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Paper title: **Modelling the impacts of alternative policy options to reduce greenhouse gas emissions from urban freight transport – a Sydney case study**

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Abstract (200 words):

This paper describes research on the impacts of alternative policies aimed at reducing the greenhouse gas emissions produced by freight transport in urban areas. A combined travel demand, traffic network and pollutant emissions modelling system was established, to test the impacts of the following generic policy initiatives: 'best practice' truck fleet fuel efficiency, general reductions in peak period traffic congestion, improved traffic management, provision of real-time traffic information, infrastructure improvements, changes to industrial land use distribution, and improved vehicle load factors. The Sydney region was used as a case study. Whilst almost all of the policy options showed the potential for some improvement in emissions outcomes, the best option overall was that directed at vehicle load factors. The policy direction aimed at changing the distribution of industrial land use provided mixed results, which suggested that complementary measures to influence modal choice for certain urban freight tasks were also required to achieve positive outcomes for this policy initiative. The value of the modelling system was clearly demonstrated by the case study.

Introduction

Road freight activity in Australian cities is growing more rapidly than passenger traffic, and although passenger traffic is expected to plateau in the near future, there is no sign of that happening for urban freight activity. As a result, the environmental impacts of urban freight traffic, especially in terms of greenhouse gas (GHG) and other air pollution, are of increasing concern to the community. In view of this, the Bureau of Transport and Regional Economics (BTRE), on behalf of the Australian Greenhouse Office (AGO), commissioned a study to investigate the sensitivity of urban freight patterns to a range of policy measures aimed at reducing GHG emissions.

While the study aimed to provide results generally applicable to all Australian urban areas, Greater Sydney was used as a case study to build on the data and models held by the Transport and Population Data Centre (TPDC) of the NSW Department of Infrastructure, Planning and Natural Resources. The TPDC Commercial Transport Study (CTS) has developed methodologies to derive freight traffic due to total requirements for freight and relative requirements for categories of goods from actual or forecasted commodity flows and associated information. This provides one of the most detailed estimations of the impacts of urban freight flows on the road network available anywhere in the world. In essence, the model links the demand for different commodities to be moved from A to B with the usual ways and means of getting the freight there. Such models are potentially powerful in predicting expected traffic on the network due to changes in the needs for different types of freight. However, most GHG policy instruments seek to vary 'the usual means of getting there' rather than reduce freight. Thus, the role of this study is to select and assess suitable policies to *change the ways and means of moving freight from A to B, rather than the overall amount of freight being moved*. The effectiveness of policies to reduce the environmental impacts of urban freight transport without putting constraints on the volume of freight or affecting the economic welfare of the city can then be compared.

GHG emissions due to urban freight depend upon the fuel use by freight vehicles. This in turn depends upon vehicle technologies, and fuel, plus travel speed and flow, hence prevailing traffic. It also depends on the numbers of trips required, the loading of vehicles and the location of the industry and business dispatching or receiving freight together with the transport infrastructure, predominantly roads, linking freight origins and destinations. Policy measures expected to produce positive GHG outcomes may thus be conveniently divided into the categories shown in Table 1.

A wide range of measures in these categories were assessed, a modelling framework was developed and a set of policies for modelling was selected. The relative impacts of policy outcomes on vehicle emissions were then modelled. The models took into account the basic factors affecting the pattern of urban freight traffic activity, the rate of emissions under different traffic conditions, and the resulting impacts in terms of patterns of emissions in different parts of cities. In addition to GHG emissions, fuel consumption and a number of air quality pollutant emissions were also modelled. This paper only discusses the results for GHG emissions: Carbon Dioxide (CO₂), Carbon Dioxide Equivalents (CO₂e), Methane (CH₄) and Nitrous Oxide (N₂O). Interested readers will find the more comprehensive results in Smith, D'Este, Taylor, Kilsby, Marquez and Zito (2003).

Table 1 Urban freight policies measure and influences on GHG

Category	Influences
Vehicle measures	The type of fuel, efficiency of motors, and influences such as vehicle weight, aerodynamic properties and driving style all influence emissions.
Traffic measures	Emissions vary with speed and differ between free flow and congested conditions, thus are affected by prevailing traffic conditions.
Vehicle movement measures	Emissions depend on numbers of trips, total trip distances, loading of vehicles and size of the vehicle used for the task.
Infrastructure and land use measures	Land use governing the location of industries and business and their distances from suppliers and customers influence trip lengths, hence fuel use and emissions as does new infrastructure to provide better connectivity.

This paper provides an overview of the study objectives, methodology, modelling results and their interpretation. It focuses on the GHG emissions impacts. A full description of the overall study is given in Smith *et al* (2003), with more detailed information available in the set of five technical papers which support the study (Smith and D'Este, 2003, Smith and Kilsby, 2003, Zito and Taylor, 2003, Marquez, 2003 and Marquez and Smith, 2003).

Responses to policy measures

The first task for the study was to establish which policies should, and equally importantly could, be modelled. That is, we wanted an initial assessment of likely policies and likely impacts, in terms of who would be affected and by how much. If detailed disaggregate data, about shipper and carrier preferences and activities, were available, likely responses to policy might be predicted with a behavioural model. In the absence of such data, a process for judging the likely responses to policies using a mix of available quantitative data and market intelligence is needed. Thus the project commenced with a review of available TPDC data and supporting data, such as information from the Australian Bureau of Statistics (ABS), plus a market study comprising formal and informal interviews with experts augmented by information from local and international reports and papers. The market study demonstrated the diversity of the freight industry and its people. The freight industry, in general, and the urban freight industry, in particular, is a set of multiple markets. The consideration set of the study was constrained by:

- the definition of 'urban freight' i.e. we were to consider carriage of goods not provision of services, and
- available data: TPDC data excludes some categories of freight. Particular exclusions are household freight such as mail delivery and 'consignment' of household garbage'.

The study thus relates particularly to the consignment and delivery of goods by business and industry. This aspect of the freight task has seen significant changes in recent years. While the concepts of supply chains, and associated logistics services date from the time carriage was by camel train, developments in information communications technologies have led to a revolution in the management of the supply chain from 'suppliers' supplier to customers' customer'. Smith *et al* (2003) provides an extensive literature review and discusses these recent key changes to the freight task in some detail. It also explores the implications for urban freight modelling. Further discussion of modelling needs and strategies may be found in

4 Modelling GHG emissions from urban freight transport

Tavasszy, Smeenk and Ruijgrok (1998), Fuller and Tsolakis (2001) and Zografos (2002). On the basis of the literature review we adopted the following procedure:

1. identify the policy variables of interest
2. establish the relevant segments of the freight task from the literature and expert advice
3. establish the likely outcome of the policy and model its traffic and hence GHG impacts.

Candidate abatement measures were identified based on the literature review, with a detailed description of the candidate measures given in Smith *et al* (2003). These measures can be categorised as follows:

- vehicle technology measures
- vehicle movement measures
- infrastructure and planning measures

A qualitative analysis of expected impacts of these emission abatement measures was then undertaken. This analysis noted what the measure would reduce: number of vehicles, number of trips, vehicle-km of travel (VKT) for the given freight task, fuel consumption and/or non-GHG emissions per litre of fuel. It then rated likely magnitude of the potential effect in terms of market impact. For each measure, the possible performance was rated against the following criteria: relative size of the GHG effect, market size affected, then overall GHG emissions/non-GHG emissions. These estimates together with proposed modelling strategies informed a knowledge transfer workshop with project stakeholders. Considerations included the particular strength of the TPDC data and modelling structure in its ability to analyse impacts at the road network link level. This can allow for variation in roads, in passenger traffic and in demand for both passenger and goods movements in different parts of a large and complex city.

It should be noted that there are a wide range of possible policy measures that could be applied, but many of these are just different ways of achieving the same outcome. For example, improved fuel efficiency and reduced emissions from each litre of fuel consumed could be achieved by a range of vehicle, engine and fuel technologies. Similarly, a reduction in traffic congestion that would benefit the efficiency of urban freight operations and reduce emissions, might be produced by policy instruments ranging from on-road parking restrictions to road pricing. As a result, a focus on identifying scenarios representing operational outcomes of policy instruments (or combinations of policies) and modelling the effects on emissions was recommended.

A final set of model scenarios, as shown in Table 2, representing policy outcomes from a broad range of policies, was then selected and modelled to estimate the likely impacts of each policy on GHG (and air quality) emissions. This paper concentrates on the result for GHG emissions only. The results for air quality emissions are discussed in Smith *et al* (2003).

Transport Modelling

Sydney was chosen for the case study because the TPDC has developed a database (the Commercial Travel Study, CTS) of commercial vehicle trips: between individual travel zones within the Greater Sydney Metropolitan Area. This provides origin-destination flows of freight vehicle trips by time of day (four time periods) and by commercial vehicle type (light commercial vehicle, rigid truck and articulated truck). The limitation of the present database is that it is limited to freight vehicle movement in Sydney in 1996. *Consequently, this meant that the study needed to test all policies as if they were effective in 1996.* The value of the

results therefore lies, not in their absolute values, but as strategic level indications of the potential magnitude of impacts relative to the base 'business as usual' scenario and to each other. It would be unrealistic to assess the on-road performance of vans and trucks without considering other traffic on the road. As the TPDC also holds a Strategic Travel Model (STM), which forecasts personal travel on the same spatial basis as the CTS, estimates of passenger vehicle trips in 1996 could also be drawn.

Table 2 The scenarios tested

Policy Outcome		Scenario Modelled
0	Base case	Travel in Sydney in 1996
1	Lower congestion	15 per cent reduction in car use in AM and PM peaks
2	Better traffic management	Five per cent extra capacity on arterial roads and speed increased 3 km/h at saturation
3	Logistical changes	Same quantity of goods moved between same places but with higher load factors and some transfer of goods to larger vehicles
4	Real-time traffic information	Major approaches to CBD and Parramatta and major orbital routes modified as per 'better traffic management'.
5	Infrastructure improvement	Sydney Orbital route at freeway standard added to 1996 road network for Sydney.
6	Infrastructure improvement with land use change and distributional feedbacks	Sydney orbital route added; plus westward shift of employment assumed, thus modified freight trip patterns.
7	Improved fuel consumption	Base case traffic with all commercial vehicles operating with fuel and emission efficient engines

A procedure using advanced assignment techniques was developed to combine outputs of the two processes – trip matrices of light, rigid and articulated commercial vehicles from the CTS, and trip matrices of passenger vehicles from the STM, and assign them all to the road network in such a way that the effects on each type of vehicle can be distinguished. Model assumptions were applied to the basic 1996 travel patterns of cars and commercial vehicles and produced detailed link-by-link estimates of traffic volumes, speeds and composition.

Figure 1 compares the contents of the CTS and STM modules that are implemented in different transport modelling packages. Figure 2 describes the integration process where assignment was carried out on the EMME/2 model platform. As Figure 2 shows, the policy interventions applied in the scenarios enter the modelling framework either by changes to the CTS tables, changes to the passenger car matrices or changes to the road network. The implementation of the scenarios is briefly described in the next section.

6 Modelling GHG emissions from urban freight transport

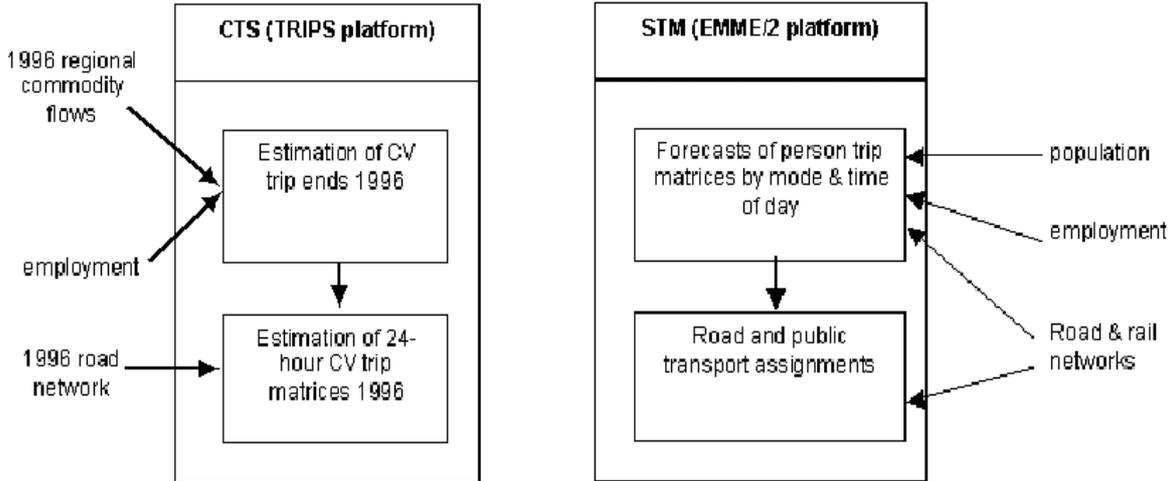


Figure 1 Comparison of CTS and STM processes

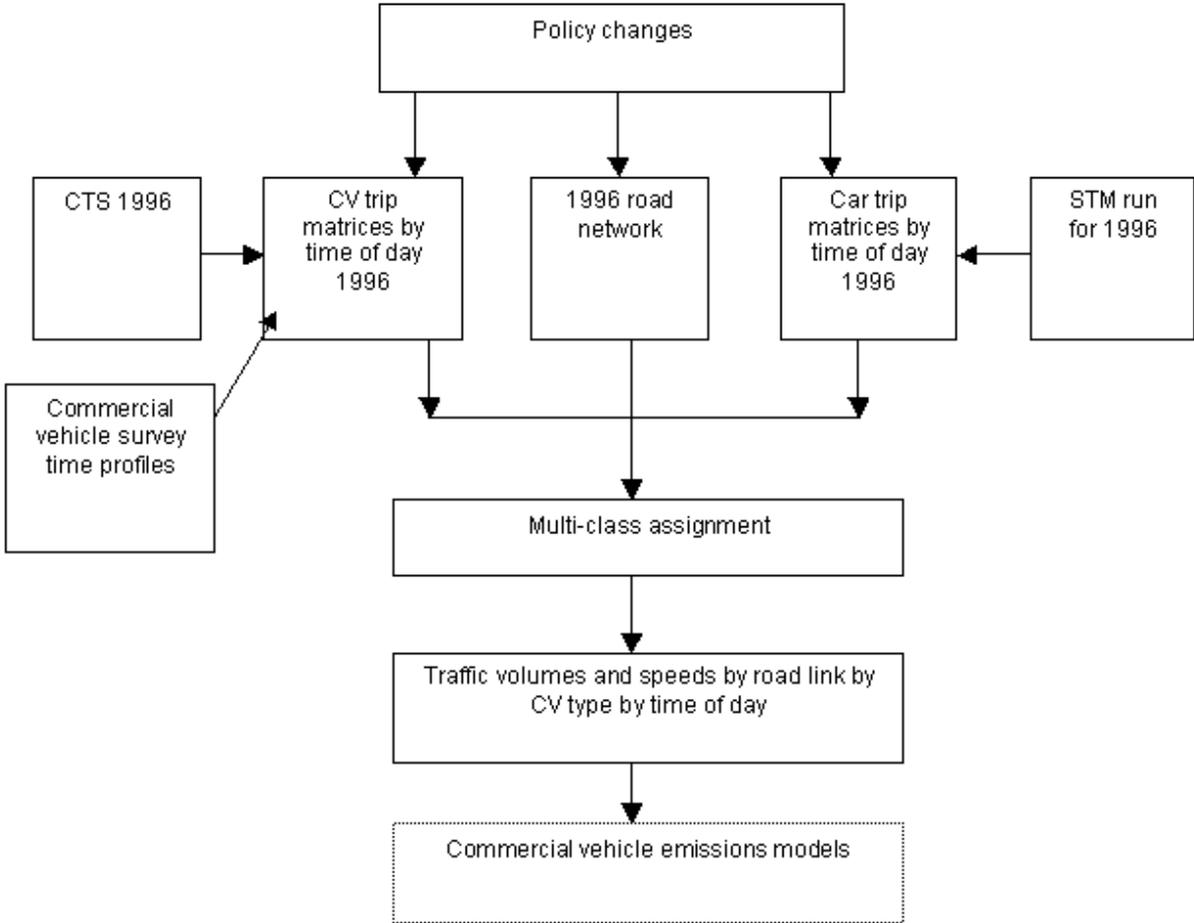


Figure 2 Use of CTS and STM processes in policy scenarios

The 1996 base case gave the benchmark against which policy variations were compared. As noted previously, the purpose of modelling was to obtain strategic level estimates of policy

impacts and compare options rather than produce absolute values for forecasting purposes. Table 3 shows the number of vehicles by vehicle type and time period, for the 1996 base case.

Table 3 Weekday trips (000s) in Sydney 1996 by vehicle type and time of day

Vehicle type	AM peak	Business hours	PM peak	Evening	24 hour*
Cars	1,146 <i>16%</i>	2,455 <i>35%</i>	1,778 <i>25%</i>	1,734 <i>24%</i>	7,113 <i>100%</i>
LCVs	74 <i>19%</i>	215 <i>53%</i>	87 <i>14%</i>	65 <i>14%</i>	443 <i>100%</i>
Rigid trucks	26 <i>19%</i>	73 <i>53%</i>	19 <i>14%</i>	20 <i>14%</i>	138 <i>100%</i>
Articulated trucks	5 <i>19%</i>	13 <i>49%</i>	3 <i>10%</i>	5 <i>22%</i>	25 <i>100%</i>
All vehicles*	1,251 <i>16%</i>	2,755 <i>36%</i>	1,888 <i>24%</i>	1,825 <i>24%</i>	7,720 <i>100%</i>

*Discrepancy in totals due to rounding

The policy scenarios listed in Table 2 were then modelled and compared to the base case. Summary results for network travel statistics in terms of average percentage changes compared to the base case are shown in Table 4. These results show only the effects on travel distance and time. Moreover, the averages hide the wide variation of impacts by time of day and across the city. Smith and Kilsby (2003) shows the detailed modelling results with time of day variation, while Marquez (2003) describes the project scenario viewing software that allows 'zooming in' on locations of interest. Thus, we stress the results summarised in Table 5 are only impact averages for reporting purposes. Results for specific times and localities may vary. Additionally, the emission modelling results in the next section are needed to give a more complete the picture of the impacts.

Emissions modelling

The transport model provided the volumes of vehicles by vehicle type on each network link, for each policy scenario. In order to assess the environmental benefits and/or disbenefits of the various scenarios, emission models were required that were sensitive to factors such as:

- VKT by vehicle type and by fuel type
- variations in the loads carried by freight vehicles
- average travel speeds for vehicles on each link in the network under different traffic conditions and congestion levels
- effects of changes in engine and fuel technology for freight vehicles.

Table 4 Summary of effects of policies relative to 1996 base case

	Scenario	Lower congestion	Better traffic management	Logistical changes	Real-time traffic information	Infrastructure improvement	Infrastructure improvement with land use change
Trips (000)							
	Cars	-6%	0%	0%	0%	0%	0%
	LCVs	0%	0%	-22%	0%	0%	0%
	Rigids	0%	0%	-22%	0%	0%	1%
	Artics	0%	0%	-8%	0%	0%	+20%
	All vehicles	-5%	0%	-2%	0%	0%	0%
VKT (000)							
Daily vehicle kilometres of travel	Cars	-7%	0%	0%	0%	-7%	-7%
	LCVs	-1%	0%	-17%	0%	0%	+2%
	Rigids	-1%	0%	-21%	0%	+1%	+4%
	Artics	-1%	0%	-10%	0%	0%	+24%
	All vehicles	-6%	0%	-2%	0%	-6%	-6%
VHT ² (000)							
	Cars	-13%	-4%	-1%	-6%	-10%	-9%
	LCVs	-6%	-4%	-18%	-7%	-2%	-1%
	Rigids	-4%	-4%	-21%	-5%	-1%	+3%
	Artics	-4%	-3%	-9%	-4%	-1%	+29%
	All vehicles	-13%	-4%	-3%	-6%	-9%	-8%
Average speed (km/h)							
	Cars	+5%	+3%	+1%	+4%	+4%	+3%
	LCVs	+3%	+3%	+1%	+5%	+1%	+2%
	Rigids	+2%	+3%	0%	+3%	+1%	+1%
	Artics	-1%	0%	0%	0%	0%	-6%
	All vehicles	+5%	+3%	+1%	+4%	+4%	+3%

No such models could be found from previous studies, so new models had to be developed. While some Australian data did exist for the required emission factors, a complete picture could not be formed solely on the basis of the available Australian data. Other data sources were required to expand and enrich the database of emissions factors. Given the requirements of the emissions modelling approach adopted for the study and the results of the literature review conducted in its initial stages, the European Emissions Inventory Guidebook (European Environment Agency, 2002), was used to provide the basic models relating emission rate, average link speed, fuel type, vehicle type and vehicle load factor. Published Australian data were then used to derive calibration points to transform the models for European vehicles into models for equivalent Australian vehicles. The data sources used for this transformation were AGO (1998), Environment Australia (2001) and Apelbaum Consulting Group (2001). A particular advantage of the method adopted in this study is that it can be refined over time. As better Australian emissions data become available these calibration points can be updated and extended to reflect the changing performance of the Australian vehicle fleet.

Table 5 Transport effects of policy scenarios

<p>Lower congestion</p> <p>Lowering peak congestion reduces both peak VKT and VHT. The percentage reduction in VHT exceeds that of VKT and average travel speeds increase. This only occurs in peak periods and the 24-hour performance is therefore watered down. The majority of commercial vehicle movement takes place outside the peaks.</p>
<p>Better traffic management</p> <p>Improvement of the performance of arterial roads improves traffic flow but the overall effect is small, because the better-performing roads tend to attract more traffic, which slows them down again.</p>
<p>Logistics Measures</p> <p>A move to higher load factors and load consolidation produces a large net decline in VKT by commercial vehicles and hence is likely to reduce emissions. There is very little change in operating speed, since VHT declines in roughly the same proportion as VKT.</p>
<p>Real-time traffic information</p> <p>This increases the performance of the principal arterial and orbital routes. It has practically no effect on commercial vehicle VKT but VHT decreases slightly and hence higher operating speeds are achieved (for light CV's and rigid trucks).</p>
<p>Effects of infrastructure improvement</p> <p>If trip patterns did not change, the addition of the Sydney Orbital to Sydney's road infrastructure in 1996 would have encouraged longer but faster trips by both cars and commercial vehicles, with the result that VKT would go up, VHT would go down and average travel speed would increase.</p>
<p>Effects of infrastructure improvement with land use change</p> <p>Relocation of some freight-generating employment from inner areas to Western Sydney actually increased commercial vehicle activity because some of the displaced movement would still have the docks and central industrial areas as its destination pattern. Some increase may be a result of modelling assumptions but it is also likely that larger scale land use changes such as new freight terminals are needed when industry is moved.</p>

The following generic formula was used to calculate the total amount of emissions produced by all vehicles travelling on each link in the network. The formula is such that it enables the emissions results to be sensitive to parameters such as increasing load factors, *changing proportions of vehicle and fuel types in the vehicle fleet, and different congestion levels*. This is an important feature as many of the policy options being tested vary these and other parameters in different ways on a link-by-link basis. The total amount of emissions for any link *a* is given by:

$$\text{Link Emission}(a) = \sum_{\text{Vehicle Type } i} \sum_{\text{Fuel Type } j} \text{Volume} * \text{Fleet Proportion}_{ij} * \text{Emissions Factor}(a)_{ij} * \text{SCF}_{ij} * \text{LCF}_{ij} * \text{Length}$$

where:

- Link Emission (a) = Total amount of emission type a_{ij} produced on link (a)
 Volume = Total number of vehicles on link
 Vehicle Type i = All vehicle types being considered

Fuel Type j	= All fuel types being considered
Fleet Proportion ij	= Proportion of vehicle type i and fuel type j on the link
Emissions factor ij	= Base emissions factor for type a emission for veh type i and fuel type j
SCFij	= Speed correction factor for vehicle type i and fuel type j
LCFij	= Load Correction Factor for vehicle type i and fuel type j
Length	= Length of the link (km)

In all, 132 emission streams were created for use in this project, with a total of 12 emissions (including fuel consumption) for the four vehicle types each with three fuel types (petrol, diesel and LPG¹).

The freight vehicle fleet fuel efficiency scenario required a slightly different approach for emissions modelling. Whilst all other scenarios involved vehicle movement or traffic changes and so required travel demand modelling, this scenario was modelled during the emission estimation process only and thus did not require separate travel demand modelling. The fuel consumption and emissions characteristics of the freight vehicles in the base scenario were changed on the basis of the following assumptions, consistent with known and available fuel and engine technologies:

- LCVs to have the same emissions performance as passenger vehicles
- emissions performance for rigid and articulated trucks was determined using scale factors for the best available current emissions performance using results from the Diesel NEPM preparatory project 2 (Environment Australia, 2001)

Results

The results of the study provides policy implications of two types

- *implications of scenario results*: The study results provide comparative impacts of policy outcomes and hence comparative impacts of a wide range of policy measures as each outcome represents multiple measures, and
- *viability and value of the process*: The study showed that it was possible to model the impacts of greenhouse abatement measures for urban freight in Australian cities at a fine grained network level by making best use of available data sources; and also showed analysis at that level is worthwhile since location of the measures impacted both locations of outcomes and their total impacts.

This section first reviews the study scenario results, discusses the implications and concludes with a consideration of broader implications of the value of the methodology for policy testing, using the scenarios identified in Table 2.

Scenarios 1, 2, 5 and 6 affected all traffic demands and movements, i.e. private vehicles as well as freight vehicles. Scenario 4 – real-time traffic information systems – was set to affect all traffic in our model but could be directed explicitly at the freight vehicle fleet only. Scenarios 3 and 7 affected freight vehicles only.

¹ Emission estimates were not obtained for LPG fuelled articulated vehicles since the available vehicle fleet data (ABS, 1999) indicated that there were only three of these vehicles registered in the Sydney metropolitan area.

In all scenarios except 3 and 6, the freight vehicle travel demand was the same as that in the base case, in terms of vehicle trip O-D patterns in space and over time. In scenario 3 (higher load factors), the number of freight vehicle trips was reduced, although the total freight movements (in terms of tonnages) were the same as in the base case. In scenario 6 (industry relocation with infrastructure improvements) spatial patterns of freight vehicle trips and private vehicle trips were modified as some industries moved west from their present eastern area locations in the metropolitan area, although the total numbers of vehicle trips remained unchanged. In scenario 1 (reduced peak period congestion), the numbers of peak period private vehicle trips were reduced but off peak private vehicle trips and all freight vehicle trips were unaltered. In scenarios 2 (better traffic management) and 4 (real time traffic information) all travel demand remained the same as in the base case.

Consideration of the model results for the different scenarios allows the exploration of the likely impacts of the alternative policies on greenhouse gas emissions, and on the emissions of air pollutants. A starting point for this exploration is to consider the modelled contributions of freight vehicles in the base case 1996 Sydney network, divided into the three vehicle classes of light commercial vehicles (LCV), rigid trucks (RT) and articulated trucks (AT), to travel demand and to overall greenhouse gas emissions. To visualise the overall impacts of freight transport in the study area network, it is also necessary to compare the freight transport task and the emissions from that task with the task and emissions from private vehicles (PV). Table 7 shows some summary statistics for the base case, in terms of the percentages of vehicle trips, vehicle-kilometres of travel (VKT), vehicle hours of travel (VHT), and total greenhouse gas emissions (GHG, in carbon dioxide equivalents, CO₂e) for daily travel in the study area network.

This table indicates that, on a daily basis, freight vehicles make 7.9 per cent of all vehicle trips and perform 9.4 per cent of all VKT and 9.2 per cent of all VHT. They generate 17.8 per cent of all GHG emissions from road transport in performing their travel tasks. Using these results it is possible, as shown in Table 6, to develop a 'passenger car equivalent' (PCU) for each vehicle class, in terms of the contributions of each vehicle class to total GHG emissions.

Table 6 Percentage contributions to total travel and total greenhouse gas emissions by different vehicle classes on the Sydney 1996 base case network

Vehicle type	Trips	Veh-km of travel	Veh-hours of travel	Total GHG emissions (CO ₂ e)	PCU equivalent of GHG emissions
Private vehicles	92.1%	90.5%	90.7%	82.9%	1.00
Light commercial vehicles	5.8%	6.1%	6.3%	6.6%	1.18
Rigid trucks	1.8%	2.7%	2.4%	7.3%	2.95
Articulated trucks	0.3%	0.7%	0.6%	3.2%	4.99
Totals	100.0%	100.0%	100.0%	100.0%	

Given that the PCU value for a private vehicle is 1.00, the PCU equivalent for LCVs may be taken as about 1.3, whilst that for rigid trucks 3.0 and for articulated trucks, about 4.4. Thus,

for instance, three LCVs may be considered as producing GHG emissions equivalent to four passenger cars, on average, whilst one articulated truck produces GHG emissions equivalent to those of 4.4 passenger cars. These GHG-PCU values may be compared to the commonly assumed traffic-PCU values, predominantly based on vehicle lengths, of 1.0 for LCVs, 2.0 for rigid trucks, and 3.0 for articulated trucks, used in the assessment of traffic operating conditions and traffic capacity of roads.

The contributions of the four vehicle types to emissions of specific greenhouse gases, the ‘direct’ GHG emissions of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O), as well as the total CO₂e, in the base case network are shown in Table 7. This table indicates some differences in the relative contributions of freight vehicles to the emissions of specific gases, notably the significant emissions of methane by the LCV vehicle class (15.0 per cent of total CH₄ emissions compared to 7.0 per cent of CO₂e emissions and 5.8 per cent of VKT in the network. On the other hand, freight vehicles make smaller percentage contributions to total N₂O emissions, where the percentage contribution of private cars is 90.7 per cent (compared to the 82.2 per cent contribution of private cars to total CO₂e).

Table 7 Percentage contributions to total VKT, total GHG emissions & individual ‘direct’ greenhouse gas emissions by different vehicle classes on the Sydney 1996 base case network

Vehicle type	Vehicle-kilometres of travel	Greenhouse gas			
		CO ₂	CH ₄	N ₂ O	CO ₂ e
Private vehicles	90.5%	82.7%	84.6%	91.1%	82.9%
Light commercial vehicles	6.1%	6.6%	14.0%	2.9%	6.6%
Rigid trucks	2.7%	7.4%	1.3%	4.7%	7.3%
Articulated trucks	0.7%	3.3%	0.1%	1.2%	3.2%
Totals	100.0%	100.0%	100.0%	100.0%	100.0%

Figure 3 indicates the GHG emissions performance of freight vehicles on the study network under different scenarios as a percentage of the base case. This figure presents a set of bar charts for each of the direct greenhouse gases and for total GHG emissions in CO₂ equivalents. The following results, which have strong implications for the determination of policies with respect to freight transport in urban areas, may be drawn from Figure 3:

- all of the policy measures, except for that of infrastructure improvements coupled with land use change through industry relocation, provide some positive benefit, in terms of GHG emissions. In the case of the land use change scenario, as will be discussed later, there are specific reasons why no positive benefit to GHG emissions from freight transport was achieved, which could be overcome by complementary policies including other infrastructure improvements

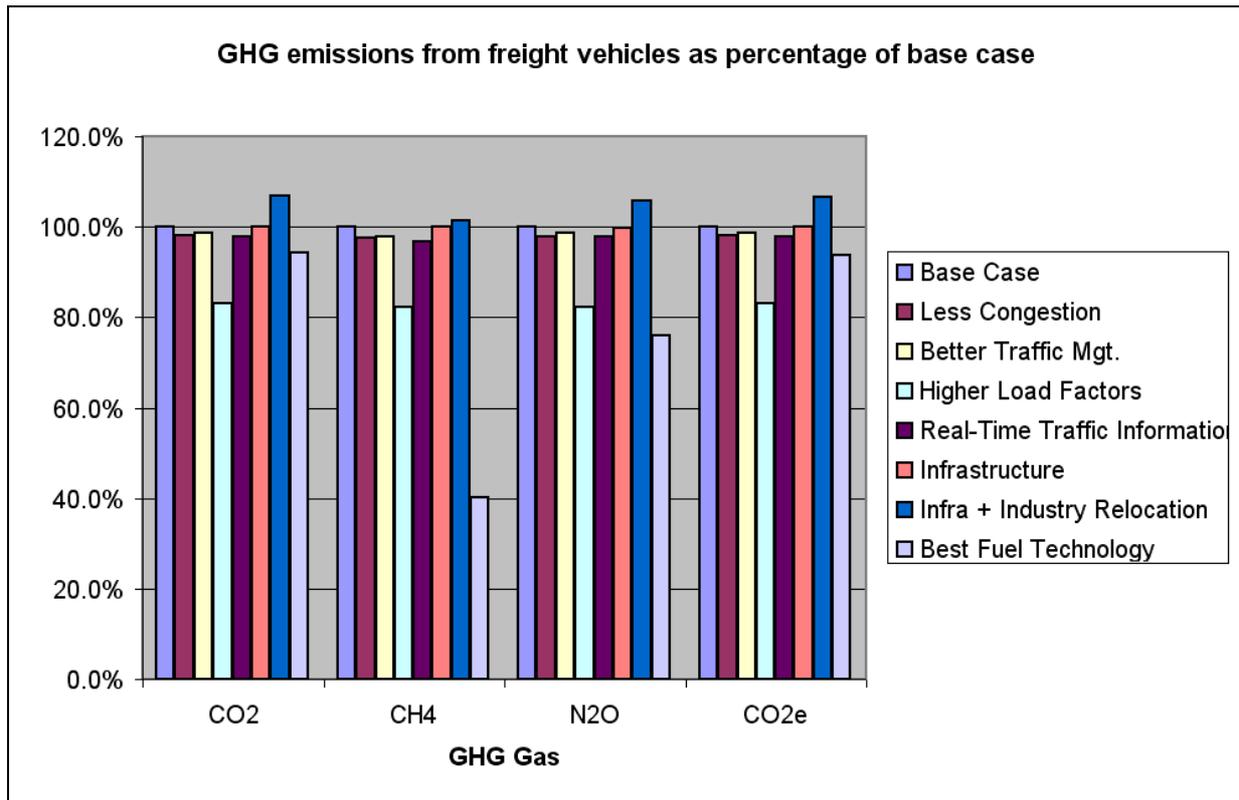


Figure 3 GHG emissions from freight vehicles by scenario

- the policy initiative that has the largest positive effect on GHG emissions from freight transport is that of higher load factors for freight vehicles. This measure produced a reduction of about 17 per cent in total GHG emissions when compared to the base case
- the application of best fuel technology was the second best policy measure, and indeed this initiative produced the largest reductions in emissions of CH₄ and N₂O from urban freight
- for all of the other policy measures producing reductions in GHG emissions from urban freight transport, the percentage reductions in total GHG emissions from freight transport were relatively small, of the order of three per cent or less. However in absolute terms of total quantities of GHG emissions the policy options were still important
- the policy option of infrastructure improvement coupled with industry relocation, for the case of the Sydney Orbital, led to an increase in overall GHG emissions from freight transport of about 6.5 per cent. This increase was almost entirely due to a singular effect, the doubling of the work tasks of articulated vehicles (as measured in terms of VKT performed), which led to an increase of about 30 per cent in GHG emissions from this vehicle class. The reason for this increase in vehicle work is the major role played by articulated vehicles in transporting commodities and goods between the port and the industrial complexes. The location of the port obviously remains fixed, whilst the industrial sites have shifted a considerable distance to the west. Modelling for this scenario reasonably assumed that the port-factory movements would continue to be made by road using the largest freight vehicles (i.e. articulated vehicles), as no alternative transport mode was available. Complementary measures, such as constructing new railway infrastructure, to provide a direct connection to the port, could mitigate GHG emissions from this particular freight task.

It is also important to examine the effects of the policies in the context of all traffic on the network. The total picture of GHG emissions on the study area network, from all transport sources including passenger vehicles, is provided in Figure 4. This chart is similar to Figure 3, but shows the relative GHG emissions performance of each policy scenario including emissions from private vehicles.

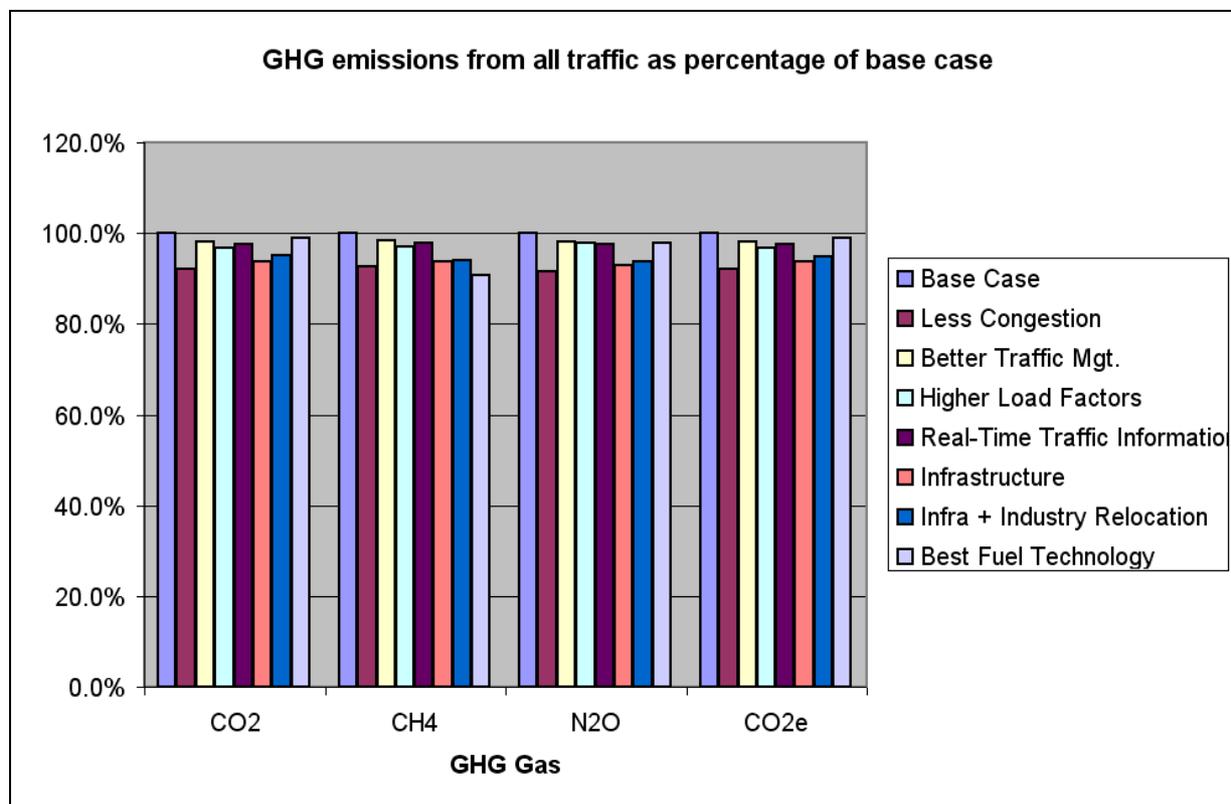


Figure 4 GHG emissions from all vehicles by scenario

Figure 4 shows that all of the policy options have positive effects on GHG emissions when total emissions from all road transport sources are considered. This includes the scenario with industry relocation and infrastructure provision, which yields a total GHG emissions reduction of about five per cent. The reductions in GHG emissions from private vehicle travel outweigh the increased emissions from the freight vehicles. The policy option with the greatest effect on total GHG emissions from transport is that of reduced peak period traffic congestion. The 20 per cent reduction in private vehicle trips assumed under this scenario leads to an overall decrease of around eight per cent in total GHG emissions. The decrease in GHG emissions from freight vehicles in this case is around 2.3 per cent, indicating that the substantial benefit comes from reductions in the GHG emissions of private cars.

The policy question is how to achieve such reductions? One potential answer is the application of congestion charging ('road pricing') for peak period motor vehicle trips, as adopted in Singapore (with electronic road pricing) and now in central London (through a cordon charge licensing scheme enforced by video surveillance). Other previous studies – see for example May et al (1996), AATSE (1997), Bray and Tisato (1997) and Taylor (1999ab) – have suggested the potential for congestion charging to reduce air pollutant emissions from urban road transport.

The infrastructure improvement option (without industry relocation) provided the second best result in terms of total GHG emissions (6.2 per cent). The benefit is derived from free flowing traffic. However it is important to remember that such an effect will only apply if the new infrastructure does not induce extra passenger vehicle trips. We believe evidence from the literature supports our assumption that the new infrastructure will not induce extra freight trips but that assumption would not hold for passenger trips, although as numbers of the links on the Sydney orbital are, or will be, subject to tolling, induced demand could be dampened.

The other scenarios affecting general traffic activity (i.e. better traffic management and real time traffic information) led to reductions in total GHG emissions of about two per cent.

The freight transport-specific policy measures of higher load factors and best fuel technology found to offer the most promise in reducing GHG emissions from freight vehicles provided reductions in the total GHG emissions of 3.3 per cent and 1.1 per cent respectively, because these measures were solely targeted at urban freight transport. Private vehicle emissions were not directly affected by these policy measures except at the margin – higher load factors mean slightly fewer freight vehicles on the road.

The modelling results also permit a more detailed view of the emissions impacts on each vehicle class under each policy scenario. For the case of the total GHG emissions (measured in terms of CO₂ equivalents), Figure 5 shows the overall emissions impacts for each freight vehicle class.

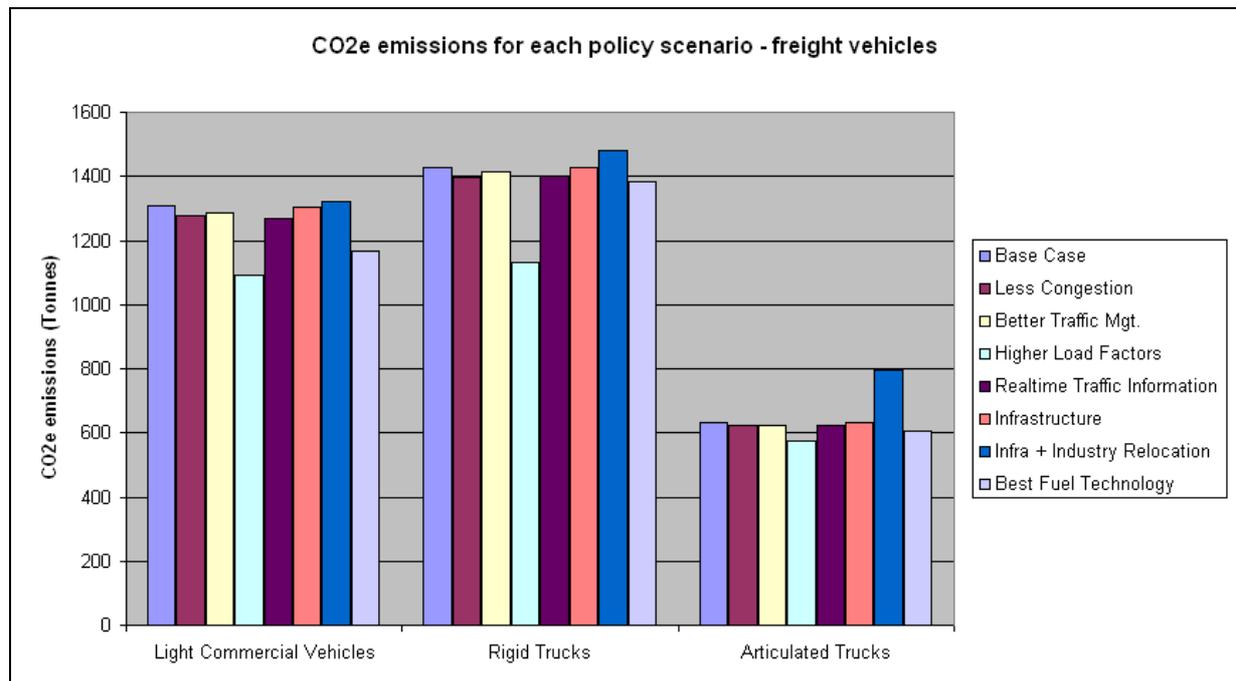


Figure 5 Total modelled CO₂e emissions (in tonnes per day) for each freight vehicle type under the different policy scenarios

Figure 5 indicates that the different policy options can have different effects on the freight vehicle classes. Higher load factors have most effects (both absolutely and proportionately) on the GHG emissions performance of light commercial vehicles and rigid trucks. The impact

of this policy scenario on articulated trucks is much less, probably reflecting the more specialised freight tasks undertaken by this vehicle type in urban areas. Similarly, best fuel technology has most effect on the emissions performance of light commercial vehicles, the freight vehicle class known to be growing in importance in urban freight.

The impact on GHG emissions from articulated vehicles in the scenario with industry relocation following the construction of the Sydney Orbital is also clearly apparent, whilst this scenario has only a small effect for the other freight vehicle classes. We note again that while the size of this impact may be overestimated, due to modelling simplification in moving only manufacturing west, the direction of the impact is likely to be correct.

The other policy scenarios show slight decreases in total GHG emissions for all freight vehicles.

Context is again important when examining these results and the emissions performance of private vehicles under the same policy scenarios also needs to be considered. Figure 6 provides a similar chart to Figure 5, but with the inclusion (in absolute terms) of the total GHG emissions from private vehicles as well as freight vehicles. The data for freight vehicles are exactly the same as those in Figure 5, but the scale of the plot is changed because of the inclusion of the emissions from private vehicles. Private vehicle CO₂e emissions are just over four times the total CO₂e emissions from all freight vehicles.

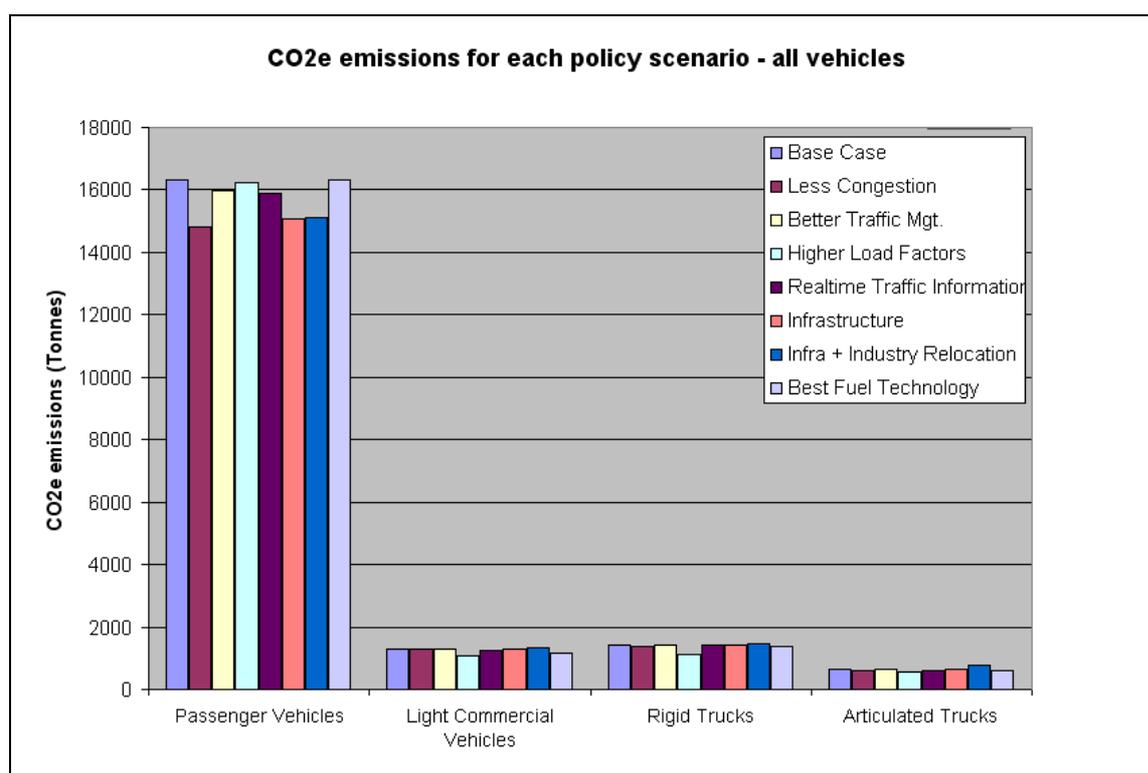


Figure 6 Total modelled CO₂e emissions (in tonnes per day) for all vehicle types under the different policy scenarios

As discussed previously, the ‘reduced congestion’ scenario has the most impact on reducing CO₂e emissions because this has a major effect on the emissions from private vehicles. All of

the scenarios have positive effects on GHG emissions, with the two infrastructure improvement options having the next best effects again due to improvements in private vehicle emissions. 'Better traffic management' also provided a noticeable effect on private vehicle emissions, more so proportionately than for freight vehicles. 'Best fuel technology' was applied to freight vehicles only and higher loads factors/larger vehicles had only a small effect due to reduced freight vehicle numbers in the traffic stream.

In terms of the individual greenhouse gases, CO₂ emissions performance was virtually the same as that for CO₂e, not unexpectedly given that CO₂ is the dominant component of CO₂e. 'Higher load factors' reduced CO₂e emissions from freight vehicles by 17.0 per cent, with a 16.6 per cent reduction for LCVs, 20.6 per cent reduction for rigid trucks, and 9.1 per cent for articulated trucks. The corresponding reductions from 'best fuel technology' were, respectively, 6.3, 10.8, 3.2 and 4.2 per cent. The emissions performances for the other components of CO₂e, i.e. CH₄ and N₂O, are worthy of some attention because there are some relative differences in outcomes for the different freight vehicle classes. Figure 7 shows the emissions of CH₄ for freight vehicles under the different policy scenarios, and Figure 8 shows the equivalent plot for N₂O.

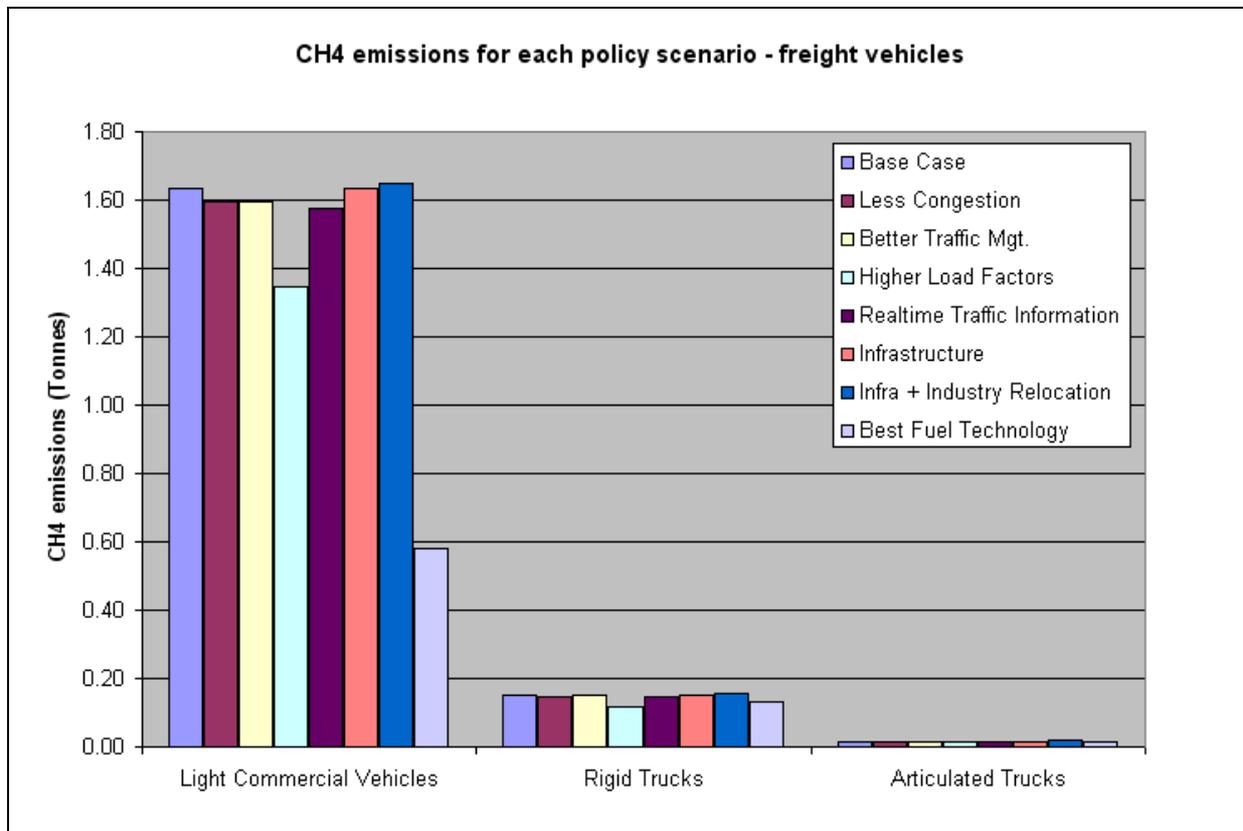


Figure 7 Total modelled CH₄ emissions (in tonnes per day) for each freight vehicle type under the different policy scenarios

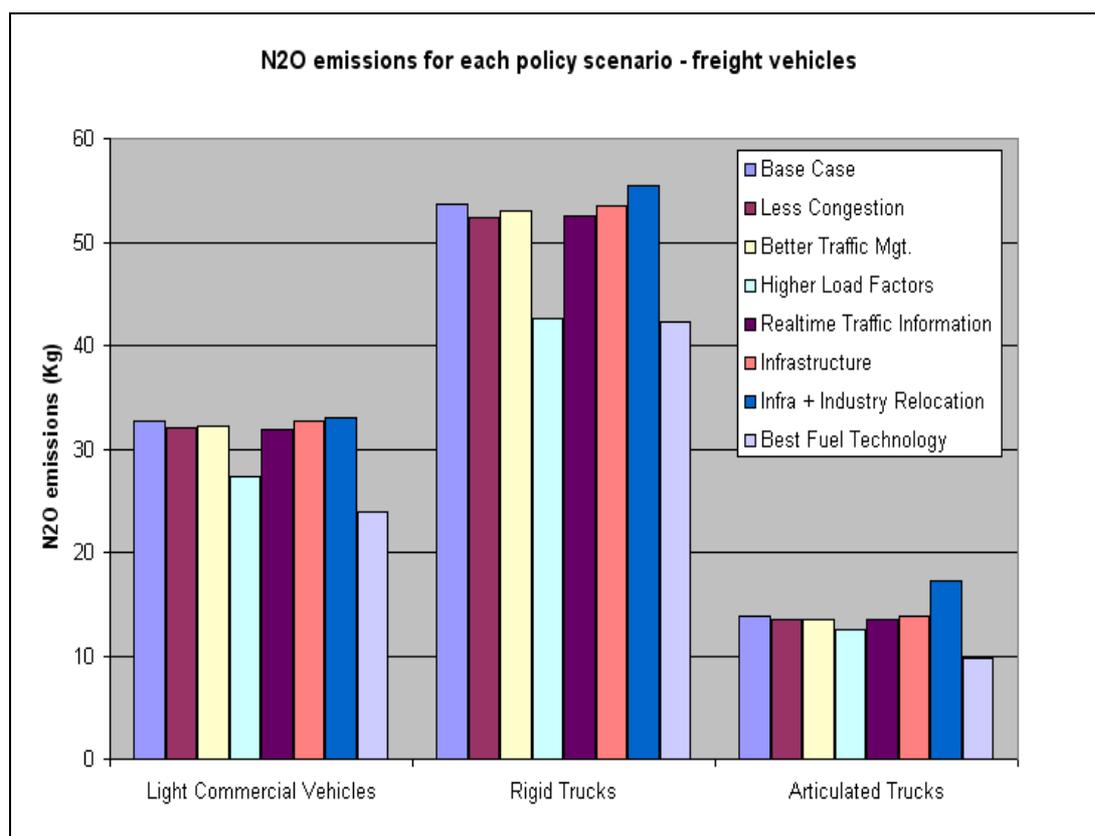


Figure 8 Total modelled N₂O emissions (in tonnes per day) for each freight vehicle type under the different policy scenarios

Methane emissions from freight vehicles (Figure 7) are dominated by the LCVs. The ‘best fuel technology’ scenario achieved a significant reduction in CH₄ emissions from this vehicle class (64.5 per cent) and therefore from freight vehicles generally (60 per cent). ‘Higher load factors’ has the second best impact, 17.6 per cent reduction in CH₄ emissions from LCVs, 17.8 per cent from all freight vehicles. All but one of the other scenarios offered small reductions in CH₄ emissions, of the order of 1-4 per cent. The exception was the ‘infrastructure and land use change’ scenario, which for the modelled case yielded a small increase (1.4 per cent for all freight vehicles). For the N₂O emissions, as shown in Figure 8, the rigid truck class was the largest contributor amongst the freight vehicles. ‘Higher load factors’ and ‘better fuel technology’ had roughly equal impacts on N₂O emissions from RTs (20.7 per cent and 21.0 per cent respectively), but over all of the freight vehicles ‘higher load factors’ reduced N₂O emissions by 17.7 per cent whilst ‘best fuel technology’ reduced them by 24.0 per cent.

Discussion and conclusions

The study has important implications both for policies and the way their impacts might be modelled: These can be summarised into the following categories.

Policy conclusions

Relative impacts of policies on urban freight emissions. While all but one tested scenarios, produced some improvements in GHG emissions the most successful policy options for reducing GHG emissions from freight transport were 'higher load factors' and 'best fuel technology'. These two policy options also lead to the best performances in the air quality emissions

Both were directed at freight transport alone and could be encouraged by incentives for carriers and shippers. A range of policies from city logistics to new fuel standards is available. Moreover consideration of the model structure by the study team leads us to expect that a combination of these two scenarios would be additive and could lead to quite significant reductions in GHG emissions from freight vehicles. Policies to encourage replacement of vehicles could lead to more fuel efficient and larger vehicles capable of carrying high loads in line with trends to larger vehicles. At the same time positive impacts of higher loadings signals potential GHG problems due to low loadings from just in time operation.

Impacts on total fleet emissions. In terms of total GHG emissions from road transport, the scenario leading to the largest overall reductions in GHG was that of 'less peak period traffic congestion'. This policy option was proposed as a means of improving the emissions performance of freight vehicles. There is measurable reduction of GHG from free flowing freight traffic but the major reduction stems from less passenger vehicles. We believe the suggested 15% reduction is a realistic target. Note that this reduction in peak hour traffic may assisted by incentives to shift some travel from the peaks. Peak road use pricing could produce such a shift. However it also might be produced by a basket of measures from improved public transport to parking restrictions at destinations. As an overall reduction in congestion represents another largely independent dimension of policy 'higher load factors' and 'best fuel technologies' would be additive on top of the effect of reduced congestion. Indeed, reduced congestion could be a powerful enabling policy in terms of achieving higher load factors. A range of freight management practices, to increase loads should be easier to implement and more successful if there was less congestion. For example, fitting in more pickups and deliveries and thus getting better load factor while still meeting time constraints would be easier if there was less congestion.

Variability with location and time of day. The study showed that the impacts of policies vary with location and with time of day. Such variation is clearly important for air quality outcomes since the location of emissions in part determines location of air pollutant concentrations and hence population exposure. However it can also be important for GHG. Location of measures, such as new traffic management measures or new infrastructure will help determine to total GHG impact of the initiative. Similarly targeting time of day initiatives can result in more GHG savings. Thus time and location should be considered in assessment of potential policies.

Modelling implications

Modelling policy outcomes. Modelling outcomes, both allowed us to make use of data which only provided numbers of freight vehicle trips by origin-destination and provided a rich set of results for strategic level modelling as each outcome scenario represents multiple policies.

'What if' scenarios. In view of current rapid changes in urban freight which may even be uncoupling the link between freight demand and GDP modelling based on trends from passed behaviour could be unreliable. A 'what if' model which looks at the effect of specifically targeted initiatives of GHG is of value in that situation.

Network level modelling. The study successfully demonstrated that impacts of policy are spatially sensitive and therefore a network level model is more useful for policy assessment. This is true for all traffic but particularly true for freight traffic.

Applicability to urban Australia. It is very likely that the results of the major policy scenarios are broadly applicable to other large Australian cities. It is certainly likely that better logistics leading to trip reduction and better fuel efficiencies would apply. While Sydney is currently more congested than other cities, Brisbane and Melbourne are catching up, so it is also likely that congestion reduction would have a significant effect. However to model spatial and temporal variation GHG emission and exposure of population to air pollution it would be necessary to specifically apply the modelling framework. The detailed base results for Sydney provide the opportunity for data transfer to compensate for lack of data elsewhere.

Overall the results show the advantage of a multi-pronged approach to reducing emissions from urban freight. Underlying policies for reducing traffic congestion as a whole targeted at all road users might be overlaid with specific urban freight policies targeted at improving load factors and getting best fuel technology vehicles into the fleet. Such policies would address direct aspects of factors affecting emissions from urban freight and be additive and complementary. Policies to encourage purchase of new vehicles and policies targeting peak hour congestion would be good starting points.

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