CHARACTERISTICS

	Average load (tonnes)			Tonne-kilometres (million)		
Year	LCV	Rigid	Articulated	LCV	Rigid	Articulated
1971	0.14	2.33	8.84	1371	10619	15200
1972	0.14	2.35	9.38	1439	10605	16606
1973	0.14	2.37	9.93	1525	10666	17793
1974	0.14	2.38	10.47	1683	10950	19051
1975	0.14	2.40	11.01	1822	11217	20745
1976	0.15	2.42	11.49	1990	11672	23041
1977	0.15	2.57	11.74	2203	12115	25233
1978	0.15	2.74	11.98	2413	12713	27215
1979	0.15	2.92	12.23	2599	13642	31895
1980	0.15	2.76	12.62	2587	14524	35217
1981	0.15	2.60	13.05	2703	15197	36506
1982	0.16	2.41	13.42	2875	16243	40248
1983	0.16	2.59	13.82	2859	15552	41361
1984	0.16	2.78	14.29	3145	16494	46156
1985	0.16	2.97	14.68	3519	18117	52664
1986	0.18	3.11	15.01	3754	18579	54051
1987	0.19	3.23	15.26	4116	19464	56172
1988	0.20	3.29	15.57	4682	21126	59721
1989	0.20	3.35	15.69	4725	21657	63666
1990	0.21	3.36	15.78	4725	21992	64611
1991	0.21	3.36	15.89	4751	20547	62906
1992	0.21	3.36	15.97	4867	21429	66965
1993	0.21	3.36	16.03	5069	22644	70819
1994	0.21	3.39	16.15	5391	23400	71009
1995	0.22	3.42	16.26	5733	24181	74087
1996	0.22	3.46	16.38	6097	24987	77116
1997	0.23	3.49	16.49	6484	25821	80295
1998	0.23	3.53	16.61	6895	26682	83422
1999	0.23	3.56	16.72	7333	27573	86895
2000	0.24	3.60	16.84	7798	28493	90509
2001	0.24	3.63	16.96	8293	29443	94264
2002	0.25	3.67	17.08	8820	30425	98155
2003	0.25	3.71	17.20	9379	31441	102180
2004	0.26	3.74	17.32	9975	32490	106436
2005	0.26	3.78	17.44	10608	33574	110819
2006	0.27	3.82	17.57	11281	34694	115425
2007	0.27	3.86	17.69	11997	35851	120152
2008	0.28	3.90	17.81	12758	37047	125094
2009	0.28	3.94	17.94	13568	38283	130148
2010	0.29	3.97	18.07	14429	39561	135610
2011	0.29	4.01	18.19	15345	40880	141074
2012	0.30	4.05	18.32	16319	42244	146736
2013	0.31	4.09	18.45	17355	43654	152691
2014	0.31	4.14	18.58	18457	45110	159033
2015	0.32	4.18	18.71	19628	46615	165357

Sources ABS (1993a and earlier); Cosgrove & Gargett (1992); BTCE estimates.

TABLE VIII.5 FREIGHT VEHICLE CHARACTERISTICS

	VKT (million km)			Average L/100km		
Year	*LCV*	*Rigid*	*Articulated*	*LCV*	*Rigid*	*Articulated*
1971	9839	4560	1720	13.44	22.81	45.70
1972	10257	4520	1769	13.60	23.79	45.98
1973	10807	4510	1792	13.80	24.58	47.02
1974	11798	4600	1819	13.94	25.37	48.14
1975	12684	4675	1884	14.10	26.16	49.15
1976	13667	4826	2005	14.26	27.00	50.32
1977	14943	4712	2149	14.29	27.48	51.33
1978	16130	4637	2271	14.32	27.98	52.38
1979	17165	4670	2607	14.35	28.71	53.13
1980	16931	5259	2790	14.16	27.60	53.42
1981	17444	5835	2798	13.90	26.34	53.54
1982	18474	6734	3000	13.80	25.26	53.70
1983	18121	6004	2993	13.65	25.29	53.61
1984	19602	5934	3229	13.53	25.44	53.57
1985	21629	6102	3588	13.40	25.61	53.60
1986	21432	5977	3602	13.40	25.74	53.72
1987	21843	6021	3680	13.40	25.90	53.89
1988	23301	6429	3836	13.40	26.06	54.17
1989	23616	6459	4059	13.45	26.38	52.92
1990	22926	6546	4095	13.50	26.45	51.95
1991	22814	6114	3959	13.60	26.86	50.64
1992	23222	6385	4192	13.60	26.56	49.95
1993	24184	6747	4417	13.60	26.56	49.95
1994	25238	6904	4398	13.60	26.50	49.71
1995	26337	7063	4556	13.60	26.50	49.35
1996	27486	7227	4709	13.60	26.50	48.98
1997	28684	7394	4869	13.60	26.50	48.63
1998	29935	7565	5023	13.60	26.50	48.27
1999	31242	7740	5196	13.60	26.50	47.91
2000	32605	7919	5374	13.60	26.50	47.56
2001	34029	8102	5558	13.60	26.50	47.21
2002	35515	8289	5747	13.60	26.50	46.87
2003	37066	8481	5941	13.60	26.50	46.52
2004	38685	8677	6145	13.60	26.50	46.18
2005	40376	8878	6353	13.60	26.50	45.84
2006	42141	9083	6571	13.60	26.50	45.51
2007	43984	9294	6792	13.60	26.50	45.17
2008	45908	9509	7022	13.60	26.50	44.84
2009	47916	9728	7255	13.60	26.50	44.51
2010	50013	9954	7507	13.60	26.50	44.19
2011	52203	10184	7754	13.60	26.50	43.86
2012	54488	10419	8009	13.60	26.50	43.54
2013	56875	10660	8276	13.60	26.50	43.22
2014	59367	10907	8559	13.60	26.50	42.90
2015	61968	11159	8838	13.60	26.50	42.48

Sources ABS (1993a and earlier); BTCE estimates.

TABLE VIII.6 FREIGHT VEHICLE FUEL CONSUMPTION

	Fuel consumption (PJ)		
Year	*LCV*	*Rigid*	*Articulated*
1971	39.55	45.78	29.64
1972	42.01	47.38	30.78
1973	45.31	48.90	31.98
1974	50.19	51.51	33.34
1975	55.07	54.03	35.35
1976	60.19	56.36	38.04
1977	67.20	57.60	42.31
1978	73.36	57.94	45.69
1979	79.14	60.30	53.27
1980	76.85	65.76	57.36
1981	77.01	69.88	57.66
1982	80.97	77.62	62.04
1983	79.28	69.59	61.82
1984	85.01	69.60	66.69
1985	93.33	72.33	74.17
1986	93.13	71.49	74.64
1987	94.91	72.70	76.50
1988	102.22	76.37	80.15
1989	104.21	75.35	82.88
1990	103.01	72.68	82.07
1991	106.88	61.84	77.36
1992	108.79	65.01	80.83
1993	113.20	68.74	84.30
1994	117.92	68.87	84.34
1995	122.98	70.47	86.74
1996	128.25	72.10	89.00
1997	133.76	73.77	91.34
1998	139.51	75.47	93.54
1999	145.49	77.22	96.04
2000	151.49	79.01	98.60
2001	158.09	80.83	101.22
2002	164.98	82.70	103.90
2003	172.18	84.62	106.61
2004	179.69	86.58	109.46
2005	187.53	88.58	112.34
2006	195.72	90.63	115.33
2007	204.26	92.73	118.34
2008	213.18	94.87	121.44
2009	222.49	97.07	124.54
2010	232.21	99.31	127.91
2011	242.35	101.61	131.15
2012	252.94	103.96	134.47
2013	264.00	106.37	137.92
2014	275.54	108.83	141.59
2015	287.59	111.35	144.75

Sources ABS (1993a and earlier); BTCE estimates.

TABLE VIII.7 FREIGHT VEHICLE EMISSIONS

	Emissions (gigagrams)						
Year	CO_2	CH_4	N_2O	NO_x	*CO*	*NMVOCs*	CO_2 *equivalent*
1991	16440	3.08	0.47	119	527	80	18786
1992	17016	3.12	0.49	124	533	81	19424
1993	17791	3.26	0.51	130	554	84	20300
1994	18104	3.43	0.52	132	580	88	20693
1995	18701	3.62	0.54	137	603	91	21387
1996	19303	3.85	0.56	141	625	94	22087
1997	19924	4.16	0.58	146	647	98	22809
1998	20544	4.61	0.60	151	668	101	23531
1999	21188	5.31	0.62	156	686	103	24278
2000	21807	6.47	0.63	161	698	105	24994
2001	22529	6.82	0.66	166	725	109	25835
2002	23275	7.19	0.68	172	752	113	26706
2003	24046	7.59	0.71	178	781	117	27605
2004	24849	8.01	0.73	185	810	122	28542
2005	25677	8.46	0.76	191	840	126	29509
2006	26537	8.94	0.79	198	872	131	30514
2007	27423	9.45	0.82	205	904	136	31549
2008	28342	9.99	0.85	212	938	141	32623
2009	29288	10.57	0.88	220	973	146	33730
2010	30281	11.18	0.91	228	1008	152	34890
2011	31294	11.84	0.94	236	1045	157	36076
2012	32342	12.55	0.98	244	1082	163	37303
2013	33431	13.31	1.01	253	1121	169	38578
2014	34567	14.12	1.05	262	1160	175	39909
2015	35703	14.98	1.09	272	1200	181	41243

Note Detailed emission estimates for years prior to 1991 are not provided for trucks because vintage-specific emission factors are available only for cars. The truck emission projections are calculated by assuming emission factors, by vehicle type, and remain constant (at the values given in appendix V). Historical values for estimated CO_2 equivalent emissions are presented by vehicle type in table VIII.9.

Source BTCE estimates.

TABLE VIII.8 LONG-TERM DATA SERIES FOR ROAD TRANSPORT

Year ending June	Number of cars[a] ('000)	Number of commercial vehicles[b] ('000)	CPI[c]	Total freight[d] (billion tonne-kilometres)	Long-haul road freight rates[e] (current $ per tonne)	Real Australian GDP[f] (1989–90 prices $ million)
1929	474.8	71.4				43446.68
1930	467.4	104.0				44074.82
1931	429.6	97.6				39922.09
1932	420.3	96.0				40599.08
1933	436.8	107.5				43034.90
1934	431.5	140.1				44640.16
1935	457.9	154.0				45638.19
1936	484.6	180.2				47969.32
1937	499.3	214.3				49518.74
1938	535.1	241.6				52687.40
1939	562.5	257.8				50579.60
1940	559.5	260.9				53357.40
1941	538.5	262.0				57356.60
1942	450.8	250.4				65766.76
1943	471.9	255.5				71496.82
1944	493.6	273.7				70645.34
1945	505.9	290.5				66562.40
1946	522.9	333.1				63812.53
1947	548.3	377.9				61879.24
1948	588.7	418.8				66883.46
1949	651.1	456.7				70184.71
1950	764.2	506.1	7.2619			75879.88
1951	879.3	555.4	8.2237			80255.97
1952	1028.0	587.6	10.0993			82608.02
1953	1104.9	586.6	11.0131			81965.92
1954	1195.5	611.2	11.2535			87123.68
1955	1342.4	654.3	11.3497			92316.33
1956	1429.9	693.2	11.7825			96957.62
1957	1537.4	710.3	12.4558			98863.00
1958	1660.9	731.0	12.6001			100970.77
1959	1784.2	755.0	12.7925			108466.64
1960	1937.6	784.1	13.1291			114252.55
1961	2070.0	800.0	13.6581	13.00		118000.47
1962	2200.7	814.6	13.7062	14.00		119207.91
1963	2377.0	832.1	13.7543	16.00		127171.40
1964	2582.6	846.2	13.8986	17.00		135881.65
1965	2791.5	858.0	14.3795	19.00	37.11	145562.08
1966	2946.6	867.8	14.9085	20.00	37.34	147976.96
1967	2104.2	880.0	15.2932	22.00	38.73	157350.27
1968	3305.0	891.8	15.8223	23.00	40.36	163150.13
1969	3499.1	911.4	16.2070	25.00	42.21	177730.06
1970	3719.7	937.5	16.7360	26.00	43.14	187968.81

TABLE VIII.8 LONG-TERM DATA SERIES FOR ROAD TRANSPORT (Continued)

Year ending June	Number of cars[a] ('000)	Number of commercial vehicles[b] ('000)	CPI[c]	Total freight[d] (billion tonne-kilometres)	Long-haul road freight rates[e] (current $ per tonne)	Real Australian GDP[f] (1989–90 prices $ million)
1971	4000.0	957.6	17.5536	27.19	45.69	196288.26
1972	4220.0	994.6	18.7559	28.65	48.01	204133.08
1973	4330.0	1014.5	19.8620	29.98	51.49	213611.09
1974	4730.0	1092.1	22.4590	31.68	56.36	225783.13
1975	4980.0	1157.6	26.2101	33.78	63.55	232441.37
1976	5110.0	1194.9	29.577	36.70	69.35	238548.44
1977	5350.0	1286.8	33.712	39.55	74.68	245716.22
1978	5460.0	1332.7	36.887	42.34	78.40	246777.15
1979	5650.0	1390.6	39.916	48.14	82.11	261212.17
1980	5790.0	1407.7	43.956	52.32	83.03	265352.48
1981	6020.0	1455.2	48.092	54.40	85.59	273194.98
1982	6290.0	1535.3	53.904	59.37	90.69	278627.77
1983	6480.0	1565.2	59.201	59.77	96.72	274246.49
1984	6680.0	1616.9	63.818	65.80	98.81	290084.83
1985	6930.0	1663.5	67.665	74.30	102.52	305506.95
1986	7110.0	1683.8	73.340	76.38	107.62	318738.43
1987	7230.0	1684.1	80.169	79.75	116.51	327413.37
1988	7380.0	1690.0	86.037	85.53	123.80	342964.74
1989	7570.0	1726.8	92.385	90.05	130.96	356910.37
1990	7800.0	1750.6	100.000	91.33	138.49	369029.00
1991	8010.0	1782.3	105.300	88.20	148.54	366685.01
1992	8190.0	1898.0	107.300	93.26	151.35	368691.64
1993	8330.0	1944.7	108.400	98.53	154.40	379787.24

Sources a. CBCS (1973, pp. 30–31); ABS (1992a, 1992b and earlier); BTCE estimates.

b. CBCS (1973, pp. 32–33); ABS (1992b and earlier); BTCE estimates.

c. Maddock & McLean (1987, p. 356); ABS (1994d,1994e).

d. Cosgrove & Gargett (1992, p. 236); BTCE estimates.

e. BTCE (1990, p. 49); TransEco (1994 and earlier).

f. Maddock & McLean (1987, pp. 356, 359); ABS (1994c, 1994d).

TABLE VIII.9 ROAD EMISSIONS BY VEHICLE TYPE

(gigagrams, CO_2 equivalent)

Year	*Cars*	*Buses*	*LCVs*	*Rigid and other trucks*	*Articulated trucks*	*Total*[a]
1971	24540	522	3103	3558	2272	34328
1972	25492	530	3296	3678	2359	35690
1973	26399	544	3555	3792	2451	37075
1974	28166	554	3938	3992	2556	39541
1975	29810	567	4320	4184	2710	41925
1976	30896	571	4722	4458	2916	43896
1977	32239	579	5229	4431	3243	46055
1978	33306	586	5708	4438	3502	47874
1979	34086	595	6158	4587	4083	49843
1980	34204	626	5979	4965	4397	50505
1981	34417	656	5992	5258	4420	51077
1982	35938	688	6300	5818	4756	53834
1983	35657	765	6169	5194	4739	52857
1984	36853	846	6615	5165	5112	54925
1985	38030	932	7262	5345	5685	57588
1986	38744	992	7229	5263	5721	58284
1987	38807	1054	7368	5335	5864	58762
1988	39970	1112	7935	5591	6144	61087
1989	41261	1134	8148	5487	6353	62717
1990	42038	1198	8055	5266	6291	63182
1991	41440	1185	8357	4494	5930	61740
1992	41660	1256	8490	4731	6203	62674
1993	41695	1328	8830	5002	6468	63657
1994	41522	1338	9203	5015	6474	63888
1995	41502	1350	9592	5131	6663	64572
1996	41414	1361	9996	5250	6841	65196
1997	41290	1373	10412	5371	7026	65806
1998	41137	1384	10835	5496	7200	66387
1999	40929	1396	11257	5622	7398	66937
2000	40736	1409	11640	5752	7601	67472
2001	40663	1421	12142	5885	7809	68253
2002	40534	1432	12664	6021	8021	69007
2003	40375	1444	13209	6160	8236	69758
2004	40070	1455	13778	6302	8463	70401
2005	39853	1467	14370	6447	8692	71162
2006	39741	1478	14988	6595	8930	72067
2007	39594	1488	15633	6746	9170	72966
2008	39392	1499	16304	6901	9418	73849
2009	39069	1509	17005	7059	9666	74642
2010	38763	1519	17735	7220	9935	75507
2011	38651	1529	18497	7384	10196	76591
2012	38430	1539	19291	7551	10461	77606
2013	38169	1549	20118	7721	10739	78630
2014	37869	1559	20981	7894	11033	79671
2015	37734	1568	21881	8070	11293	80880

a. Includes motorcycle emissions (assumed constant at 334 Gg per annum).

Note Estimated values for years prior to 1990 are very approximate, since vintage-specific emission factors are available only for cars. Factors for all other vehicle types have been kept constant (at the values given in appendix V).

Source BTCE estimates.

APPENDIX IX RAIL TRANSPORT DATA

TABLE IX.1 RAIL PROJECTIONS

Year ending June	PASNU (thousand)	PASKMNU (billion)	NUavtrip (km)	PASU (million)	RAUSPFC ($ million)	AUSTFAR
1973		4.98		464.40		
1974		3.77		470.00		
1975		3.18		451.00		
1976		2.61		442.00		
1977		2.73		432.00		
1978	9067.13	2.72	299.98	420.00		
1979	8731.74	2.65	303.49	416.00		
1980	8503.61	2.61	306.93	437.00		
1981	9346.16	2.97	317.78	445.00		
1982	8985.42	2.88	320.52	454.00		
1983	9419.91	2.96	314.23	442.00		
1984	9297.61	2.88	309.76	444.00		
1985	10104.36	2.96	292.94	448.77	183349.7	66.12
1986	8941.54	2.71	303.08	479.40	190193.3	70.41
1987	9235.82	2.71	293.42	492.29	191569.7	77.69
1988	9747.80	2.93	300.58	510.37	199137.0	83.67
1989	10039.33	2.89	287.87	523.78	208326.4	92.25
1990	9651.66	2.51	260.06	500.22	218097.5	100.00
1991	9521.47	2.48	260.46	510.58	220240.0	112.18
1992	8848.55	2.30	260.00	518.32	225778.9	121.40
1993	8584.97	2.23	260.00	495.75	232142.4	127.45
1994	8605.00	2.24	260.00	510.04	239571.0	127.45
1995	8666.45	2.25	260.00	524.76	247237.2	127.45
1996	8707.48	2.26	260.00	539.94	255148.8	127.45
1997	8748.72	2.27	260.00	555.58	263313.6	127.45
1998	8790.15	2.29	260.00	571.70	271739.6	127.45
1999	8831.78	2.30	260.00	588.82	280707.0	127.45
2000	8873.62	2.31	260.00	606.49	289970.4	127.45
2001	8915.65	2.32	260.00	624.72	299539.4	127.45
2002	8957.89	2.33	260.00	643.51	309424.2	127.45
2003	9000.34	2.34	260.00	662.90	319635.2	127.45
2004	9042.99	2.35	260.00	682.90	330183.2	127.45
2005	9085.84	2.36	260.00	703.54	341079.2	127.45
2006	9128.91	2.37	260.00	724.82	352334.8	127.45
2007	9172.18	2.38	260.00	746.77	363961.9	127.45
2008	9215.66	2.40	260.00	769.41	375972.6	127.45
2009	9259.35	2.41	260.00	792.77	388379.7	127.45
2010	9303.25	2.42	260.00	816.86	401196.2	127.45
2011	9347.36	2.43	260.00	841.71	414435.7	127.45
2012	9391.69	2.44	260.00	867.34	428112.1	127.45
2013	9436.23	2.45	260.00	893.78	442239.8	127.45
2014	9480.99	2.47	260.00	921.05	456833.7	127.45
2015	9525.96	2.48	260.00	949.19	471909.2	127.45

Sources BTCE estimates; BTCE (1994a) Indicators Database; Cosgrove & Gargett (1992, p. 238).

TABLE IX.1 RAIL PROJECTIONS (continued)

Year ending June	PASKMU (billion)	Uavtrip (km)	GNBT (million)	GBT (million)	GNBAvhaul (km)	GBAvhaul (km)	GNBTKM (billion)	GBTKM (billion)
1978	5.71	13.6		81.23	490.05	208.2	14.63	16.91
1979	5.67	13.6		83.56	505.8	203.2	16.42	16.98
1980	6.13	14.0		95.66	444.06	216.9	14.63	20.75
1981	6.29	14.1		98.89	548.6	211.3	16.53	20.90
1982	6.46	14.2		99.60	495.5	239.5	14.14	23.85
1983	6.30	14.2	22.99	101.71	485.6	224.6	11.18	22.84
1984	6.35	14.3	25.03	117.16	545	224.8	13.62	26.33
1985	6.43	14.3	24.78	134.60	557.71	224.9	13.80	30.28
1986	6.97	14.5	26.79	145.55	570.43	225.1	15.28	32.77
1987	7.18	14.6	27.42	148.70	583.14	225.3	15.98	33.50
1988	7.47	14.6	28.94	147.13	595.86	225.5	17.23	33.17
1989	7.67	14.6	31.97	143.86	608.57	225.6	19.42	32.46
1990	7.47	14.9	30.84	155.84	621.29	225.8	19.18	35.19
1991	7.52	14.7	29.59	159.29	634	226.0	18.77	36.00
1992	7.52	14.5	30.06	166.59	634	226.0	19.01	37.65
1993	7.18	14.5	31.05	171.12	634	226.0	20.73	38.67
1994	7.39	14.5	32.09	175.02	634	226.0	20.98	39.55
1995	7.60	14.5	33.15	178.86	634	226.0	21.02	40.42
1996	7.82	14.5	34.25	183.19	634	226.0	21.72	41.40
1997	8.05	14.5	35.39	187.09	634	226.0	22.44	42.28
1998	8.28	14.5	36.56	192.49	634	226.0	23.18	43.50
1999	8.53	14.5	37.77	196.75	634	226.0	23.95	44.47
2000	8.78	14.5	39.02	201.22	634	226.0	24.74	45.48
2001	9.05	14.5	40.31	205.64	634	226.0	25.56	46.47
2002	9.32	14.5	41.64	210.01	634	226.0	26.40	47.46
2003	9.60	14.5	43.01	214.35	634	226.0	27.27	48.44
2004	9.89	14.5	44.43	218.64	634	226.0	28.17	49.41
2005	10.19	14.5	45.89	222.89	634	226.0	29.10	50.37
2006	10.50	14.5	47.40	227.10	634	226.0	30.05	51.33
2007	10.82	14.5	48.96	231.28	634	226.0	31.04	52.27
2008	11.14	14.5	50.57	235.42	634	226.0	32.06	53.20
2009	11.48	14.5	52.23	239.53	634	226.0	33.12	54.13
2010	11.83	14.5	53.95	243.60	634	226.0	34.20	55.05
2011	12.19	14.5	55.72	247.64	634	226.0	35.33	55.97
2012	12.56	14.5	57.55	251.65	634	226.0	36.48	56.87
2013	12.94	14.5	59.43	255.63	634	226.0	37.68	57.77
2014	13.34	14.5	61.38	259.58	634	226.0	38.91	58.67
2015	13.75	14.5	63.39	263.50	634	226.0	40.19	59.55

Sources BTCE (1994a) Indicators Database; ABS (1986a, p. 4); Cosgrove & Gargett (1992, p. 238); BTCE estimates.

TABLE IX.1 RAIL PROJECTIONS (continued)

Year ending June	FC (PJ)	PFT (million)	PFTKM (billion)	PAvhaul (km)	CGEXP ('000 tonnes)	IOP ('000 tonnes)
1973		95	20.0	210.53		
1974	27.66	115	26.5	230.43		
1975	29.07	128	30.2	235.94		
1976	29.89	117	26.3	224.79		
1977	29.94	124	27.3	220.16		
1978	30.27	121	28.4	234.71	50963	89.53
1979	30.90	114	25.6	224.56	49015	87.43
1980	30.76	123	27.8	226.02	62711	93.63
1981	30.80	124	28.9	233.06	60965	94.50
1982	30.60	121	27.4	226.45	60347	86.24
1983	28.21	110	25.0	227.27	64743	80.99
1984	30.36	108	23.3	215.74	80674	79.75
1985	32.12	129	28.4	220.16	108969	91.35
1986	31.23	126	29.2	231.75	111886	92.79
1987	32.35	132	30.3	229.55	116174	96.77
1988	32.28	136	31.0	227.94	116950	102.53
1989	30.54	135	28.7	212.59	110728	97.47
1990	30.18	148	32.5	219.59	120017	109.89
1991	30.02	158	35.3	223.42	128712	111.40
1992	29.37	151	35.1	232.56	134815	115.53
1993	28.83	159	35.8	224.87	141230	116.31
1994	28.89	164.2	36.9	224.87	148819	120.00
1995	29.48	168.2	37.8	224.87	153639	123.00
1996	30.09	172.2	38.7	224.87	159137	126.00
1997	30.66	174.9	39.3	224.87	164142	128.00
1998	31.30	177.6	39.9	224.87	171162	130.00
1999	31.86	179.0	40.2	224.87	176755	131.00
2000	32.48	181.9	40.9	224.87	182687	133.20
2001	33.09	184.9	41.6	224.87	188620	135.40
2002	33.71	187.8	42.2	224.87	194553	137.60
2003	34.34	190.8	42.9	224.87	200485	139.80
2004	34.96	193.8	43.6	224.87	206418	142.00
2005	35.59	196.7	44.2	224.87	212351	144.20
2006	36.22	199.7	44.9	224.87	218283	146.40
2007	36.86	202.6	45.6	224.87	224216	148.60
2008	37.50	205.6	46.2	224.87	230148	150.80
2009	38.15	208.5	46.9	224.87	236081	153.00
2010	38.79	211.5	47.6	224.87	242014	155.20
2011	39.45	214.5	48.2	224.87	247946	157.40
2012	40.11	217.4	48.9	224.87	253879	159.60
2013	40.77	220.4	49.6	224.87	259812	161.80
2014	41.44	223.3	50.2	224.87	265744	164.00
2015	42.12	226.3	50.9	224.87	271677	166.20

Sources ABARE (S. Bush, pers. comm. 10 February 1994; 1993b, pp. 93, 246, 303); Bush et al. (1993, p. 112); Cosgrove & Gargett (1992, p. 234); BTCE estimates.

TABLE IX.1 RAIL PROJECTIONS (continued)

Year ending June	Specific Fuel Intensities				
	PASU	PASNU	PF	GB	GNB
1978	0.68	1.02	0.15	0.45	0.79
1979	0.67	0.98	0.14	0.44	0.76
1980	0.66	0.95	0.14	0.42	0.74
1981	0.65	0.92	0.13	0.41	0.71
1982	0.63	0.91	0.13	0.41	0.71
1983	0.62	0.91	0.13	0.41	0.70
1984	0.61	0.90	0.13	0.40	0.70
1985	0.60	0.90	0.13	0.40	0.70
1986	0.58	0.89	0.13	0.39	0.66
1987	0.56	0.88	0.13	0.37	0.62
1988	0.54	0.87	0.13	0.36	0.58
1989	0.53	0.93	0.13	0.32	0.56
1990	0.53	0.99	0.13	0.29	0.55
1991	0.52	1.05	0.13	0.25	0.53
1992	0.52	1.05	0.13	0.25	0.53
1993	0.52	1.05	0.13	0.25	0.53
1994	0.52	1.05	0.12	0.25	0.53
1995	0.52	1.04	0.12	0.25	0.52
1996	0.51	1.04	0.12	0.25	0.52
1997	0.51	1.03	0.12	0.24	0.52
1998	0.51	1.03	0.12	0.24	0.51
1999	0.51	1.02	0.12	0.24	0.51
2000	0.50	1.02	0.12	0.24	0.50
2001	0.50	1.01	0.12	0.23	0.50
2002	0.50	1.01	0.12	0.23	0.50
2003	0.50	1.00	0.12	0.23	0.49
2004	0.49	1.00	0.12	0.23	0.49
2005	0.49	0.99	0.11	0.22	0.49
2006	0.49	0.99	0.11	0.22	0.48
2007	0.49	0.98	0.11	0.22	0.48
2008	0.48	0.98	0.11	0.22	0.48
2009	0.48	0.97	0.11	0.21	0.47
2010	0.48	0.97	0.11	0.21	0.47
2011	0.48	0.96	0.11	0.21	0.46
2012	0.47	0.96	0.11	0.21	0.46
2013	0.47	0.95	0.11	0.20	0.46
2014	0.47	0.95	0.11	0.20	0.45
2015	0.47	0.95	0.11	0.20	0.45

Sources BTCE estimates derived from data contained in Bush et al. (1993, p. 112); Apelbaum (1993, pp. 94–95, 98, 100, 153, 158); Cosgrove & Gargett (1992, pp. 234, 238); and BTCE (1994a) Indicators Database.

TABLE IX.2 AVERAGE FUEL INTENSITY INDEX FOR RAIL (1987–88=100)

Year ending June	*Average Fuel Intensity Index*
1978	128
1979	127
1980	123
1981	115
1982	117
1983	118
1984	116
1985	112
1986	103
1987	103
1988	100
1989	92
1990	89
1991	87
1992	84
1993	80

Notes 1. Part of the decline in intensity is due to the increasing penetration of electric rail.
2. End-use figures for electricity consumption do not include generation and transmission losses.

Sources BTCE estimates using data contained in Bush et al. (1993, p. 112); Apelbaum (1993, pp. 94–95, 98, 100, 153, 158); Cosgrove & Gargett (1992, pp. 234, 238); and BTCE (1994a) Indicators Database.

TABLE IX.3 RAIL FUEL CONSUMPTION PROJECTIONS

(petajoules)

Year ending June	*FC*	*ADO*	*Electricity*	*IDF*	*Coal*
1974	27.66	24.99	2.37	0.00	0.30
1975	29.07	26.26	2.47	0.00	0.34
1976	29.89	27.10	2.51	0.00	0.28
1977	29.94	27.18	2.50	0.00	0.26
1978	30.27	27.56	2.51	0.00	0.20
1979	30.90	28.27	2.44	0.00	0.19
1980	30.76	28.01	2.59	0.00	0.16
1981	30.80	27.80	2.84	0.00	0.16
1982	30.60	27.62	2.84	0.00	0.14
1983	28.21	25.14	2.96	0.00	0.11
1984	30.36	25.07	3.26	2.00	0.03
1985	32.12	25.90	3.50	2.69	0.03
1986	31.23	24.75	3.81	2.64	0.03
1987	32.35	25.79	3.93	2.60	0.03
1988	32.28	25.18	4.47	2.57	0.06
1989	30.54	22.79	5.17	2.53	0.05
1990	30.18	23.02	5.47	1.66	0.03
1991	30.02	22.97	5.51	1.54	0.00
1992	29.37	22.00	5.67	1.70	0.00
1993	28.83	21.10	5.63	2.10	0.00
1994	28.89	20.99	5.80	2.10	0.00
1995	29.48	21.35	6.02	2.10	0.00
1996	30.09	21.74	6.26	2.10	0.00
1997	30.66	22.06	6.49	2.10	0.00
1998	31.30	22.45	6.75	2.10	0.00
1999	31.86	22.76	7.00	2.10	0.00
2000	32.48	23.11	7.26	2.10	0.00
2001	33.09	23.47	7.53	2.10	0.00
2002	33.71	23.82	7.79	2.10	0.00
2003	34.34	24.18	8.06	2.10	0.00
2004	34.96	24.53	8.33	2.10	0.00
2005	35.59	24.88	8.61	2.10	0.00
2006	36.22	25.24	8.89	2.10	0.00
2007	36.86	25.59	9.17	2.10	0.00
2008	37.50	25.95	9.45	2.10	0.00
2009	38.15	26.31	9.74	2.10	0.00
2010	38.79	26.67	10.03	2.10	0.00
2011	39.45	27.03	10.32	2.10	0.00
2012	40.11	27.39	10.61	2.10	0.00
2013	40.77	27.76	10.91	2.10	0.00
2014	41.44	28.13	11.21	2.10	0.00
2015	42.12	28.51	11.51	2.10	0.00

Sources BTCE estimates; ABARE (S. Bush, pers. comm. 10 February 1994); Bush et al. (1993, p. 112).

TABLE IX.4 RAIL EMISSION PROJECTIONS

(gigagrams)

Year ending June	CO_2	NO_x	CH_4	*NMVOCs*	*CO*	N_2O	CO_2 *equivalent*
1974	2415.8	45.26	0.15	3.10	14.62	0.06	2839
1975	2535.2	47.55	0.16	3.26	15.37	0.06	2980
1976	2599.3	49.01	0.17	3.36	15.85	0.06	3057
1977	2600.3	49.13	0.17	3.37	15.89	0.06	3060
1978	2624.2	49.77	0.17	3.42	16.11	0.06	3089
1979	2653.6	50.91	0.17	3.51	16.52	0.06	3130
1980	2673.7	50.61	0.17	3.47	16.37	0.06	3147
1981	2727.4	50.51	0.17	3.45	16.26	0.06	3199
1982	2713.0	50.52	0.17	3.42	16.15	0.06	3182
1983	2570.2	46.07	0.16	3.12	14.72	0.06	3001
1984	2780.5	49.66	0.17	3.36	15.84	0.06	3244
1985	2952.3	52.50	0.18	3.55	16.73	0.07	3443
1986	2953.2	50.77	0.17	3.40	16.05	0.06	3427
1987	3055.7	52.60	0.18	3.52	16.64	0.07	3547
1988	3161.2	52.07	0.17	3.44	16.29	0.07	3647
1989	3181.9	48.64	0.16	3.14	14.91	0.06	3635
1990	3217.0	47.85	0.16	3.06	14.55	0.06	3662
1991	3213.3	47.59	0.16	3.04	14.45	0.06	3656
1992	3181.5	46.30	0.15	2.94	13.99	0.06	3612
1993	3155.0	45.47	0.15	2.88	13.70	0.06	3578
1994	3186.4	45.46	0.15	2.86	13.64	0.06	3609
1995	3265.0	46.31	0.15	2.91	13.86	0.06	3696
1996	3347.6	47.21	0.15	2.96	14.09	0.06	3787
1997	3425.1	48.01	0.16	3.00	14.29	0.06	3871
1998	3514.0	48.94	0.16	3.04	14.53	0.06	3969
1999	3593.5	49.72	0.16	3.08	14.71	0.07	4056
2000	3678.1	50.60	0.16	3.13	14.93	0.07	4148
2001	3762.9	51.47	0.17	3.17	15.15	0.07	4241
2002	3847.9	52.35	0.17	3.21	15.37	0.07	4334
2003	3933.0	53.24	0.17	3.26	15.58	0.07	4427
2004	4018.2	54.12	0.17	3.30	15.80	0.07	4521
2005	4103.6	55.01	0.18	3.35	16.01	0.07	4614
2006	4189.1	55.90	0.18	3.39	16.23	0.07	4708
2007	4274.7	56.80	0.18	3.43	16.45	0.08	4802
2008	4360.5	57.70	0.18	3.48	16.67	0.08	4896
2009	4446.3	58.61	0.19	3.52	16.89	0.08	4990
2010	4532.2	59.52	0.19	3.57	17.11	0.08	5084
2011	4618.1	60.44	0.19	3.61	17.33	0.08	5179
2012	4704.2	61.37	0.19	3.66	17.55	0.08	5273
2013	4790.3	62.30	0.20	3.70	17.78	0.08	5368
2014	4876.4	63.25	0.20	3.75	18.01	0.09	5463
2015	4961.7	64.20	0.20	3.80	18.24	0.09	5557

Notes 1. Includes emissions from the generation of electricity for trains and trams. Energy consumption by trams is essentially constant (Apelbaum 1993, p. 92), giving emissions of the order of 60 Gg CO_2 equivalent.

2. Historical emission estimates are based on constant emission factors (given in table 3.6), and are therefore very approximate.

Source BTCE estimates.

APPENDIX X AVIATION DATA

International Aviation Average Kilometres Flown

In order to calculate the average distance flown per passenger, a split was made into inbound passengers and outbound passengers.

For each category the number of passengers travelling to a particular destination was determined by choosing 10 regions and classifying each passenger into a destination (or departure) region.

An average distance flown per passenger was calculated by multiplying the proportion of total passengers to a particular region by the stage distance, and summing over all regions. Tables X.7 and X.8 detail the regions, stage distances, passenger numbers and average kilometres for both inbound and outbound passengers.

TABLE X.1 DOMESTIC AVIATION PROJECTIONS

Year ending June	*APASS (million)*	*AVKM (km)*	*FPASSKM (million)*	*APASSKM (million)*	*PASSKM (million)*	*SKM (million)*
1978	10.91	706.71	307.89	7708.00	8015.41	11963.3
1979	11.32	710.16	372.58	8039.00	8412.07	12173.76
1980	12.02	732.09	481.39	8798.00	9278.90	12816.16
1981	11.61	746.46	511.42	8669.57	9180.99	12406.74
1982	11.39	810.51	578.45	9234.58	9813.04	13958.80
1983	10.55	799.84	558.13	8436.23	8994.36	13246.48
1984	11.02	811.51	604.01	8945.26	9549.27	13262.87
1985	11.71	825.55	657.42	9668.33	10325.75	14164.26
1986	12.35	840.63	796.66	10385.15	11181.81	15401.94
1987	12.53	871.38	1038.80	10919.29	11958.08	16585.41
1988	13.39	887.15	1324.33	11881.67	13206.01	17561.18
1989	13.47	908.12	1512.37	12234.90	13747.27	17993.81
1990	8.81	961.09	1547.81	8464.57	10012.38	13867.56
1991	13.08	983.92	1643.68	12872.29	14516.01	20502.83
1992	16.60	1031.98	1950.22	17131.35	19081.57	24338.74
1993	16.49	1022.52	2136.24	16859.66	18996.30	24767.01
1994	16.65	1022.52	2280.75	17028.80	19309.55	25175.42
1995	16.38	1022.52	2429.18	16749.75	19178.93	25005.13
1996	17.15	1022.52	2628.01	17536.79	20164.80	26290.48
1997	17.95	1022.52	2842.11	18357.29	21199.40	27639.38
1998	18.79	1022.52	3072.65	19212.67	22285.33	29055.18
1999	19.69	1022.52	3339.81	20129.61	23469.41	30598.97
2000	20.62	1022.52	3655.76	21086.62	24742.38	32258.64
2001	21.60	1022.52	4000.23	22085.47	26085.70	34010.04
2002	22.62	1022.52	4375.80	23127.99	27503.79	35858.92
2003	23.68	1022.52	4785.28	24216.07	29001.36	37811.42
2004	24.79	1022.52	5231.73	25351.72	30583.45	39874.13
2005	25.95	1022.52	5712.06	26537.02	32249.08	42045.74
2006	27.16	1022.52	6235.19	27774.13	34009.32	44340.70
2007	28.43	1022.52	6804.92	29065.31	35870.24	46766.93
2008	29.74	1022.52	7425.41	30412.94	37838.35	49332.92
2009	31.12	1022.52	8101.18	31819.48	39920.66	52047.80
2010	32.55	1022.52	8827.36	33287.51	42114.87	54908.57
2011	34.05	1022.52	9617.38	34819.70	44437.09	57936.23
2012	35.62	1022.52	10476.85	36418.88	46895.73	61141.76
2013	37.25	1022.52	11411.87	38087.96	49499.83	64536.94
2014	38.95	1022.52	12429.08	39830.00	52259.09	68134.40
2015	40.73	1022.52	13535.71	41648.20	55183.91	71947.73

Sources BTCE estimates; BTCE (1994a) Indicators Database.

TABLE X.1 DOMESTIC AVIATION PROJECTIONS (continued)

Year ending June	LF	RGNF ($ million)	RMEDF	FI (L/skm)	Avtur FC (megalitres)
1978	0.670	234497	0.67	0.0918	1098.54
1979	0.691	245989	0.74	0.0888	1081.13
1980	0.724	253959	0.76	0.0880	1127.90
1981	0.740	264120	0.81	0.0906	1123.85
1982	0.703	270846	0.90	0.0864	1205.65
1983	0.679	266364	0.99	0.0882	1168.65
1984	0.720	277221	1.00	0.0877	1163.32
1985	0.729	292587	1.01	0.0842	1193.22
1986	0.726	305381	0.99	0.0833	1283.38
1987	0.721	311743	0.98	0.0804	1333.58
1988	0.752	328941	0.97	0.0813	1427.82
1989	0.764	344504	0.96	0.0782	1406.88
1990	0.722	355471	0.98	0.0811	1124.31
1991	0.708	352147	0.90	0.0701	1437.69
1992	0.784	354776	0.70	0.0645	1569.45
1993	0.767	365062	0.74	0.0663	1642.06
1994	0.767	376744.0	0.73	0.0645	1624.57
1995	0.767	388799.8	0.72	0.0637	1592.78
1996	0.767	401241.4	0.71	0.0629	1652.79
1997	0.767	414081.1	0.70	0.0620	1714.60
1998	0.767	427331.7	0.69	0.0612	1778.26
1999	0.767	441433.7	0.69	0.0604	1847.29
2000	0.767	456001.0	0.68	0.0595	1920.65
2001	0.767	471049.0	0.67	0.0587	1996.63
2002	0.767	486593.6	0.66	0.0579	2075.34
2003	0.767	502651.2	0.65	0.0570	2156.89
2004	0.767	519238.7	0.64	0.0562	2241.39
2005	0.767	536373.6	0.63	0.0554	2328.48
2006	0.767	554073.9	0.63	0.0545	2418.69
2007	0.767	572358.3	0.62	0.0537	2512.13
2008	0.767	591246.2	0.61	0.0529	2608.93
2009	0.767	610757.3	0.60	0.0521	2709.20
2010	0.767	630912.3	0.59	0.0512	2812.44
2011	0.767	651732.4	0.59	0.0504	2919.32
2012	0.767	673239.5	0.58	0.0496	3029.98
2013	0.767	695456.4	0.57	0.0487	3144.55
2014	0.767	718406.5	0.56	0.0479	3263.15
2015	0.767	742113.9	0.56	0.0471	3385.91

Sources BTCE estimates; BTCE (1994a) Indicators Database; ABARE (pers. comm. 1994).

TABLE X.2 AVIATION GASOLINE FUEL CONSUMPTION PROJECTIONS

Year ending June	*FC (PJ)*	*FC (ML)*
1974	3.5	105.74
1975	3.5	105.74
1976	3.5	105.74
1977	3.65	110.27
1978	3.8	114.80
1979	3.8	114.80
1980	3.8	114.80
1981	3.75	113.29
1982	3.7	111.78
1983	3.65	110.27
1984	3.6	108.76
1985	3.6	108.76
1986	3.6	108.76
1987	3.75	113.29
1988	3.9	117.82
1989	4.1	123.87
1990	4.3	129.91
1991	3.5	105.74
1992	3.3	99.70
1993	3.5	105.74
1994	3.55	107.25
1995	3.6	108.76
1996	3.65	110.27
1997	3.7	111.78
1998	3.75	113.29
1999	3.8	114.80
2000	3.85	116.31
2001	3.9	117.82
2002	3.95	119.34
2003	4.0	120.85
2004	4.05	122.36
2005	4.1	123.87
2006	4.15	125.38
2007	4.2	126.89
2008	4.25	128.40
2009	4.3	129.91
2010	4.35	131.42
2011	4.4	132.93
2012	4.45	134.44
2013	4.5	135.95
2014	4.55	137.46
2015	4.6	138.97

Sources BTCE estimates; Bush et al. (1993, p. 112).

TABLE X.3 DOMESTIC AVIATION TURBINE FUEL—PROJECTED GREENHOUSE GAS EMISSION LEVELS

Year ending June	FC (ML)	FC (PJ)	CO_2 (Gg)	NO_x (Gg)	CH_4 (Gg)	NMVOC (Gg)	CO (Gg)	N_2O (Gg)	Total CO_2 equivalent (Gg)
1974	894.86	32.93085	2232.711	8.891	0.036	0.329	2.602	0.066	2331.041
1975	987.92	36.35546	2464.900	9.816	0.040	0.364	2.872	0.073	2573.455
1976	999.55	36.78344	2493.917	9.932	0.040	0.368	2.906	0.074	2603.751
1977	1028.74	37.85763	2566.747	10.222	0.042	0.379	2.991	0.076	2679.788
1978	1098.54	40.42627	2740.901	10.915	0.044	0.404	3.194	0.081	2861.612
1979	1081.13	39.78558	2697.463	10.742	0.044	0.398	3.143	0.080	2816.260
1980	1127.90	41.50672	2814.156	11.207	0.046	0.415	3.279	0.083	2938.093
1981	1123.85	41.35768	2804.051	11.167	0.045	0.414	3.267	0.083	2927.543
1982	1205.65	44.36792	3008.145	11.979	0.049	0.444	3.505	0.089	3140.625
1983	1168.65	43.00632	2915.828	11.612	0.047	0.430	3.397	0.086	3044.243
1984	1163.32	42.81018	2902.530	11.559	0.047	0.428	3.382	0.086	3030.359
1985	1193.22	43.9105	2977.132	11.856	0.048	0.439	3.469	0.088	3108.246
1986	1283.38	47.22838	3202.084	12.752	0.052	0.472	3.731	0.094	3343.106
1987	1333.58	49.07574	3327.335	13.250	0.054	0.491	3.877	0.098	3473.873
1988	1427.82	52.54378	3562.468	14.187	0.058	0.525	4.151	0.105	3719.361
1989	1406.88	51.77318	3510.222	13.979	0.057	0.518	4.090	0.104	3664.814
1990	1124.31	41.37461	2805.198	11.171	0.046	0.414	3.269	0.083	2928.741
1991	1437.69	52.90699	3587.094	14.285	0.058	0.529	4.180	0.106	3745.072
1992	1569.45	57.75576	3915.841	15.594	0.064	0.578	4.563	0.116	4088.296
1993	1642.06	60.42781	4097.005	16.316	0.066	0.604	4.774	0.121	4277.440
1994	1624.57	59.78431	4053.376	16.142	0.066	0.598	4.723	0.120	4231.889
1995	1592.78	58.61445	3974.059	15.826	0.064	0.586	4.631	0.117	4149.079
1996	1652.79	60.82263	4123.774	16.422	0.067	0.608	4.805	0.122	4305.388
1997	1714.60	63.09716	4277.987	17.036	0.069	0.631	4.985	0.126	4466.392
1998	1778.26	65.43981	4436.819	17.669	0.072	0.654	5.170	0.131	4632.219
1999	1847.29	67.98011	4609.052	18.355	0.075	0.680	5.370	0.136	4812.037
2000	1920.65	70.67979	4792.090	19.084	0.078	0.707	5.584	0.141	5003.136
2001	1996.63	73.47603	4981.675	19.839	0.081	0.735	5.805	0.147	5201.071
2002	2075.34	76.37265	5178.066	20.621	0.084	0.764	6.033	0.153	5406.111
2003	2156.89	79.37359	5381.530	21.431	0.087	0.794	6.271	0.159	5618.535
2004	2241.39	82.48298	5592.346	22.270	0.091	0.825	6.516	0.165	5838.636
2005	2328.48	85.68801	5809.647	23.136	0.094	0.857	6.769	0.171	6065.508
2006	2418.69	89.00769	6034.722	24.032	0.098	0.890	7.032	0.178	6300.494
2007	2512.13	92.44635	6267.863	24.961	0.102	0.924	7.303	0.185	6543.903
2008	2608.93	96.00846	6509.374	25.922	0.106	0.960	7.585	0.192	6796.050
2009	2709.20	99.69865	6759.569	26.919	0.110	0.997	7.876	0.199	7057.264
2010	2812.44	103.4976	7017.139	27.944	0.114	1.035	8.176	0.207	7326.177
2011	2919.32	107.4309	7283.816	29.006	0.118	1.074	8.487	0.215	7604.599
2012	3029.98	111.5032	7559.917	30.106	0.123	1.115	8.809	0.223	7892.860
2013	3144.55	115.7193	7845.768	31.244	0.127	1.157	9.142	0.231	8191.300
2014	3263.15	120.0840	8141.697	32.423	0.132	1.201	9.487	0.240	8500.262
2015	3385.91	124.6014	8447.974	33.642	0.137	1.246	9.844	0.249	8820.028

Sources BTCE estimates; ABARE (pers. comm. 1994).

TABLE X.4 DOMESTIC AVIATION GASOLINE—PROJECTED GREENHOUSE GAS EMISSION LEVELS

Year ending June	FC (ML)	FC (PJ)	CO_2 (Gg)	NO_x (Gg)	CH_4 (Gg)	NMVOC (Gg)	CO (Gg)	N_2O (Gg)	Total CO_2 equivalent (Gg)
1974	105.7402	3.5	238	0.266	0.200	1.796	79.800	0.0032	340.1878
1975	105.7402	3.5	238	0.266	0.200	1.796	79.800	0.0032	340.1878
1976	105.7402	3.5	238	0.266	0.200	1.796	79.800	0.0032	340.1878
1977	110.2719	3.65	248.2	0.277	0.208	1.872	83.220	0.0033	354.7672
1978	114.8036	3.8	258.4	0.289	0.217	1.949	86.640	0.0034	369.3467
1979	114.8036	3.8	258.4	0.289	0.217	1.949	86.640	0.0034	369.3467
1980	114.8036	3.8	258.4	0.289	0.217	1.949	86.640	0.0034	369.3467
1981	113.2931	3.75	255	0.285	0.214	1.924	85.500	0.0034	364.4869
1982	111.7825	3.7	251.6	0.281	0.211	1.898	84.360	0.0033	359.6271
1983	110.2719	3.65	248.2	0.277	0.208	1.872	83.220	0.0033	354.7672
1984	108.7613	3.6	244.8	0.274	0.205	1.847	82.080	0.0032	349.9074
1985	108.7613	3.6	244.8	0.274	0.205	1.847	82.080	0.0032	349.9074
1986	108.7613	3.6	244.8	0.274	0.205	1.847	82.080	0.0032	349.9074
1987	113.2931	3.75	255	0.285	0.214	1.924	85.500	0.0034	364.4869
1988	117.8248	3.9	265.2	0.296	0.222	2.001	88.920	0.0035	379.0664
1989	123.8671	4.1	278.8	0.312	0.234	2.103	93.480	0.0037	398.5057
1990	129.9094	4.3	292.4	0.327	0.245	2.206	98.040	0.0039	417.9450
1991	105.7402	3.5	238	0.266	0.200	1.796	79.800	0.0032	340.1878
1992	99.6979	3.3	224.4	0.251	0.188	1.693	75.240	0.0030	320.7485
1993	105.7402	3.5	238	0.266	0.200	1.796	79.800	0.0032	340.1878
1994	107.2508	3.55	241.4	0.270	0.202	1.821	80.940	0.0032	345.0476
1995	108.7613	3.6	244.8	0.274	0.205	1.847	82.080	0.0032	349.9074
1996	110.2719	3.65	248.2	0.277	0.208	1.872	83.220	0.0033	354.7672
1997	111.7825	3.7	251.6	0.281	0.211	1.898	84.360	0.0033	359.6271
1998	113.2931	3.75	255	0.285	0.214	1.924	85.500	0.0034	364.4869
1999	114.8036	3.8	258.4	0.289	0.217	1.949	86.640	0.0034	369.3467
2000	116.3142	3.85	261.8	0.293	0.219	1.975	87.780	0.0035	374.2065
2001	117.8248	3.9	265.2	0.296	0.222	2.001	88.920	0.0035	379.0664
2002	119.3353	3.95	268.6	0.300	0.225	2.026	90.060	0.0036	383.9262
2003	120.8459	4	272	0.304	0.228	2.052	91.200	0.0036	388.7860
2004	122.3565	4.05	275.4	0.308	0.231	2.078	92.340	0.0036	393.6458
2005	123.8671	4.1	278.8	0.312	0.234	2.103	93.480	0.0037	398.5057
2006	125.3776	4.15	282.2	0.315	0.237	2.129	94.620	0.0037	403.3655
2007	126.8882	4.2	285.6	0.319	0.239	2.155	95.760	0.0038	408.2253
2008	128.3988	4.25	289	0.323	0.242	2.180	96.900	0.0038	413.0851
2009	129.9094	4.3	292.4	0.327	0.245	2.206	98.040	0.0039	417.9450
2010	131.4199	4.35	295.8	0.331	0.248	2.232	99.180	0.0039	422.8048
2011	132.9305	4.4	299.2	0.334	0.251	2.257	100.320	0.0040	427.6646
2012	134.4411	4.45	302.6	0.338	0.254	2.283	101.460	0.0040	432.5244
2013	135.9517	4.5	306	0.342	0.257	2.309	102.600	0.0041	437.3843
2014	137.4622	4.55	309.4	0.346	0.259	2.334	103.740	0.0041	442.2441
2015	138.9728	4.6	312.8	0.350	0.262	2.360	104.880	0.0041	447.1039

Sources BTCE estimates; Bush et al. (1993, p. 112).

TABLE X.5 TOTAL DOMESTIC AVIATION EMISSION PROJECTIONS

Year ending June	CO_2 (Gg)	NO_x (Gg)	CH_4 (Gg)	NMVOC (Gg)	CO (Gg)	N_2O (Gg)	Total CO_2 equivalent (Gg)
1974	2470.711	9.157	0.236	2.125	82.402	0.069	2671.229
1975	2702.900	10.082	0.239	2.159	82.672	0.076	2913.643
1976	2731.917	10.198	0.240	2.163	82.706	0.077	2943.938
1977	2814.947	10.499	0.250	2.251	86.211	0.079	3034.556
1978	2999.301	11.204	0.261	2.354	89.834	0.084	3230.959
1979	2955.863	11.031	0.260	2.347	89.783	0.083	3185.607
1980	3072.556	11.496	0.262	2.364	89.919	0.086	3307.439
1981	3059.051	11.452	0.259	2.337	88.767	0.086	3292.030
1982	3259.745	12.261	0.260	2.342	87.865	0.092	3500.252
1983	3164.028	11.889	0.255	2.303	86.617	0.089	3399.010
1984	3147.330	11.832	0.252	2.275	85.462	0.089	3380.266
1985	3221.932	12.129	0.254	2.286	85.549	0.091	3458.154
1986	3446.884	13.025	0.257	2.319	85.811	0.098	3693.013
1987	3582.335	13.535	0.268	2.415	89.377	0.102	3838.360
1988	3827.668	14.483	0.280	2.526	93.071	0.109	4098.427
1989	3789.022	14.290	0.291	2.621	97.570	0.107	4063.320
1990	3097.598	11.498	0.291	2.620	101.309	0.087	3346.686
1991	3825.094	14.551	0.258	2.325	83.980	0.109	4085.259
1992	4140.241	15.845	0.252	2.270	79.803	0.118	4409.045
1993	4335.005	16.582	0.266	2.400	84.574	0.124	4617.628
1994	4294.776	16.412	0.268	2.419	85.663	0.123	4576.937
1995	4218.859	16.100	0.270	2.433	86.711	0.120	4498.987
1996	4371.974	16.700	0.275	2.481	88.025	0.125	4660.155
1997	4529.587	17.317	0.280	2.529	89.345	0.130	4826.019
1998	4691.819	17.954	0.286	2.578	90.670	0.134	4996.706
1999	4867.452	18.643	0.291	2.629	92.010	0.139	5181.384
2000	5053.890	19.376	0.297	2.682	93.364	0.145	5377.343
2001	5246.875	20.135	0.303	2.735	94.725	0.150	5580.137
2002	5446.666	20.921	0.309	2.790	96.093	0.156	5790.037
2003	5653.530	21.735	0.315	2.846	97.471	0.162	6007.321
2004	5867.746	22.578	0.322	2.902	98.856	0.169	6232.282
2005	6088.447	23.447	0.328	2.960	100.249	0.175	6464.013
2006	6316.922	24.347	0.334	3.019	101.652	0.182	6703.860
2007	6553.463	25.280	0.341	3.079	103.063	0.189	6952.128
2008	6798.374	26.245	0.348	3.140	104.485	0.196	7209.135
2009	7051.969	27.245	0.355	3.203	105.916	0.203	7475.209
2010	7312.939	28.275	0.362	3.267	107.356	0.211	7748.982
2011	7583.016	29.341	0.369	3.332	108.807	0.219	8032.264
2012	7862.517	30.444	0.376	3.398	110.269	0.227	8325.385
2013	8151.768	31.586	0.384	3.466	111.742	0.235	8628.684
2014	8451.097	32.768	0.391	3.535	113.227	0.244	8942.506
2015	8760.774	33.992	0.399	3.606	114.724	0.253	9267.132

Source BTCE estimates.

TABLE X.6 INTERNATIONAL AVIATION MODEL PROJECTIONS

Year ending June	IN-PASS	OUT-PASS ('000)	AVKM-IN (km)	AVKM-OUT (km)	IPKM (million)	LF	TIPKM (million)	SKM (million)
1978	580882	1004.93	8691.75	8659.49	27502.13	58.8	29152.26	49578.67
1979	699523	1132.04	8859.10	8884.29	32509.02	66.7	34356.18	51508.52
1980	876733	1204.67	7894.75	7995.79	33107.68	66.7	34883.89	52299.69
1981	913502	1194.68	7303.50	7261.42	30693.72	64.7	32243.40	49854.51
1982	951590	1248.13	7196.08	7154.88	31555.88	63.7	33049.65	51862.92
1983	930400	1259.06	7023.02	6994.74	30682.07	60.3	32038.07	53131.13
1984	992400	1310.01	6949.23	7018.00	32180.12	63.6	33501.51	52716.78
1985	1061800	1497.82	6935.45	7020.85	35760.08	66.8	37116.79	55605.68
1986	1263600	1495.95	6819.76	6933.26	37978.54	67.7	39117.89	57781.23
1987	1589500	1569.04	6805.13	6742.79	42792.87	68.4	44032.58	64422.21
1988	1990400	1653.23	6773.00	6751.95	49287.11	70.9	50664.24	71458.74
1989	2220500	1848.24	6907.02	6862.20	56040.06	69.4	57548.27	82982.37
1990	2147300	2092.25	6778.39	6903.47	57998.06	67.4	59499.40	88278.05
1991	2227400	2112.86	6815.23	6867.53	59380.68	64.9	60856.91	93842.57
1992	2519700	2177.67	6338.24	6883.73	61921.86	65.4	63397.79	96938.52
1993	2785600	2297.28	6557.33	7080.58	69064.31	65.0	70445.59	108377.8
1994	2974037	2243.68	6557.33	7080.58	70776.65	65.7	72192.18	109912.0
1995	3167590	2350.65	6557.33	7080.58	74829.73	66.4	76326.33	115012.3
1996	3426858	2471.85	6557.33	7080.58	79946.36	67.0	81545.29	121626.9
1997	3706037	2599.11	6557.33	7080.58	85409.81	67.7	87118.00	128630.6
1998	4006657	2732.72	6557.33	7080.58	91244.40	68.4	93069.29	136048.1
1999	4355018	2876.89	6557.33	7080.58	97854.65	69.1	99811.74	144464.4
2000	4767007	3017.79	6557.33	7080.58	105253.1	69.8	107358.2	153868.4
2001	5216191	3165.41	6557.33	7080.58	113234.5	70.5	115499.2	163934.4
2002	5705928	3320.08	6557.33	7080.58	121847.5	71.1	124284.4	174713.0
2003	6239879	3482.12	6557.33	7080.58	131144.8	71.8	133767.7	186258.8
2004	6822035	3651.90	6557.33	7080.58	141183.7	72.5	144007.4	198630.9
2005	7448376	3831.86	6557.33	7080.58	151946.4	73.2	154985.4	211781.3
2006	8130518	4020.50	6557.33	7080.58	163564.0	73.9	166835.2	225869.2
2007	8873432	4218.25	6557.33	7080.58	176107.4	74.5	179629.5	240966.4
2008	9682533	4425.54	6557.33	7080.58	189654.0	75.2	193447.0	257150.1
2009	10563717	4642.84	6557.33	7080.58	204287.6	75.9	208373.3	274503.8
2010	11510642	4873.26	6557.33	7080.58	219969.2	76.6	224368.6	292944.1
2011	12540806	5114.93	6557.33	7080.58	236901.7	77.3	241639.8	312710.3
2012	13661528	5368.39	6557.33	7080.58	255189.0	78.0	260292.8	333903.3
2013	14880767	5634.23	6557.33	7080.58	274943.5	78.6	280442.4	356631.9
2014	16207184	5913.05	6557.33	7080.58	296287.4	79.3	302213.2	381013.7
2015	17650200	6205.48	6557.33	7080.58	319353.2	80.0	325740.3	407175.3

Sources BTCE estimates using data contained in Apelbaum (1993, p. 161); DTC (1993b, pp. 16,17 and earlier editions); BTCE (1994a) Indicators Database.

TABLE X.6 INTERNATIONAL AVIATION MODEL PROJECTIONS (continued)

Year ending June	AFC (ML)	TFC (ML)	FI (L/skm)	RGNE ($ million)	G7GDP	RIFARE	ROFARE	RTWI
1978	928.31	2210.26	0.0446		83.05	0.15	0.12	57.08
1979	913.59	2175.21	0.0422		86.78	0.12	0.10	54.04
1980	953.11	2269.31	0.0434		88.73	0.10	0.09	54.19
1981	949.69	2261.17	0.0454		89.30	0.09	0.08	56.14
1982	1018.80	2425.71	0.0468		89.95	0.08	0.08	57.91
1983	991.80	2361.43	0.0444		90.53	0.07	0.07	54.23
1984	989.50	2355.95	0.0447		94.80	0.07	0.06	55.86
1985	1114.20	2652.86	0.0477		98.25	0.06	0.06	51.03
1986	1136.40	2705.71	0.0468	323826	101.63	0.05	0.05	44.02
1987	1200.10	2857.38	0.0444	321908	104.23	0.05	0.05	42.58
1988	1357.30	3231.67	0.0452	337795	108.75	0.04	0.04	44.82
1989	1567.00	3730.95	0.0450	361351	113.03	0.04	0.04	51.01
1990	1711.60	4075.24	0.0462	373619	116.03	0.04	0.04	52.14
1991	1780.60	4239.52	0.0452	362986	117.53	0.03	0.03	51.35
1992	1889.08	4497.81	0.0464	364538	119.00	0.03	0.03	49.77
1993	2042.00	4861.90	0.0449	374779	120.73	0.03	0.03	43.07
1994	2050.132	4881.267	0.0444	386771.9	124.11	0.03	0.03	43.85
1995	2123.528	5056.019	0.0440	399148.6	127.58	0.03	0.03	44.64
1996	2222.669	5292.069	0.0435	411921.4	131.15	0.03	0.03	45.44
1997	2326.348	5538.923	0.0431	425102.9	134.83	0.03	0.03	46.26
1998	2434.784	5797.105	0.0426	438706.2	138.60	0.03	0.03	47.09
1999	2558.102	6090.718	0.0422	453183.5	142.76	0.03	0.03	46.71
2000	2695.542	6417.957	0.0417	468138.5	147.04	0.03	0.03	46.34
2001	2840.899	6764.046	0.0413	483587.1	151.45	0.03	0.03	45.97
2002	2994.666	7130.157	0.0408	499545.5	156.00	0.03	0.03	45.60
2003	3157.365	7517.535	0.0404	516030.5	160.68	0.03	0.03	45.24
2004	3329.549	7927.498	0.0399	533059.5	165.50	0.03	0.03	45.06
2005	3509.955	8357.036	0.0395	550650.4	170.46	0.03	0.03	44.88
2006	3700.753	8811.316	0.0390	568821.9	175.58	0.03	0.03	44.70
2007	3902.570	9291.833	0.0386	587593.0	180.84	0.03	0.03	44.52
2008	4116.072	9800.171	0.0381	606983.6	186.27	0.03	0.03	44.34
2009	4341.961	10338.00	0.0377	627014.0	191.86	0.03	0.03	44.34
2010	4578.274	10900.65	0.0372	647705.5	197.61	0.03	0.02	44.34
2011	4828.088	11495.45	0.0368	669079.8	203.54	0.03	0.02	44.34
2012	5092.189	12124.26	0.0363	691159.4	209.65	0.03	0.02	44.34
2013	5371.409	12789.07	0.0359	713967.7	215.94	0.02	0.02	44.34
2014	5666.623	13491.96	0.0354	737528.6	222.41	0.02	0.02	44.34
2015	5983.997	14247.61	0.0350	761867.1	229.09	0.02	0.02	44.34

Sources BTCE estimates using data contained in Apelbaum (1993, p. 113); ABARE (pers. comm. 1994); BTCE (1994a) Indicators Database.

TABLE X.7 AVERAGE KILOMETRES FLOWN BY INBOUND PASSENGERS

	Distance	*Passenger numbers*														
Country	*(km)*	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*
NZ	2200	526490	605461	601345	564048	551620	589002	651579	747513	960017	1011182	1007192	941662	933410	1008119	1027036
Malaysia	6300	15151	245019	319313	356697	350289	352966	410645	457055	593395	640351	705703	763018	760496	770809	863909
Japan	7800	31454	38566	51270	61781	63972	70488	95619	116848	207843	265138	345905	404407	489989	579871	667801
Other Asia	7500	249374	165567	225684	268141	280582	301279	354099	374368	433695	463189	539835	570398	509359	596605	683439
US	12000	223216	147096	141527	127304	126724	163178	171103	186816	257847	273283	302284	254822	279145	335802	390118
Europe	17000	481923	473897	363055	341338	291917	271741	297161	309017	377399	388754	393431	383371	388520	187383	211168
Indonesia	5500	99944	120320	165257	178318	172009	178479	192697	217278	233665	250950	271776	291347	288604	316683	285244
Africa	11000	24364	26979	28755	29566	29150	25426	27186	29791	22651	20333	20232	23290	24552	7846	25655
Pacific Is	4000	97311	217457	228778	268584	257065	243424	259265	264602	313654	352707	275678	456551	472467	475406	403048
Other	10000	42927	19088	30434	38960	37020	38922	43632	36607	36112	38839	42300	44984	22311	27852	32893
Pass No		1792154	2059450	2155418	2234737	2160348	2234905	2502986	2739895	3436278	3704726	3904336	4133850	4168853	4306376	4590311
Total km		1.59E+10	1.63E+10	1.57E+10	1.61E+10	1.52E+10	1.55E+10	1.74E+10	1.87E+10	2.34E+10	2.51E+10	2.7E+10	2.8E+10	2.84E+10	2.73E+10	3.01E+10
AVKM		8859.098	7894.748	7303.50	7196.082	7023.02	6949.225	6935.452	6819.764	6805.129	6773.004	6907.023	6778.389	6815.228	6338.237	6557.331

Note E stands for exponent. That is, 1.59E+10 means 1.59×10^{10}.

Sources BTCE estimates; Apelbaum (1993, p. 161); DTC (1993b, p. 16 and earlier editions).

TABLE X.8 AVERAGE KILOMETRES FLOWN BY OUTBOUND PASSENGERS

	Distance	Passenger numbers														
Country	*(km)*	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*
NZ	2200	498216	581198	586538	560201	560083	600558	652366	731219	950650	983758	988744	951952	947950	1020062	1038657
Malaysia	6300	10300	219755	293762	330805	325700	337342	392813	427854	542582	585821	655922	700157	697940	738206	838236
Japan	7800	35711	41016	53820	67026	66314	75086	99766	118125	198998	257948	347132	395376	486152	580730	579038
Other Asia	7500	224782	136654	194134	226774	236834	259947	302494	316355	377256	412135	491989	527967	529904	562726	456253
US	12000	219722	166240	144312	134361	134021	174613	175804	188765	252695	272741	296190	280913	307006	362222	419618
Europe	17000	461871	455408	336226	319343	284649	283344	313164	332027	358220	365937	404049	420759	394112	402076	447535
Indonesia	5500	106067	125387	160412	173189	167653	180003	194856	211371	230659	243763	266788	283369	289307	318233	291896
Africa	11000	22371	24259	26082	25876	26550	25673	25530	25721	21023	19010	19815	22599	21523	24470	32558
Pacific Is	4000	94686	188270	206931	247520	250503	230713	243910	258544	309911	336586	394927	446582	460562	465717	380177
Other	10000	42873	21479	28329	38686	38040	40493	45840	35281	32913	41059	42398	49245	28914	29405	40069
Pass No		1716599	1959666	2030546	2123781	2090347	2207772	2446543	2645262	3274907	3518758	3907954	4078919	4163370	4503847	4524037
Total km		1.52E+10	1.56E+10	1.47E+10	1.52E+10	1.46E+10	1.54E+10	1.71E+10	1.83E+10	2.20E+10	2.37E+10	2.68E+10	2.81E+10	2.85E+10	3.1E+10	3.20E+10
AVKM		8884.29	7995.79	7261.42	7154.88	6994.74	7018.00	7020.85	6933.26	6742.79	6751.95	6862.20	6903.47	6867.53	6883.73	7080.58

Note E stands for exponent. That is, 1.52E+10 means 1.52 x 10^{10}.

Sources BTCE estimates; Apelbaum (1993, p. 161); DTC (1993b, p. 17 and earlier editions).

TABLE X.9 INTERNATIONAL AVIATION TURBINE FUEL—PROJECTED GREENHOUSE GAS EMISSION LEVELS

Year ending June	AFC (ML)	AFC (PJ)	CO_2 (Gg)	NO_x (Gg)	CH_4 (Gg)	NMVOC (Gg)	CO (Gg)	N_2O (Gg)	Total CO_2 equivalent (Gg)
1974	756.19	27.828	1886.724	7.235	0.011	0.111	1.391	0.056	1964.970
1975	834.83	30.722	2082.934	7.988	0.012	0.123	1.536	0.061	2169.318
1976	844.66	31.083	2107.460	8.082	0.012	0.124	1.554	0.062	2194.861
1977	869.32	31.991	2168.988	8.318	0.013	0.128	1.600	0.064	2258.940
1978	928.31	34.162	2316.171	8.882	0.014	0.137	1.708	0.068	2412.227
1979	913.59	33.620	2279.444	8.741	0.013	0.134	1.681	0.067	2373.977
1980	953.11	35.074	2378.048	9.119	0.014	0.140	1.754	0.070	2476.670
1981	949.69	34.949	2369.515	9.087	0.014	0.140	1.747	0.070	2467.783
1982	1018.80	37.492	2541.947	9.748	0.015	0.150	1.875	0.075	2647.366
1983	991.80	36.498	2474.581	9.490	0.015	0.146	1.825	0.073	2577.206
1984	989.50	36.414	2468.842	9.468	0.015	0.146	1.821	0.073	2571.230
1985	1114.20	41.003	2779.974	10.661	0.016	0.164	2.050	0.082	2895.265
1986	1136.40	41.820	2835.363	10.873	0.017	0.167	2.091	0.084	2952.952
1987	1200.10	44.164	2994.298	11.483	0.018	0.177	2.208	0.088	3118.477
1988	1357.30	49.949	3386.518	12.987	0.020	0.200	2.497	0.100	3526.963
1989	1567.00	57.666	3909.728	14.993	0.023	0.231	2.883	0.115	4071.872
1990	1711.60	62.987	4270.510	16.377	0.025	0.252	3.149	0.126	4447.617
1991	1780.60	65.526	4442.668	17.037	0.026	0.262	3.276	0.131	4626.914
1992	1889.08	69.518	4713.330	18.075	0.028	0.278	3.476	0.139	4908.801
1993	2042.00	75.146	5094.872	19.538	0.030	0.301	3.757	0.150	5306.166
1994	2050.132	75.445	5115.162	19.616	0.030	0.302	3.772	0.151	5327.297
1995	2123.528	78.146	5298.288	20.318	0.031	0.313	3.907	0.156	5518.018
1996	2222.669	81.794	5545.648	21.266	0.033	0.327	4.090	0.164	5775.637
1997	2326.348	85.610	5804.331	22.258	0.034	0.342	4.280	0.171	6045.048
1998	2434.784	89.600	6074.884	23.296	0.036	0.358	4.480	0.179	6326.822
1999	2558.102	94.138	6382.566	24.476	0.038	0.377	4.707	0.188	6647.263
2000	2695.542	99.196	6725.485	25.791	0.040	0.397	4.960	0.198	7004.404
2001	2840.899	104.545	7088.157	27.182	0.042	0.418	5.227	0.209	7382.117
2002	2994.666	110.204	7471.811	28.653	0.044	0.441	5.510	0.220	7781.682
2003	3157.365	116.191	7877.751	30.210	0.046	0.465	5.810	0.232	8204.457
2004	3329.549	122.527	8307.358	31.857	0.049	0.490	6.126	0.245	8651.881
2005	3509.955	129.166	8757.478	33.583	0.052	0.517	6.458	0.258	9120.668
2006	3700.753	136.188	9233.526	35.409	0.054	0.545	6.809	0.272	9616.458
2007	3902.570	143.615	9737.068	37.340	0.057	0.574	7.181	0.287	10140.883
2008	4116.072	151.471	10269.763	39.383	0.061	0.606	7.574	0.303	10695.671
2009	4341.961	159.784	10833.366	41.544	0.064	0.639	7.989	0.320	11282.647
2010	4578.274	168.481	11422.978	43.805	0.067	0.674	8.424	0.337	11896.711
2011	4828.088	177.674	12046.273	46.195	0.071	0.711	8.884	0.355	12545.855
2012	5092.189	187.393	12705.216	48.722	0.075	0.750	9.370	0.375	13232.126
2013	5371.409	197.668	13401.880	51.394	0.079	0.791	9.883	0.395	13957.682
2014	5666.623	208.532	14138.452	54.218	0.083	0.834	10.427	0.417	14724.801
2015	5983.997	220.211	14930.311	57.255	0.088	0.881	11.011	0.440	15549.501

Sources BTCE estimates; ABARE (pers. comm. 1994).

TABLE X.10 AVIATION TURBINE FUEL—TOTAL PROJECTED GREENHOUSE GAS EMISSION LEVELS

Year ending June	*FC (PJ)*	*FC (ML)*	*CO_2 (Gg)*	*NO_x (Gg)*	*CH_4 (Gg)*	*NMVOC (Gg)*	*CO (Gg)*	*N_2O (Gg)*	*Total CO_2 equivalent (Gg)*
1974	60.759	1651.05	4119.436	16.127	0.047	0.441	3.993	0.122	4296.012
1975	67.077	1822.75	4547.834	17.804	0.052	0.486	4.408	0.134	4742.773
1976	67.867	1844.21	4601.378	18.013	0.053	0.492	4.460	0.136	4798.612
1977	69.849	1898.06	4735.736	18.539	0.054	0.507	4.590	0.140	4938.729
1978	74.588	2026.85	5057.072	19.797	0.058	0.541	4.902	0.149	5273.839
1979	73.406	1994.72	4976.906	19.483	0.057	0.532	4.824	0.147	5190.237
1980	76.581	2081.01	5192.203	20.326	0.060	0.555	5.033	0.153	5414.763
1981	76.306	2073.54	5173.565	20.253	0.059	0.553	5.015	0.153	5395.326
1982	81.860	2224.45	5550.092	21.727	0.064	0.594	5.380	0.164	5787.992
1983	79.505	2160.45	5390.409	21.101	0.062	0.576	5.222	0.159	5621.450
1984	79.224	2152.82	5371.372	21.026	0.062	0.574	5.203	0.158	5601.589
1985	84.913	2307.42	5757.105	22.516	0.065	0.603	5.519	0.170	6003.511
1986	89.048	2419.78	6037.448	23.625	0.069	0.640	5.822	0.178	6296.058
1987	93.239	2533.68	6321.633	24.733	0.072	0.667	6.085	0.186	6592.350
1988	102.492	2785.12	6948.986	27.173	0.078	0.725	6.648	0.205	7246.324
1989	109.439	2973.88	7419.950	28.972	0.080	0.748	6.973	0.219	7736.686
1990	104.361	2835.91	7075.709	27.548	0.071	0.666	6.418	0.209	7376.358
1991	118.433	3218.29	8029.762	31.322	0.084	0.791	7.456	0.237	8371.986
1992	127.274	3458.53	8629.171	33.669	0.091	0.856	8.039	0.255	8997.098
1993	135.573	3684.06	9191.877	35.853	0.097	0.905	8.531	0.271	9583.606
1994	135.229	3674.71	9168.538	35.757	0.096	0.900	8.495	0.270	9559.187
1995	136.760	3716.31	9272.347	36.144	0.096	0.899	8.538	0.274	9667.097
1996	142.617	3875.46	9669.423	37.689	0.100	0.935	8.895	0.285	10081.025
1997	148.707	4040.94	10082.318	39.295	0.104	0.973	9.265	0.297	10511.440
1998	155.040	4213.04	10511.703	40.965	0.108	1.013	9.650	0.310	10959.041
1999	162.118	4405.38	10991.617	42.831	0.112	1.056	10.077	0.324	11459.300
2000	169.876	4616.19	11517.574	44.874	0.117	1.104	10.544	0.340	12007.540
2001	178.021	4837.53	12069.832	47.020	0.123	1.153	11.032	0.356	12583.188
2002	186.576	5070.01	12649.877	49.274	0.128	1.205	11.544	0.373	13187.793
2003	195.565	5314.26	13259.280	51.641	0.134	1.258	12.080	0.391	13822.992
2004	205.010	5570.93	13899.704	54.128	0.140	1.315	12.643	0.410	14490.517
2005	214.854	5838.43	14567.125	56.719	0.146	1.374	13.228	0.430	15186.175
2006	225.195	6119.44	15268.247	59.441	0.152	1.435	13.841	0.450	15916.952
2007	236.061	6414.70	16004.931	62.300	0.159	1.499	14.484	0.472	16684.786
2008	247.480	6725.00	16779.137	65.305	0.166	1.566	15.158	0.495	17491.721
2009	259.483	7051.16	17592.935	68.463	0.174	1.636	15.865	0.519	18339.911
2010	271.978	7390.71	18440.117	71.749	0.181	1.709	16.600	0.544	19222.889
2011	285.105	7747.41	19330.088	75.201	0.189	1.785	17.371	0.570	20150.454
2012	298.896	8122.17	20265.133	78.828	0.198	1.865	18.178	0.598	21124.986
2013	313.387	8515.96	21247.648	82.638	0.206	1.948	19.025	0.627	22148.982
2014	328.616	8929.78	22280.149	86.641	0.216	2.035	19.913	0.657	23225.063
2015	344.812	9369.90	23378.286	90.897	0.225	2.127	20.854	0.690	24369.529

Sources BTCE estimates; ABARE (pers. comm. 1994).

APPENDIX XI SHIPPING DATA

TABLE XI.1 REPRESENTATIVE DISTANCES FOR THE OVERSEAS FREIGHT TASK—SHIPPING

Area	*Representative ports*	*Distance (km)*
North America (and Hawaii)	Melbourne–Norfolk	17 950
South America	Melbourne–Valparaiso	11 430
Europe (including former USSR)	Melbourne–London	20 440
Africa	Melbourne–Capetown	11 000
Asia	Melbourne–Yokohama	9 100
	Melbourne–Singapore	7 100
	Singapore–Yokohama	5 350
Middle East	Melbourne–Kuwait	12 900
Papua New Guinea, New Zealand and Pacific Islands	Adelaide–Auckland	3 750
Trade area not specified		11 756

Sources Apelbaum (1993, p. 169); Caney & Reynolds (1988, pp. 151, 167, 175).

TABLE XI.2 REPRESENTATIVE DISTANCES FOR THE OVERSEAS PASSENGER TASK—SHIPPING

Area	*Representative ports*	*Distance (km)*
Africa	Melbourne–Capetown	11 000
America	Melbourne–Norfolk	17 950
Asia	Melbourne–Singapore	7 100
Europe–Mediterranean (Italy, Greece, Yugoslavia)	Melbourne–Tunis	16 600
Europe–Other	Melbourne–London	20 440
Oceania	Sydney–Auckland	2 350
Not stated		8 045

Source Apelbaum (1993, p. 170).

TABLE XI.3 FUEL UPLIFTED IN AUSTRALIA FOR INTERNATIONAL SHIPPING

Year ending June	*Automotive diesel oil (PJ)*	*Industrial diesel fuel (PJ)*	*Fuel oil (PJ)*	*Total (PJ)*
1974	0.96	8.04	66.2	75.2
1975	0.85	6.98	59.1	66.9
1976	1.18	6.73	52.7	60.7
1977	1.63	8.71	55.0	65.4
1978	1.54	8.11	52.8	62.4
1979	1.40	6.75	51.2	59.3
1980	1.42	7.24	40.5	49.2
1981	1.42	6.31	41.0	48.7
1982	1.99	4.97	27.8	34.7
1983	1.59	4.22	29.5	36.2
1984	0.80	3.58	25.4	30.5
1985	0.71	3.48	25.3	30.2
1986	0.91	3.07	16.2	20.6
1987	1.40	3.22	17.3	21.9
1988	2.73	3.24	18.8	24.8
1989	3.10	2.78	22.1	28.0
1990	2.71	2.85	23.0	28.6
1991	2.51	1.91	21.4	25.8
1992	2.82	1.74	20.3	24.9
1993	3.13	1.48	20.2	24.9
1994	3.15	1.49	20.4	25.0
1995	3.27	1.54	21.1	25.9
1996	3.37	1.59	21.8	26.8
1997	3.46	1.63	22.3	27.4
1998	3.56	1.68	23.0	28.3
1999	3.64	1.72	23.6	28.9
2000	3.64	1.72	23.6	28.9
2001	3.63	1.71	23.5	28.8
2002	3.63	1.72	23.5	28.9
2003	3.62	1.71	23.4	28.8
2004	3.62	1.71	23.4	28.7
2005	3.62	1.71	23.4	28.7
2006	3.62	1.71	23.4	28.8
2007	3.62	1.71	23.4	28.8
2008	3.62	1.71	23.4	28.7
2009	3.62	1.71	23.4	28.7
2010	3.63	1.72	23.5	28.8
2011	3.64	1.72	23.6	28.9
2012	3.65	1.73	23.6	29.0
2013	3.66	1.73	23.7	29.1
2014	3.67	1.73	23.7	29.1
2015	3.67	1.73	23.7	29.2

Sources Bush et al. (1993); BTCE estimates.

TABLE XI.4 INTERNATIONAL SHIPPING EMISSION PROJECTIONS

Year ending June	CO_2 (Gg)	NO_x (Gg)	CH_4 (Gg)	NMVOCs (Gg)	CO (Gg)	N_2O (Gg)	CO_2 equivalent (Gg)
1974	5483.308	146.066	0.244	0.285	7.189	0.150	6715.391
1975	4877.633	130.002	0.216	0.257	6.318	0.134	5974.129
1976	4420.367	117.500	0.198	0.288	6.076	0.121	5412.405
1977	4758.316	125.766	0.217	0.365	7.331	0.131	5821.837
1978	4543.543	120.175	0.207	0.347	6.907	0.125	5559.621
1979	4322.550	114.740	0.194	0.311	6.121	0.119	5291.803
1980	3579.245	94.254	0.165	0.321	5.899	0.098	4377.278
1981	3548.587	93.784	0.162	0.307	5.479	0.097	4341.957
1982	2522.217	66.092	0.118	0.347	4.530	0.069	3083.368
1983	2634.015	69.593	0.120	0.230	4.097	0.072	3222.807
1984	2223.988	58.961	0.100	0.138	3.231	0.061	2722.011
1985	2198.606	58.342	0.099	0.126	3.134	0.060	2691.221
1986	1499.418	39.350	0.070	0.142	2.623	0.041	1832.893
1987	1590.215	41.581	0.075	0.195	2.955	0.044	1943.231
1988	1794.492	46.640	0.086	0.335	3.661	0.050	2191.913
1989	2032.468	53.177	0.096	0.367	3.763	0.056	2484.841
1990	2075.734	54.475	0.097	0.328	3.654	0.057	2538.466
1991	1876.234	49.479	0.086	0.292	3.041	0.052	2296.074
1992	1806.552	47.527	0.084	0.322	3.059	0.050	2210.368
1993	1805.220	47.475	0.084	0.351	3.081	0.050	2208.860
1994	1818.012	47.813	0.084	0.353	3.101	0.050	2224.521
1995	1884.741	49.568	0.087	0.366	3.215	0.052	2306.171
1996	1945.753	51.172	0.090	0.378	3.319	0.054	2380.824
1997	1992.841	52.411	0.092	0.387	3.399	0.055	2438.441
1998	2052.679	53.984	0.095	0.399	3.501	0.056	2511.660
1999	2102.806	55.303	0.098	0.409	3.587	0.058	2572.994
2000	2101.234	55.261	0.097	0.408	3.584	0.058	2571.071
2001	2092.810	55.040	0.097	0.407	3.570	0.058	2560.764
2002	2096.044	55.125	0.097	0.407	3.575	0.058	2564.721
2003	2090.677	54.984	0.097	0.406	3.566	0.058	2558.154
2004	2085.816	54.856	0.097	0.405	3.558	0.057	2552.206
2005	2087.425	54.898	0.097	0.406	3.560	0.057	2554.174
2006	2089.974	54.965	0.097	0.406	3.565	0.058	2557.294
2007	2089.723	54.959	0.097	0.406	3.564	0.058	2556.987
2008	2088.598	54.929	0.097	0.406	3.562	0.057	2555.609
2009	2088.316	54.922	0.097	0.406	3.562	0.057	2555.265
2010	2094.932	55.096	0.097	0.407	3.573	0.058	2563.360
2011	2100.830	55.251	0.097	0.408	3.583	0.058	2570.577
2012	2106.036	55.388	0.098	0.409	3.592	0.058	2576.947
2013	2110.574	55.507	0.098	0.410	3.600	0.058	2582.500
2014	2114.468	55.609	0.098	0.411	3.607	0.058	2587.264
2015	2117.740	55.696	0.098	0.411	3.612	0.058	2591.268

Note Historical emission estimates are very approximate, since constant emission factors (given in appendix V) are assumed.

Source BTCE estimates.

TABLE XI.5 FUEL CONSUMPTION IN COASTAL SHIPPING

Year ending June	Automotive diesel oil (PJ)	Industrial diesel fuel (PJ)	Fuel oil (PJ)	Black coal (PJ)	Total (PJ)
1974	3.76	9.16	33.02	0	45.94
1975	3.84	7.61	28.69	0	40.14
1976	3.49	8.10	24.40	0	36.05
1977	5.07	10.40	27.35	0	42.82
1978	4.40	15.40	31.82	0	51.62
1979	5.74	10.70	27.41	0	43.85
1980	8.28	8.61	31.45	0	48.34
1981	6.89	7.54	33.46	0	47.89
1982	5.01	6.41	27.27	0	38.69
1983	4.54	5.41	27.48	0.58	38.00
1984	4.26	3.14	26.41	3.62	37.43
1985	4.26	3.58	22.88	3.32	34.03
1986	3.34	2.76	24.66	3.30	34.06
1987	5.55	2.31	24.05	3.70	35.62
1988	4.32	1.78	24.50	3.51	34.10
1989	3.89	1.52	22.00	3.91	31.33
1990	3.44	1.34	18.71	3.48	26.97
1991	2.30	1.24	15.30	3.73	22.56
1992	5.72	1.45	14.89	2.82	25.88
1993	5.72	1.45	14.89	2.82	25.88
1994	2.36	0.98	13.96	2.36	19.66
1995	2.37	0.99	14.05	2.37	19.78
1996	2.38	0.99	14.10	2.38	19.85
1997	2.38	0.99	14.09	2.38	19.85
1998	2.40	1.00	14.20	2.40	20.00
1999	2.40	1.00	14.20	2.40	20.00
2000	2.41	1.00	14.28	2.41	20.12
2001	2.43	1.00	14.39	2.43	20.26
2002	2.45	1.00	14.50	2.45	20.43
2003	2.43	1.00	14.37	2.43	20.23
2004	2.41	1.00	14.24	2.41	20.05
2005	2.39	0.99	14.12	2.39	19.88
2006	2.37	0.99	14.01	2.37	19.73
2007	2.35	0.98	13.92	2.35	19.60
2008	2.34	0.97	13.83	2.34	19.48
2009	2.33	0.97	13.76	2.33	19.38
2010	2.32	0.96	13.70	2.32	19.29
2011	2.30	0.96	13.63	2.30	19.20
2012	2.30	0.96	13.59	2.30	19.14
2013	2.29	0.95	13.54	2.29	19.08
2014	2.28	0.95	13.51	2.28	19.03
2015	2.28	0.95	13.50	2.28	19.02

Note Excludes ferries, fishing vessels and pleasure craft.

Sources Bush et al. (1993); BTCE estimates.

TABLE XI.6 COASTAL SHIPPING EMISSIONS PROJECTIONS

Year ending June	*CO_2 (Gg)*	*NO_x (Gg)*	*CH_4 (Gg)*	*NMVOCs (Gg)*	*CO (Gg)*	*N_2O (Gg)*	*CO_2 equivalent (Gg)*
1974	3325.671	85.684	0.164	0.596	7.590	0.092	4056.912
1975	2905.017	74.789	0.143	0.580	6.700	0.080	3543.875
1976	2604.475	66.529	0.131	0.551	6.580	0.072	3173.982
1977	3090.768	78.270	0.160	0.752	8.569	0.086	3762.846
1978	3721.102	93.755	0.195	0.756	10.813	0.103	4525.816
1979	3157.352	79.745	0.164	0.825	8.993	0.088	3842.967
1980	3486.337	88.562	0.179	1.061	9.404	0.097	4248.035
1981	3462.226	88.856	0.173	0.900	8.326	0.096	4223.474
1982	2797.827	71.894	0.139	0.685	6.622	0.077	3413.243
1983	2762.227	70.252	0.133	2.776	5.986	0.075	3379.837
1984	2779.090	65.200	0.123	2.441	4.996	0.071	3351.040
1985	2523.520	583700	0.114	2.264	5.020	0.065	3039.775
1986	2531.036	59.612	0.111	2.194	4.274	0.065	3053.225
1987	2645.220	61.205	0.119	2.341	5.119	0.068	3183.227
1988	2537.495	59.348	0.111	2.183	4.281	0.065	3057.448
1989	2343.382	53.452	0.101	1.955	3.885	0.059	2811.798
1990	2018.725	45.774	0.087	1.681	3.402	0.050	2420.053
1991	1703.979	37.132	0.071	1.335	2.601	0.041	2029.383
1992	1739.428	37.576	0.074	1.395	3.059	0.042	2069.604
1993	1490.457	31.023	0.062	1.151	2.625	0.035	1763.341
1994	1468.940	33.729	0.063	1.230	2.409	0.037	1764.400
1995	1478.161	33.941	0.064	1.238	2.424	0.037	1775.476
1996	1483.295	34.058	0.064	1.242	2.433	0.037	1781.643
1997	1482.985	34.051	0.064	1.242	2.432	0.037	1781.270
1998	1494.448	34.314	0.064	1.252	2.451	0.038	1795.040
1999	1493.994	34.304	0.065	1.251	2.450	0.038	1794.494
2000	1503.028	34.511	0.065	1.259	2.465	0.038	1805.343
2001	1514.077	34.765	0.065	1.268	2.483	0.038	1818.617
2002	1526.096	35.041	0.066	1.278	2.503	0.038	1833.054
2003	1511.728	34.711	0.065	1.266	2.480	0.038	1815.795
2004	1498.172	34.400	0.065	1.255	2.457	0.038	1799.512
2005	1485.692	34.113	0.064	1.244	2.437	0.037	1784.522
2006	1474.004	33.845	0.064	1.235	2.418	0.037	1770.483
2007	1464.711	33.362	0.063	1.227	2.402	0.037	1759.321
2008	1455.258	33.415	0.063	1.219	2.387	0.037	1747.967
2009	1447.873	33.245	0.062	1.213	2.375	0.036	1739.096
2010	1441.520	33.099	0.062	1.207	2.364	0.036	1731.466
2011	1434.604	32.940	0.062	1.202	2.353	0.036	1723.158
2012	1429.791	32.830	0.062	1.198	2.345	0.036	1717.377
2013	1425.328	32.727	0.061	1.194	2.338	0.036	1712.017
2014	1422.173	32.655	0.061	1.191	2.333	0.036	1708.227
2015	1420.788	32.623	0.061	1.190	2.330	0.036	1706.563

Notes 1. Excludes ferries, fishing vessels and pleasure craft.

2. Historical emission estimates are very approximate, since constant emission factors (given in appendix V) are assumed.

Source BTCE estimates.

TABLE XI.7 SHIPPING PROJECTIONS

Year ending June	tc/tft	EXP ('000 tonnes)	IMP ($ million)	SGNE85 ($ million)	BULKIN ('000 tonnes)	BULKOUT ('000 tonnes)	NBULKIN ('000 tonnes)	NBLKOUT ('000 tonnes)
1983	0.157	141271	3531	198031	18628	167403	4995	6767
1984	0.154	176555	3821	209554	16885	203519	5682	6316
1985	0.120	214651	4843	220274	17476	238916	5906	7169
1986	0.105	210435	4722	229143	14489	237107	6181	7300
1987	0.113	205364	5391	228138	16873	230551	6604	8633
1988	0.128	225178	6267	239338	20146	258824	6834	9069
1989	0.131	224279	7575	255935	26790	257982	7792	8330
1990	0.135	236337	7723	264533	25822	270280	6140	8585
1991	0.124	254351	7749	256754	25649	294374	6369	9914
1992	0.125	267716	8384	258103	20916	297528	6290	9335
1993	0.125	276798	9164	265642	25774	300309	6463	9267
1994	0.122	290891	9739	274142	26765	315599	6591	9731
1995	0.124	301827	10313	282915	27755	327463	6722	9958
1996	0.127	311330	10887	291968	28745	337774	6855	10189
1997	0.129	318460	11462	301311	29735	345508	6990	10426
1998	0.131	327914	12036	310953	30726	355765	7128	10669
1999	0.134	334834	12610	321215	31716	363272	7274	11028
2000	0.133	343241	13184	331815	32706	372393	7422	11399
2001	0.131	351647	13758	342765	33696	381514	7574	11783
2002	0.131	360054	14332	354076	34686	390634	7728	12180
2003	0.129	368461	14906	365760	35677	399755	7886	12590
2004	0.128	376868	15481	377831	36667	408875	8047	12993
2005	0.128	385275	16055	390299	37657	417996	8211	13409
2006	0.127	393682	16629	403179	38647	427117	8378	13839
2007	0.127	402089	17203	416484	39638	436237	8549	14282
2008	0.126	410496	17777	430228	40628	445358	8724	14740
2009	0.126	418902	18351	444425	41618	454479	8902	15188
2010	0.126	427309	18925	459091	42608	463599	9083	15650
2011	0.126	435716	19499	474241	43599	472720	9269	16126
2012	0.126	444123	20074	489891	44589	481840	9458	16617
2013	0.126	452530	20648	506058	45579	490961	9651	17122
2014	0.126	460937	21222	522757	46569	500082	9848	17643
2015	0.126	469344	21796	540008	47560	509202	10049	18180

Sources ABS (1991c and earlier issues); ABARE (1993a); BTCE (1994a); Apelbaum (1993); ABARE (Bush, S. pers comm. 2 March 1994); BTCE estimates.

TABLE XI.7 SHIPPING PROJECTIONS (continued)

Year ending June	XRATE (USD/ AUD)	Average distance (in) (km)	Average distance (out) (km)	Average distance (pas) (km)	FI(liner) (L/tkm)	FI (dry bulk) (L/tkm)	CBLK ('000 tonnes)	CCOM ('000 tonnes)
1983	1.247	10878	12591	7960	0.00541	0.00340	34127	31046
1984	1.234	10814	12783	8168	0.00400	0.00251	39237	36450
1985	1.066	10734	12848	10733	0.00438	0.00275	39190	36167
1986	1.022	10645	12802	9886	0.00351	0.00221	41321	38162
1987	1.020	10827	12944	8937	0.00340	0.00214	41190	37889
1988	1.157	11116	12960	7870	0.00303	0.00191	39930	36776
1989	1.326	10945	12766	7938	0.00331	0.00208	39399	36016
1990	1.290	11154	12763	8007	0.00320	0.00201	41117	37760
1991	1.313	11326	12764	8075	0.00289	0.00182	40830	37450
1992	1.258	11876	12805	8144	0.00279	0.00175	40099	36283
1993	1.115	11249	12795	8144	0.00274	0.00172	40542	36472
1994	1.135	11293	12786	8144	0.00269	0.00169	40815	37571
1995	1.156	11336	12776	8144	0.00264	0.00166	41079	37845
1996	1.176	11380	12767	8144	0.00260	0.00163	41220	37992
1997	1.197	11423	12757	8144	0.00255	0.00160	41197	37967
1998	1.219	11466	12747	8144	0.00251	0.00157	41529	38313
1999	1.209	11509	12738	8144	0.00240	0.00155	41501	38283
2000	1.196	11552	12728	8144	0.00242	0.00152	41759	38553
2001	1.190	11595	12719	8144	0.00238	0.00149	42079	38886
2002	1.180	11638	12709	8144	0.00233	0.00147	42427	39250
2003	1.171	11681	12700	8144	0.00229	0.00144	42816	39656
2004	1.166	11723	12690	8144	0.00225	0.00141	43230	40088
2005	1.162	11765	12681	8144	0.00221	0.00139	43677	40558
2006	1.157	11807	12672	8144	0.00217	0.00136	44152	41055
2007	1.152	11849	12662	8144	0.00213	0.00134	44708	41639
2008	1.148	11891	12653	8144	0.00210	0.00132	45264	42224
2009	1.148	11933	12644	8144	0.00206	0.00129	45894	42889
2010	1.148	11974	12634	8144	0.00202	0.00127	46569	43600
2011	1.148	12015	12625	8144	0.00199	0.00125	47231	44301
2012	1.148	12056	12616	8144	0.00195	0.00123	47978	45093
2013	1.148	12097	12607	8144	0.00192	0.00120	48749	45911
2014	1.148	12138	12598	8144	0.00188	0.00118	49579	46795
2015	1.148	12178	12589	8144	0.00185	0.00116	50491	47768

Notes 1. FI(dry bulk) assumes that half the dry bulk ships experience a backhauling problem and arrive in Australia empty.

2. FI(passenger ships) is assumed to be constant and equal to 0.00573 L/tonne-km.

Sources BTCE (1994a); Apelbaum (1993); BTCE (1992); Drewry Shipping Consultants (1993 and earlier issues); BTCE estimates.

GLOSSARY

Activity levels are data on the magnitude of human activities resulting in emissions taking place over a given period of time. The units in which an activity level is expressed generally depend on the units of the emission factors that are available for equipment undertaking the activity. For example, activity data for calculating CO_2 emissions from transport vehicles are the annual amounts of fuel burned by the vehicles. Typically, activity levels relating to non-CO_2 emissions from road vehicles are more appropriately expressed in terms of annual distance travelled.

Aerosols are small particles which are suspended in a gas (such as the atmosphere).

Anthropogenic (or enhanced) greenhouse effect: where concentrations of some greenhouse gases in the atmosphere are increasing as a result of human activity.

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.

Automotive diesel oil (ADO) is a medium petroleum oil (obtained from the distillation of crude oil) used as fuel in high-speed and medium-speed compression ignition engines. It is mainly used in heavy road vehicles, rail transport, agricultural equipment and mining equipment.

Automotive gasoline (petrol) is a light petroleum oil used as fuel in spark ignition internal combustion engines (other than aviation piston engines). It is treated in refineries to reach a sufficiently high octane number for use in motor vehicles. There are two types of petrol sold in Australia: leaded and unleaded. The leaded form (containing either tetraethyl or tetramethyl lead) is used in motor vehicles manufactured prior to 1986 and the unleaded form is used mainly in post-1985 vehicles.

Aviation gasoline (avgas) is light petroleum oil specially prepared for aviation piston engines.

Aviation turbine fuel (avtur) is a medium petroleum oil used as fuel for aviation turbine (jet) engines.

Base case projections are based on the assumption that Australian governments take no action to reduce greenhouse gas emissions.

Black coal, in this Report, refers to steaming coal, used in the transport sector primarily for shipping.

Bunker, a storage facility for shipping and aviation fuel.

Buses (see Mobile sources—Road transport)

Carbon dioxide equivalent, the unit of CO_2 equivalents implies the mass of CO_2 necessary to have the same radiative effect as the mass of greenhouse gases emitted (see appendix II).

Conversion rate (see Emission factors).

Elasticity of a function is a unit-free measure of the degree to which the dependent variable (quantity demanded or quantity supplied, for example) changes in response to a change in an explanatory variable (own price, prices of other commodities and income, for example). The elasticity of a function, f(x), with respect to x is defined as:

$$\in_{f,x} = [x/f(x)][df(x)/dx] = d \ln f(x)/d \ln x.$$

Emission factors are coefficients specifying standard rates of emission per unit of activity (such as grams per kilometre travelled). Emission factors are generally based on measurement data (such as vehicle emission tests), averaged to provide representative emission rates for a given activity under a given set of operating conditions.

Emissions intensity refers to the amount of greenhouse gases produced per unit of fuel burned.

End use refers to emissions resulting solely from vehicle operation (see also Full fuel cycle).

Fluorocarbons (FCs) comprise various gases used as refrigerants in vehicle air-conditioners. These include chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs). The main refrigerant used in Australian vehicle air-conditioners is a chlorofluorocarbon denoted by CFC-12. However, Australian legislation, under the provisions of the Montreal Protocol on Ozone Depleting Substances, calls for the phasing out of chlorofluorocarbon use. All new vehicle air-conditioning systems manufactured after the end of 1994 will use CFC substitutes. For new systems, the main CFC replacement is a hydrofluorocarbon denoted by HFC-134a. For servicing existing vehicle air-conditioners the main CFC substitutes are HFC-134a and a blend containing the three fluorocarbons HCFC-22, HFC-152a and HCFC-124 (CEPA 1993).

Fuel intensity is the inverse of fuel efficiency, and refers to the *intensity of fuel use* for road vehicles. It is typically measured in litres per 100 kilometres.

Fuel oil refers to heavy petroleum oil, often the residue of petroleum distillation, used in ship furnaces.

Fugitive emissions result from the leakage of chemical substances during various human activities. The main fugitive emissions from mobile sources occur through the evaporation of fuel from gasoline vehicles and the release of fluorocarbons from vehicle air-conditioners.

Full fuel cycle refers to emissions resulting from end-use plus those resulting from feedstock extraction and refining, power generation, and energy distribution.

General aviation includes commuter and charter services, private and training flights and aerial agricultural work.

Global warming potential is an index, defined to be the warming effect over a given period due to an emission of a particular gas, relative to an equal mass of CO_2 (see appendix II).

Greenhouse effect is the phenomenon whereby water vapour and other gases present in small quantities in the atmosphere affect the earth's radiation balance, resulting in a higher surface temperature.

Greenhouse gases include water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), oxides of nitrogen (NO_x) other than nitrous oxide, carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), sulphur oxides (SO_x), and fluorocarbon (FC) species.

Gross calorific value (GCV) is the quantity of heat released by a unit quantity of fuel when it is burned completely with oxygen, and the products of combustion are returned to ambient temperature. GCV is also known as higher heating value (HHV).

Industrial diesel fuel (IDF) is a heavy petroleum oil used as fuel in low-speed compression ignition (diesel) engines. It is mainly consumed in the rail and marine transport sectors.

Life cycle refers to emissions resulting from full fuel cycle plus those resulting from vehicle manufacture and vehicle disposal. Inclusion of emissions due to the provision of transport infrastructure results in the *systems cycle*.

Light commercial vehicles are vehicles constructed primarily for carriage of goods, not exceeding 3.5 tonnes gross vehicle mass. Included are utilities, panel vans, cab chassis and forward control load-carrying vehicles.

Liquefied petroleum gas (LPG) is a light petroleum liquid, produced by compressing petroleum vapour, used in specially modified internal combustion engines. In Australia, LPG sold for automotive purposes is primarily a mixture of 70 per cent propane and 30 per cent butane, with the precise composition varying with application, season and region.

Logistic curve refers to a graph of

$$g(t) = k(1+ae^{-bt})^{-1},$$

with k, a, b constants. The function g(t) increases with t and has an upper asymptote of k. The logistic curve is typically used to model market penetration of a new product. The curve grows slowly at first, but then undergoes a period of rapid growth, followed by a levelling off as the product reaches market saturation.

Long-term passenger numbers refers to the number of Australian resident departures and foreign passenger arrivals which are undertaking travel for a period of more than 12 months.

Mobile sources are sources of greenhouse gas emissions associated with mobile fuel combustion activities, regardless of the sector or industry for which the activity is undertaken. The following source categories are included in this report:

- **Air transport** includes all civil aviation activities.
  - **Domestic aviation** consists of commercial airline and general aviation (such as private, agricultural commuter and charter) services, for both freight and passenger movements.
  - **International aviation** includes international air freight and passenger movements accomplished using fuel purchased in Australia.
- **Road transport** includes all activity (on-road and off-road) by vehicles registered for road use (with a motor vehicle registration authority), except vehicles belonging to the Australian Defence Force. Emissions by military vehicles and vehicles used exclusively for off-road purposes (such as competition motorcycles, forklifts and tractors) are accounted for in other source categories below. The road transport sector is subdivided into categories based on the vehicle definitions contained in Australian Design Rules (ADRs) for Motor Vehicles and Trailers (FORS 1989).

  - **Passenger cars** relate to all passenger vehicles which carry fewer than 10 passengers (including the driver). These consist of cars, station wagons, taxis, minibuses, four-wheel drive passenger vehicles and forward control passenger vehicles. Petrol-fuelled cars are subdivided by vehicle age into year of manufacture categories: pre-1976, 1976–1980, 1981–1985, and post-1985.

  - **Light goods vehicles** are trucks and light commercial vehicles designed to carry goods and not exceeding 3.5 tonnes gross vehicle mass. These include utilities, panel vans, cab chassis and forward control load-carrying vehicles. The equipment carried on special purpose vehicles having little freight-carrying capacity (such as ambulances, fire trucks and mobile cranes) are regarded as being equivalent to goods for the purposes of vehicle definitions (FORS 1989).

  - **Medium goods vehicles** are goods vehicles (including rigid trucks, articulated trucks and special purpose vehicles) with gross vehicle mass exceeding 3.5 tonnes but not exceeding 12 tonnes.

  - **Heavy goods vehicles** are goods vehicles (rigid trucks, articulated trucks and special purpose vehicles) exceeding 12 tonnes gross vehicle mass.

  - **Buses** are passenger vehicles with 10 or more seats, including that of the driver.

  - **Motorcycles** include all two-wheeled and three-wheeled motor vehicles.

- **Rail transport** includes non-electric railway services for both passenger and freight movement. Emissions due to the generation of electricity for electric railways are not included in end-use emissions estimates given in the Report (such as in table 7.1 or appendix V). See chapter 3 (and table IX.4) for analysis of electric trains and trams.

- **Marine transport** includes all civil maritime activity.

  - **Domestic marine transport** consists of coastal shipping (freight and cruises), interstate and urban ferry services, commercial fishing, and small pleasure craft movements.

  - **International shipping** includes passenger and freight movement by sea-going ships (of all flags) accomplished using marine bunker fuel purchased in Australia.

- **Military transport** includes all activity by military land vehicles, aircraft and ships.

- **Other mobile engines** include unregistered recreational or competition vehicles such as trail bikes and racing cars. When calculating transport sector fuel use from total fuel sales, allowances often have to be made for off-road fuel use by various types of mobile equipment. These include farm and forestry equipment (such as tractors and harvesters), industrial equipment (which is used by the manufacturing, construction and mining sectors and includes vehicles such as forklifts, bulldozers and quarry trucks) and miscellaneous mobile utility engines (such as lawn-mowers and chainsaws).

Modal composition refers to the broad type of transport used; for example, road, rail, aviation and shipping.

Motorcycle (see Mobile sources—Road transport)

Natural gas (NG) consists primarily of methane (around 90 per cent, with traces of other gaseous hydrocarbons, nitrogen and carbon dioxide) and occurs naturally in underground deposits. As a transport fuel, it is generally used in compressed or liquefied form.

Natural greenhouse effect refers to the warming effect of greenhouse gas levels in the atmosphere that are not of human origin.

Net calorific value (NCV) is the gross calorific value of a fuel less the heat of vaporisation (at 25°C and constant volume) of the water that is present in the fuel and that formed during combustion. NCV is also known as lower heating value (LHV). The International Energy Agency (IEA) generally reports energy data in terms of NCV, whereas Australian energy data are typically reported in GCVs. The IEA assumes that lower heating values are 5 per cent lower than higher heating values for oil and coal, and 10 per cent lower for natural gas (OECD 1991).

Other trucks include specialist vehicles or vehicles fitted with special purpose equipment, and having little or no significant load-carrying capacity; for example ambulances, mobile cranes, cherry pickers, fire trucks.

Oxidation, in this Report, refers to the process by which fuel is consumed by burning with oxygen. The proportion of fuel consumed by burning is referred to as the oxidised component, while a non-oxidised component results in solid combustion products such as soot and ash.

Oxidation factor represents the proportion of the fuel oxidised during combustion.

Passenger cars (see Mobile sources—Road transport).

Passenger kilometres (pkm) is the product of the number of passengers in a given vehicle on a given journey and the distance (in kilometres) travelled by that vehicle on that journey.

Pilots' dispute occurred during the period from the second quarter of 1989 to the third quarter of 1990 inclusive.

Reformulated gasoline (RFG) refers to a variety of improved (unleaded) petrol blends which are being developed to improve air quality. Typically RFGs have added oxygen and a reduced proportion of highly volatile compounds.

Rigid trucks are (non-articulated) vehicles exceeding 3.5 tonnes gross vehicle mass, constructed primarily for the carriage of goods. Included are normal rigid trucks with a towbar, drawbar or other non-articulated coupling on the rear of the vehicle for use with a trailer or dolly.

Short-term passenger numbers refers to the number of Australian resident departures and foreign passenger arrivals undertaking travel for a period of less than 12 months.

Stratosphere is a layer of the atmosphere occurring between approximately 15 and 50 kilometres altitude.

Systems cycle emissions include emissions due to transport vehicle lifecycle (fuel supply, fuel use, vehicle manufacture and disposal) and to the provision of transport infrastructure (such as roads, railways and airports).

Tonne kilometres (tkm) is the product of the weight of the freight of a given vehicle on a given haul and the distance of that haul.

Toronto target refers to a plan adopted by *The Changing Atmosphere: Implications for Global Security Conference*, held in Toronto in 1988, urging governments to cut their CO_2 emissions to 80 per cent of their 1988 levels by 2005.

Troposphere is the lower part of the earth's atmosphere (up to about 15 kilometres in altitude).

Vehicle utilisation level refers to the total distance travelled by a given vehicle in a given time period (for example, kilometres per year).

REFERENCES

Abbreviations

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ACCI	Australian Chamber of Commerce and Industry
ACS	Australian Customs Service
ADIPG	Australian Draft Inventory Preparation Group
AEC	Australian Environment Council
AGPS	Australian Government Publishing Service
AIP	Australian Institute of Petroleum
AMI	Australian Mineral Industry
BTCE	Bureau of Transport and Communications Economics
BTE	Bureau of Transport Economics
BTR	Bureau of Tourism Research
CBCS	Commonwealth Bureau of Census and Statistics
CEPA	Commonwealth Environmental Protection Agency
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DASET	Department of the Arts, Sport, the Environment and Territories
DEST	Department of the Environment, Sport and Territories
DME	Department of Minerals and Energy of NSW
DPIE	Department of Primary Industry and Energy
DTC	Department of Transport and Communications
ECMT	European Conference of Ministers of Transport
EPAV	Environmental Protection Authority of Victoria
ERDC	Energy Research and Development Corporation
FORS	Federal Office of Road Safety
ICAO	International Civil Aviation Organisation (Canada)
IEA	International Energy Association
IPCC	Intergovernmental Panel on Climate Change
ITS	Institute of Transport Studies
NELA	Nelson, English, Loxton and Andrews, Pty. Ltd.
NGAC	National Greenhouse Advisory Committee
NGGIC	National Greenhouse Gas Inventory Committee
NIEIR	National Institute of Economic and Industry Research

OECD	Organisation for Economic Cooperation and Development
OTA	Office of Technology Assessment (USA)
RCEP	Royal Commission on Environmental Pollution
RIC	Railway Industry Council
STSG	State Transport Study Group
UNEP	United Nations Environment Programme
WBC	Westpac Banking Corporation
WMO	World Meteorological Organisation
WRI	World Resources Institute

ABARE 1993a, *Agriculture and Resources Quarterly,* vol. 5, no. 4, December, ABARE, Canberra.

——1993b, *Commodity Statistical Bulletin*, ABARE, Canberra.

——1991, *Projections of Energy Demand and Supply 1989–90 to 1999–2000,* AGPS, Canberra.

ABS 1994a, *Motor Vehicle Registrations Australia,* Cat. no. 9303.0, ABS, Canberra.

——1994b, *Projections of the Populations of Australian States and Territories 1993 to 2041,* Cat. no. 3222.0, ABS, Canberra.

——1994c, *Australian National Accounts*, Cat. no. 5242.0, ABS, Canberra.

——1994d, *Australian Demographic Statistics*, Cat. no. 3101.0, ABS, Canberra.

——1994e, *Consumer Price Index*, Cat. no. 6401.0, ABS, Canberra.

——1993a, *Survey of Motor Vehicle Use Australia, 30 September 1991,* Cat. no. 9208.0, ABS, Canberra.

——1993b, *Motor Vehicle Registrations Australia*, Cat. no. 9304.0, ABS, Canberra.

——1993c, *Overseas Arrivals and Departures*, Cat. no. 3404.0, ABS, Canberra.

——1992a, *Motor Vehicle Registrations Australia*, Cat. no. 9303.0, ABS, Canberra.

——1992b, *Motor Vehicle Census Australia*, Cat. no. 9309.0, ABS, Canberra.

——1991a, *Year Book Australia 1991*, AGPS, Canberra.

——1991b, *Survey of Motor Vehicle Use Australia, 30 September 1988,* Cat. no. 9208.0, ABS, Canberra.

——1991c, *Shipping and Air Cargo Commodity Statistics Australia,* Cat. no. 9206.0, ABS, Canberra.

——1989a, *Motor Vehicle Census Australia 30 September 1988*, Cat. no. 9309.0, ABS, Canberra.

——1989b, *Recreational Fishing, Western Australia, July 1987*, Cat. no. 7602.5, ABS, Canberra.

——1986a, *Rail Transport Australia, 1983–84*, and earlier editions, Cat. no. 9213.0, ABS, Canberra.

——1986b, *Survey of Motor Vehicle Use*, Cat. no. 9208.0, ABS, Canberra.

——1983, *Survey of Motor Vehicle Usage*, Cat. no. 9208.0, ABS, Canberra.

——1981a, *Survey of Motor Vehicle Usage*, Cat. no. 9208.0, ABS, Canberra.

——1981b, *Rail, Bus and Air Transport Australia 1978–79*, ABS, Canberra.

——1978, *Survey of Motor Vehicle Usage*, Cat. no. 9208.0, ABS, Canberra.

——1973, *Survey of Motor Vehicle Usage*, Cat. no. 9208.0, ABS, Canberra.

——various years, *Balance of Payments Australia*, Cat. no. 5302.0, ABS, Canberra.

ACCI/WBC 1994, *Survey of Industrial Trends 1994*, and earlier issues, ACCI, Sydney

ACS 1991, *Annual Report 1989–90*, AGPS, Canberra.

Adena, M.A. & Montesin, H.J. 1988, *Day to Day Travel in Australia 1985–86*, FORS Report CR69, FORS, Canberra.

ADIPG 1991, *Draft Australian Greenhouse Gas Emissions Inventory 1987–88*, DASET Greenhouse Studies no. 10, AGPS, Canberra.

AIP 1992, *Oil and Australia: Forecasts 1992–2000*, AIP, Melbourne.

——1994, *Oil and Australia: Forecasts 1994–2003*, supplement to petroleum gazette 1994/1, AIP, Melbourne.

Alamdari, F.E. & Brewer, D. 1994, 'Taxation policy for aircraft emissions', *Transport Policy*, vol. 1, no. 3, pp. 149–159.

AMI 1982, *Australian Mineral Industry Annual Review 1980*, AGPS, Canberra.

Apelbaum, J. 1993, *The Australian Transport Task and the Primary Energy Consumed—1990/91 Compendium*, Part B, Study commissioned by DPIE, BTCE, Australian Automobile Association, Australian Institute of Petroleum Ltd and Electricity Supply Association of Australia Ltd, DPIE, Canberra.

Armour, L. & Jordan, D. 1992, *Greenhouse Gas Emissions and the Public Transport Corporation*, Report prepared for the Public Transport Corporation, March, Melbourne.

BIS Shrapnel 1993, *Long Term Forecasts Australia 1993–2008*, BIS Shrapnel, Melbourne.

Boeing 1994, *Current Market Outlook 1994*, Boeing Commercial Airplane Group, Seattle.

BTCE 1994a, *Transport and Communications Indicators Database*, BTCE, Canberra, (updated quarterly).

——1994b, *Alternative Fuels in Australian Transport*, Information Paper 39, AGPS, Canberra.

——1993a, *Costs of Reducing Greenhouse Gases in Australian Transport*, Working Paper 10, BTCE, Canberra.

——1993b, *The Progress of Aviation Reform*, Report 81, AGPS, Canberra.

——1993c, *Trends and Issues in International Aviation*, Report 86, AGPS, Canberra.

——1992, *Fuel Efficiency of Ships and Aircraft*, Working Paper 4, BTCE, Canberra.

——1991a, *Greenhouse Gas Emissions in Australian Transport*, Working Paper 1, BTCE, Canberra.

——1991b, *Short-Term Forecasting of Transport and Communications Activity*, Working Paper 2, BTCE, Canberra.

——1991c, *Fuel Demand Forecasts and Long-Term Price Elasticities for Fuel of Australian Transport*, Occasional Paper 103, BTCE, Canberra.

——1990, *Freight Flows in Australian Transport Corridors*, Occasional Paper 98, AGPS, Canberra.

——1989a, *Australian Non-Government Railways—Operating Statistics: 1987–88*, BTCE, Canberra.

——1988, *Trends and Prospects for Australian International Air Transport*, Occasional Paper 88, AGPS, Canberra.

BTE 1982, *Australian Rail Freight Movements 1979–80*, AGPS, Canberra.

——1980, *Consumption of Transport Energy in Australia 1975–76*, AGPS, Canberra.

——1978, *Outlook Paper: Freight Transport,* 1978 Transport Outlook Conference, AGPS, Canberra.

——1975, *Transport and Energy in Australia,* AGPS, Canberra.

BTR 1992, *Australian Tourism Forecasts—International Visitor Arrivals 1992–2001,* BTR, Canberra.

Bush, S., Leonard, M., Bowen, B., Jones, B., Donaldson, K., & Ho Trieu, L. 1993, *Energy Demand and Supply Projection Australia 1992–93 to 2004–05,* ABARE Research Report 93.2, ABARE, Canberra.

Caney, R.W. & Reynolds, J.E. 1988. *Reed's Marine Distance Tables,* Thomas Reed Publications Ltd, Surrey.

Carnovale, F., Alviano, P., Carvalho, C., Deitch, G., Jiang, S., Macaulay, D. & Summers, M. 1991, *Air Emissions Inventory Port Phillip Region: Planning for the Future,* Report SRS 91/001, EPAV, Melbourne.

CBCS 1973, *Transport and Communication 1970–71* (Bulletin 62), AGPS, Canberra.

CEPA 1993, draft revised strategy for ozone protection, Paper prepared for the Australia–New Zealand Environment Council, Canberra (unpublished).

Department of Shipping and Transport 1964, *Estimates of Motor Vehicles in Australia, 1964 to 1974,* Department of Supply, Central Drawing Office, Maribyrnong.

Commonwealth of Australia 1992, *National Greenhouse Response Strategy,* AGPS, Canberra.

Cosgrove, D.C. 1992, Emissions from transport and their environmental impacts, BTCE seminar paper, 16 December 1992 (unpublished).

Cosgrove, D.C. & Gargett, D. 1992, 'The Australian domestic transport task', *Papers of the Australasian Transport Research Forum,* vol. 17, part 1, pp. 231–249 BTCE, Canberra.

Cosgrove, D.C., Gargett, D. & Viney, P. 1989, Simple demand equations for the short-term forecasting of air passenger movements, BTCE paper presented to the Annual Conference of the Economic Society of Australia, Adelaide, 10-13 July 1989 (unpublished).

DeLuchi, M. 1993, 'Greenhouse-gas emissions from the use of new fuels for transportation and electricity', *Transportation Research,* 27A, no.3, pp. 187–191.

De Maria, S. 1992, Report on *Vehicle & Engine Monitoring & Analysis System (VEPMAS)* by Energy and Engines Research Group, for buses running on compressed natural gas in Adelaide, Sydney and Brisbane, University of South Australia (unpublished).

DME 1990, Report on a study of greenhouse gas emissions from motor vehicles in New South Wales, Greenhouse Effect Program Project, prepared by Ecogen Pty. Limited, Sydney (unpublished).

Donaldson, P.K., Gillan, P. & Jones, B.P. 1990, Road transport fuel demand in Australia: projecting vehicle fuel use, ABARE paper presented at the Conference of Economists, Economic Society of Australia, Sydney, 24-27 September.

Drewry Shipping Consultants 1993 and earlier issues, *Shipping Statistics and Economics*, Drewry International Limited, London.

DTC 1993a, *Air Transport Statistics—Domestic Airlines,* DTC, Canberra (and earlier editions).

——1993b, *Air Transport Statistics—International Scheduled Air Transport,* DTC, Canberra (and earlier editions).

——1993c, *Sea Transport Statistics—Coastal Freight*, DTC, Canberra (and earlier editions).

——1992, *Compilation of Aviation and Tourism Forecasts,* Occasional Paper, DTC, Canberra.

——1991a, *Sea Transport Statistics: Coastal Freight*, DTC, Canberra.

——1991b, *Air Transport Statistics: Domestic Airlines*, DTC, Canberra.

——1991c, *International Aviation Traffic Summary,* Aviation Statistics (unpublished).

ECMT 1994, *Transport and the greenhouse effect in the ECMT member countries, Data and Forecasts,* Report prepared for the Ad Hoc Group on Transport and the Environment, Restricted draft (3 March 1994), OECD/ECMT, Paris.

——1990, *Transport Policy and the Environment*, OECD, Paris.

EPAV 1991, *A Comparative Study of Greenhouse Gases and Air Pollutants from Petrol Fuelled Vehicles and Vehicles Using Natural Gas, Automotive Diesel Fuel or Liquefied Petroleum Gas*, EPAV, Melbourne.

Farrington, V. 1988, *Air Emission Inventories (1985) for the Australian Capital Cities,* AEC Report 22, AGPS, Canberra.

Federal Airports Administration 1991, *Aircraft Engine Emissions Database (Draft), User Version*, developed by Federal Airports Administration Office of Environment and Energy with assistance from US Environmental Protection Agency, November 26, Washington DC.

FORS 1991a, *Study on Potential to Improve Fuel Economy of Passenger Motor Vehicles*, Report prepared by Nelson English, Loxton and Andrews Pty Ltd for the Federal Office of Road Safety, Canberra.

——1991b, *A Model for the Prediction of CO_2 Emissions from Passenger Cars*, FORS, Canberra.

——1989, *Australian Design Rules For Motor Vehicles And Trailers*, Third Edition, DTC, Canberra.

Gallez, C. 1994, 'Identifying the long term dynamics of car ownership: A demographic approach', *Transport Reviews*, vol. 14, no. 1, pp. 83–102.

Gruebler, A. & Nakicenovic, N. 1991, *Evolution of Future Transport Systems: Past and Future*, International Institute for Applied Systems Analysis, Laxenburg, Austria.

Hall, N., Allen, R., Abdalla, A., Noble, K., Mikosza, T. & Dykstra, C. 1994, *Impact of B-Doubles on Grain Transport Costs*, ABARE Research Report 94.15, Canberra.

Henchy, J. & Swanton D., 1992, *International Aviation Forecasting Models*, DTC, Canberra.

Hensher, D.A. 1989, *The Structure and Performance of the Private Bus and Coach Industry in Australia* (draft report), ITS, Sydney.

Hoekman, S.K. 1992, 'Speciated measurements and calculated reactivities of vehicle exhaust emissions from conventional and reformulated gasolines', *Environmental Science and Technology, American Chemical Society*, vol. 26, no. 10, p. 2036.

ICAO 1992, *Outlook for Air Transport to the Year 2001*, ICAO, Quebec.

IEA 1992, *Energy and the Environment: Transport System Responses in the OECD, Greenhouse Gas Emissions and Road Transport*, Restricted Draft (21 January) and Restricted Draft of chapters 11, 12 and 18 (8 April), OECD/IEA, Paris.

——1993, *Cars and Climate Change*, OECD/IEA, Paris.

IPCC 1994, *Radiative Forcing of Climate Change*, The 1994 Report of the Scientific Assessment Working Group of IPCC (Summary for Policymakers), British Meteorological Office, London.

——1992, *Climate Change: The Supplementary Report to the IPCC Scientific Assessment*, Cambridge University Press, Cambridge.

——1990, *Climate Change: The IPCC Scientific Assessment*, Cambridge University Press, Cambridge.

IPCC/OECD 1994, IPCC Guidelines for National Greenhouse Gas Inventories, three volumes: The Greenhouse Gas Inventory Reporting Instructions (vol. 1); The Greenhouse Gas Inventory Workbook (vol. 2); The Greenhouse Gas Inventory Reference Manual (vol. 3), Paris (unpublished).

Itorralba, E. & Balce, M. 1992, 'The 1991 Sydney home interview survey preliminary results: Implications for modelling' in *Papers of the Transport Research Forum*, vol. 17, part 1, pp. 163–180 Canberra.

Latham, J.S. 1983, *Elasticity of Road Traffic Demand According to the Price of Fuel*, XVII World Road Congress (Conference Discussion), Sydney.

Lloyds' Register of Shipping 1990, *Marine Exhaust Emissions Research Programme–Steady State Operation*, Lloyds' Register of Shipping, London.

Maddock, R. & McLean, I. 1987, *The Australian Economy in the Long Run*, Cambridge University Press, New York.

Marchetti, C. 1983, 'The automobile in a system context', *Technological Forecasting and Social Change*, pp. 3–23.

Morgan, T.D., Betts, W.E., Hutcheson, R.C., McArragher, J.S., Schmiedel, H.P. & Snelgrove, D.G. 1993, *A Study of VOC Running Losses from European Canister-Equipped Vehicles, US and European Automotive Emissions Technology*, Report SP-957, Society of Automotive Engineers International, Warrendale.

NELA 1988, *Consumption of Transport Energy in Australia 1984–85*, National Energy Research Development and Demonstration Program–Consultancy Report 24, DPIE Canberra.

Newman, P. & Kenworthy, J. 1990, *Cities and Automobile Dependence: An International Sourcebook*, Gower, Aldershot.

NGAC 1992, *Grappling with Greenhouse: Understanding the Science of Climate Change*, DASET, Canberra.

NGGIC 1994a, *Workbook for Fuel Combustion Activities (excluding Transport)*, DEST, Canberra.

——1994b, *Workbook for Fuel Production, Transmissions, Storage and Distribution*, DEST, Canberra.

——1994c, *Summary, Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks and National Greenhouse Gas Inventory 1988 and 1990*, DEST, Canberra.

NIEIR 1994, *Energy Working Party*, NIER, Melbourne.

——1990, *Energy Working Party, Part Two*, NIER, Melbourne.

OECD 1994, *Overview of Preliminary National GHG Inventories*, Interim Report, January 1994, OECD, Paris.

——1991, *Estimation of Greenhouse Gas Emissions and Sinks*, Final Report from the OECD Experts Meeting, February 1991 (Revised August 1991), prepared for the IPCC, OECD, Paris.

OECD/IEA 1991, *Greenhouse Gas Emissions: The Energy Dimension*, OECD, Paris.

OTA 1991, *Changing by Degrees: Steps to Reduce Greenhouse Gases*, US Government Printing Office, Washington DC.

Oum, T. 1979a, *Demand for Freight Transportation with a Special Emphasis on Mode Choice in Canada*, Centre for Transportation Studies, University of British Columbia, Vancouver.

——1979b, 'Derived demand for freight transport and inter-modal competition in Canada', *Journal of Transport Economics and Policy*, vol. XIII, no.2, pp. 149–168.

Petroleum Press 1993, *The Petroleum Economist*, Petroleum Press, London (and earlier issues).

Polar Design Research Ltd 1993, *Study of Gaseous Emissions from Ships*, Report prepared for Transportation Development Centre, Vancouver.

RCEP 1994, *Transport and the Environment*, Eighteenth Report of the RCEP, HMSO, London.

RIC 1990, *Rail into the 21st Century*, AGPS, Canberra.

Shell 1993, *Fuelling Aviation*, Shell Briefing Service, no. 4, Shell International Petroleum Company Limited, London.

Sinor, J.E. Consultants Inc. 1992, *Clean Fuels Report*, June edition, JE Sinor Consultants Inc., Colorado.

Streeton, J.A. 1990, *Air Pollution Health Effects and Air Quality Objectives in Victoria*, September 1990, EPAV, Melbourne.

STSG 1985, *Trends in Morning Peak Travel in Sydney 1971–1981*, Report 202, STSG, Sydney.

TransEco 1994, *TransEco Road Freight Cost Indices*, TransEco Pty Ltd, Melbourne.

Transport Tasmania 1990, *Annual Report 1990*, Tasmanian Government Printer, Hobart.

UNEP/WMO 1994, *United Nations Framework Convention on Climate Change*, UNEP/WMO, Geneva.

Weeks, I.A., Galbally, I.E., Huang Guo-hong 1993, *Nitrous Oxide Emissions from Motor Vehicles in Australia*, Research Report to ANZECC, Final Report, CSIRO, Melbourne.

Wigan, M. 1994a, *Measurement and Evaluation of Non Motorised Transport*, Institute of Transport Studies, University of Sydney, Working Paper ITS-WP-94-15, October 1994.

——1994b, *Walking as a Transport Mode*, Institute of Transport Studies, University of Sydney, Working Paper ITS-WP-94-9, April 1994.

Wilkenfeld, G. 1991, *Greenhouse Gas Emissions from the Australian Energy System—The Impact of Energy Efficiency and Substitution*, ERDC Report 22, ERDC, Canberra.

World Bank 1992, *World Tables 1992*, Johns Hopkins University Press, Baltimore.

WRI 1994, *World Resources 1994–95*, Oxford University Press, New York.

Zillman, J.W. 1990, Transport and the global greenhouse, Paper presented at the October 1990 Transport and the Environment Symposium, Melbourne.

ABBREVIATIONS

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
ACCI	Australian Chamber of Commerce and Industry
ACS	Australian Customs Service
ADIPG	Australian Draft Inventory Preparation Group
ADO	Automotive diesel oil
ADR	Australian Design Rule
AEC	Australian Environment Council
AGA	Australian Gas Association
AGPS	Australian Government Publishing Service
AIP	Australian Institute of Petroleum
ALPGA	Australian Liquefied Petroleum Gas Association
ANMA	Australian National Maritime Association
AT	Articulated trucks
Avgas	Aviation gasoline
Avtur	Aviation turbine fuel
BTCE	Bureau of Transport and Communications Economics
BTE	Bureau of Transport Economics
BTR	Bureau of Tourism Research
CBCS	Commonwealth Bureau of Census and Statistics
CEPA	Commonwealth Environment Protection Agency
CFCs	Chlorofluorocarbons
CH_4	Methane
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CoP 1	First Conference of the Parties
CORC	Cochrane–Orcutt estimation
CPI	Consumer price index
DASET	Department of the Arts, Sport, the Environment and Territories
DEST	Department of the Environment, Sport and Territories
DH	Durbin's h statistic

DME	Department of Minerals and Energy of New South Wales
DPIE	Department of Primary Industries and Energy
DTC	Department of Transport and Communications
DW	Durbin–Watson statistic
DWT	Deadweight tonnage
ECMT	European Conference of Ministers of Transport
EM	Estimation method
EPA	Environmental Protection Agency
EPANSW	Environment Protection Authority of New South Wales
EPAV	Environment Protection Authority of Victoria
ERDC	Energy Research & Development Corporation
ESD	Ecologically sustainable development
FC	Fuel consumption
FCAI	Federal Chamber of Automotive Industries
FCs	Fluorocarbons
FE	Fuel efficiency
FFC	Full fuel cycle
FI	Fuel intensity
FO	Fuel oil
FORS	Federal Office of Road Safety
GCV	Gross calorific value
GDP	Gross domestic product
Gg	Gigagram (10^9 grams)
G7	Group of Seven major OECD economies
GWP	Global warming potential
HC	Hydrocarbon
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
H_2O	Hydrogen dioxide (water)
ICAO	International Civil Aviation Organisation
IDF	Industrial diesel fuel
IEA	International Energy Agency
IMO	International Maritime Organisation
INC	Intergovernmental Negotiating Committee
IOP	Iron ore production
IPCC	Intergovernmental Panel on Climate Change
IPT	Interim Planning Target
kg	Kilogram
km	Kilometre
kt	Kilotonne
L/100km	Litres consumed per 100 km travelled
LCV	Light commercial vehicle
ln	natural logarithm
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas

MJ	Megajoule (million joules)
ML	Megalitre (million litres)
Mt	Megatonne (million tonnes)
N_2O	Nitrous oxide
NCV	Net calorific value
NFGDP	Non-farm gross domestic product
NG	Natural gas
NGAC	National Greenhouse Advisory Committee
NGGIC	National Greenhouse Gas Inventory Committee
NGRS	National Greenhouse Response Strategy
NIEIR	National Institute of Economic and Industry Research
NMVOC	Non-methane volatile organic compound
NO_x	Nitrogen oxides
O_3	Ozone
OECD	Organisation for Economic Co-operation and Development
OLS	Ordinary Least Squares estimation
PJ	Petajoule (10^{15} joules)
pkm	Passenger-kilometre
RCEP	Royal Commission on Environmental Pollution
RFG	Reformulated gasoline
RIC	Railway Industry Council
ROT	Rigid and other trucks
SMVU	*Survey of Motor Vehicle Use*
SO_x	Sulphur oxides
tkm	Tonne-kilometre
Tm	Terametre
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
VKT	Vehicle kilometres travelled
WBC	Westpac Banking Corporation
WMO	World Meteorological Organisation
WRI	World Resources Institute