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Modeling Australian road transport emissions till 2025

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Abstract

The contribution of the road transport sector to local air pollutants is significant in urban areas. Also, road transport has been a major source of greenhouse gases in OECD countries. In Australia, road transport was responsible for 12.9% of total national greenhouse gas emissions in 2000. This paper aims at determining the criteria air pollutants and greenhouse gas emissions from the road transport sector in Australia. Transport activities are projected from a bottom-up approach for a modeling period from 2000 to 2025. Instead of using standard drive cycle emission factors, attempts have been made to quantify real-world on-road emissions. Results have been compared with the findings from existing studies. It was found that the emission of local air pollutants would be decreasing because of the new vehicle emission standards to be adopted and by 2025. CO, HC, NO_x and PM_{10} emissions would be significantly lower than the current level. Among the greenhouse gases, CH_4 and N_2O emissions are expected to decrease. The tailpipe CO_2 emission would stabilize or increase at a very slow rate, because of the expected increase in fuel efficiency. The equivalent CO_2 emission considering the global warming potential of CH_4 and N_2O is also predicted to stabilize.

Keywords: Road transport emission, green house gas, Australia.

1. Introduction

The importance of emissions from the road transport sector within the overall air pollution scene has grown substantially in recent decades. Transport is responsible for an increasing share of energy related CO_2 emission (International Energy Agency 1997). In Australia, the transport sector's share was 14.3% of national greenhouse gas emissions in 2000. Road transport alone was responsible for 12.9% of net national emissions

(Australian Green House Office 2002). Motor vehicles' contribution to local air pollution has also been significant, with 35%, 78% and 62% of HC, CO and NO_x emissions respectively in four major cities coming from the vehicle travel activities (Department of Transport and Regional Services and Environment Australia 2003). With this background this paper aims to forecast the criteria air pollutants, HC, CO, NO_x and PM_{10} and greenhouse gases CO_2, CH_4 and N_2O for a period up to 2025.

2. The model

A bottom up approach has been considered to model the emissions. Our model consists of three interconnected modules: travel activities module, fuel module and emission module. Various components of the model are depicted in Fig. 1 and Table 1.

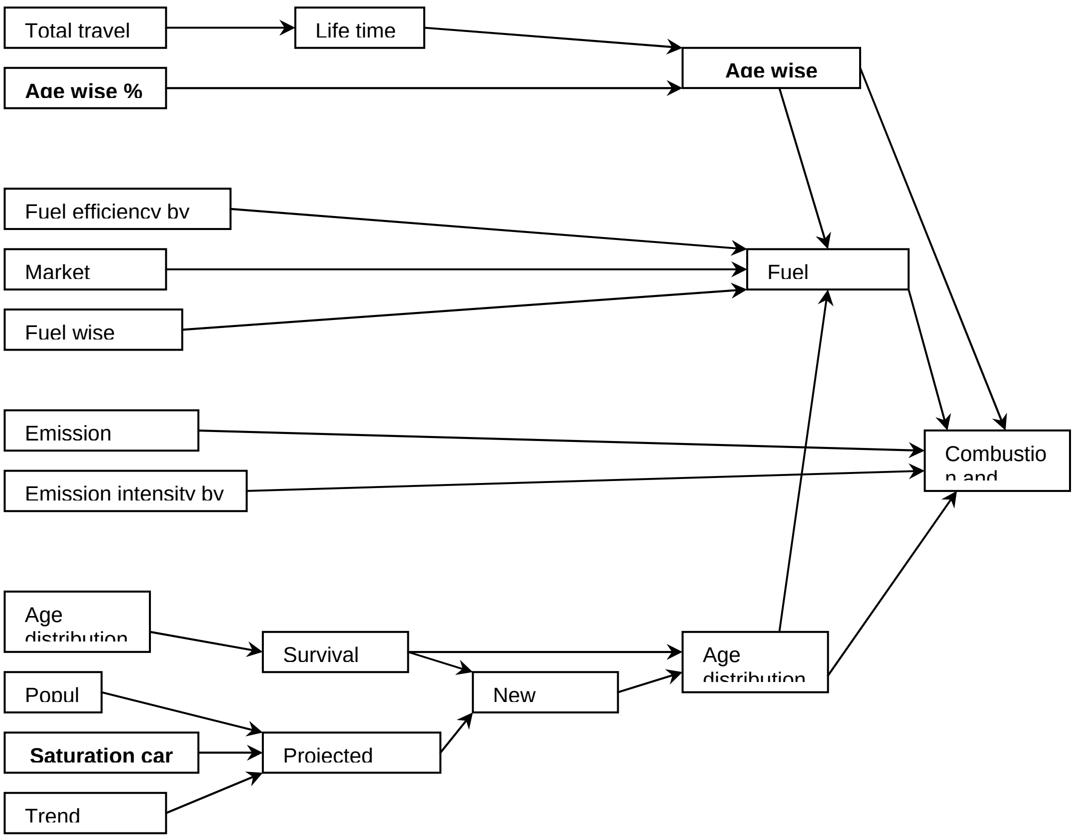

Fig. 1 Model framework

Passenger vehicles, light commercial vehicles, rigid trucks and articulated trucks are the vehicle segments considered[1]. Within the passenger vehicles, emission performance of different size classes has been modeled as well. Passenger vehicles have been segregated into five different classes: small, medium, upper medium (UM), luxury and four wheel drive sport utility vehicles (4WD).

[1] Motor cycles and buses have not been considered, as reliable emission factors are not available for Australia, also their contribution to total emissions is very small, and is not predicted to increase much.

Table 1
The emission model

Module	Output parameters
Travel activities module	Segmentation Age mix Vehicle travel activity
Fuel module	Fuel mix Fuel efficiency
Emissions module	Age wise emission intensity Vintage wise emission intensity

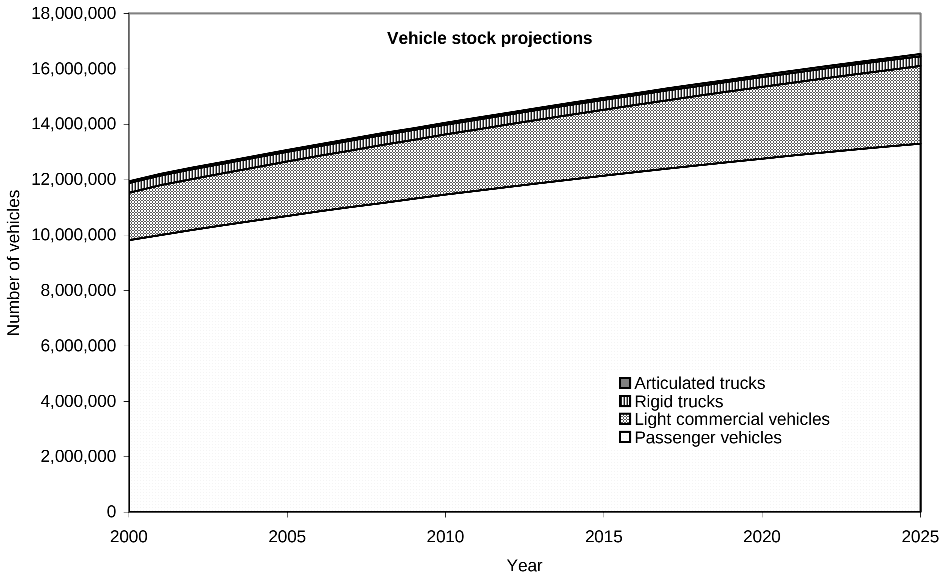

Fig. 2. Projected vehicle stock breakdown

Historical data from 1948 to 2001 on the number of vehicles belonging to the four different vehicle segments are available in Australian Bureau of Statistics database (Australian Bureau of Statistics 1948-2003). These data have been analyzed to determine the trend of growth for the commercial vehicles (light commercial vehicles, rigid trucks and articulated trucks). S shaped growth curve has been found to be satisfactory for rigid trucks (R^2=0.98), whereas light commercial vehicles showed a linear trend. These trends are extrapolated to get future stock of rigid trucks and light commercial vehicles. Linear trend for the light commercial vehicles is maintained as they are not expected to saturate during the modeling period, as a result of growth in e-commerce. Articulated trucks show a good linear fit as well for the available data points, however, a slightly concave curve has been fit (still R^2=0.99), to accommodate the expected productivity increases in the articulated trucks. ABS classification of different types of trucks has not been consistent through the years, therefore some adjustments in the data had to be made. Campervans, available from 1995, has been added to other trucks category, as prior to 1995, they belonged to other trucks category. Time series projection of other trucks gives rise to an S shape as well (R^2 = 0.98). As specific emissions data are not available on other trucks, trucks in this category have been added to rigid trucks to get total rigid truck stock during projection years.

For passenger vehicles, a car-ownership model (Bureau of Transport and Communications Economics 1995, Zachariadis et al. 1995) is developed. This model assumes an S shaped car ownership per 1000 people, indicating that the growth rate in car ownership would fall with time. This is an observed trend in the OECD countries. Australian passenger vehicle ownership is also expected to saturate during the modeling period (R^2=0.99). Car ownership in each of the model years multiplied by the projected medium range projection of population from the ABS gives the passenger vehicle stock each year. The projected segment wise vehicle stock is presented in Fig. 2.

The vehicle size breakdown within the passenger vehicles is not directly available in ABS database and a different methodology has been followed to get them through making use of survival functions and new vehicle sales. As survival functions are also required to determine the age mix of vehicles during the projection period, we model them separately.

ABS publishes the number of vehicle registrations for different vehicle segments in two, three, four or five year vintage bands, based on manufacturing year in its motor vehicle census series. The band wise breakdown is converted to year wise breakdown, with the number of vehicles in the band divided equally to each year within the band and then regressing to smoothen the step function. This gives vintage wise distribution of vehicles for the available census years. Survival patterns of the models manufactured immediately prior to the census year have been investigated by tracking the registration of those models in subsequent census years. The models tracked to determine the survival function were manufactured in 1984, 1987, 1990 and 1993.[2] Fig. 3 presents the survival functions. We assume same survival function for all types of passenger vehicles, but different functions for different vehicle segments.

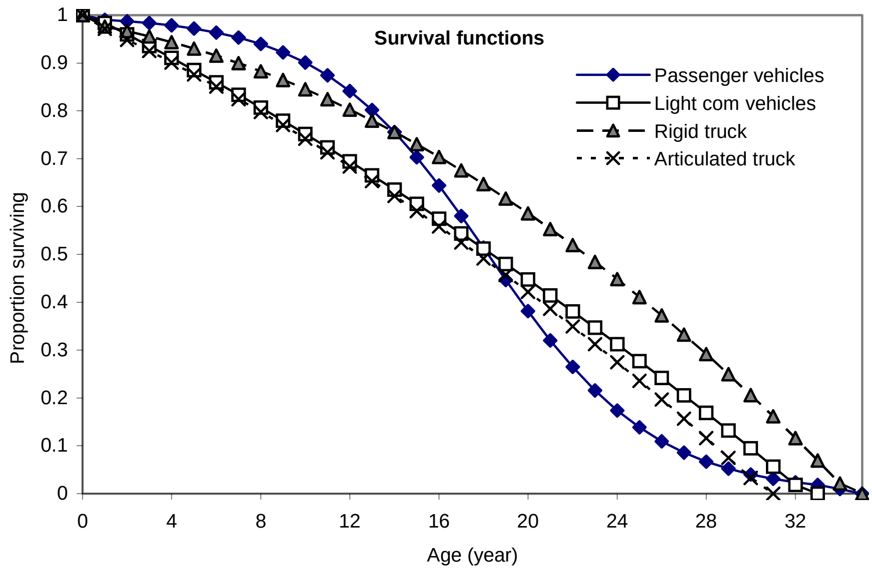

Fig. 3 Survival function for different vehicle types

[2] Later year models have not been incorporated, as they cannot substantially improve the survival models because the 'tail' of their survival function is not observable yet.

The survival function for passenger vehicles, along with the VFACTS (Polk Australia 2003) database gives size wise breakdown within the passenger vehicles segment. VFACTS contains breakdown of new passenger vehicles sales in terms of vehicle size, model, make etc, but are available from only 1991. Because the passenger vehicles have an estimated survival up to 30 years, new vehicle sales or registration data for at least 30 years prior to 2002 (i.e, from 1972) is needed to estimate the vehicle mix in 2002. We made a few assumptions to get around the data availability problem.

1. New passenger 4WD vehicle sales was zero in 1983 and increased linearly till 1991 when sales data is available.
2. New luxury vehicles have a market share of 10% all through the modeling period
3. Pre-1991 new small, medium and upper medium cars had same market share as 1991-1994.

Because new vehicle registration data is available from the ABS resources, incorporating these assumptions on market share of different sizes of passenger vehicles from 1971 provides a picture of the age and vehicle mix in 2002. For future market share we run three scenarios with various 4WD market penetration till 2025, however, we present here the base case where growth of 4WD passenger vehicles sales will continue till 2011 when it will stabilize at 34% of new passenger vehicle market share. Fig. 4 presents the breakdown within the passenger vehicle group.

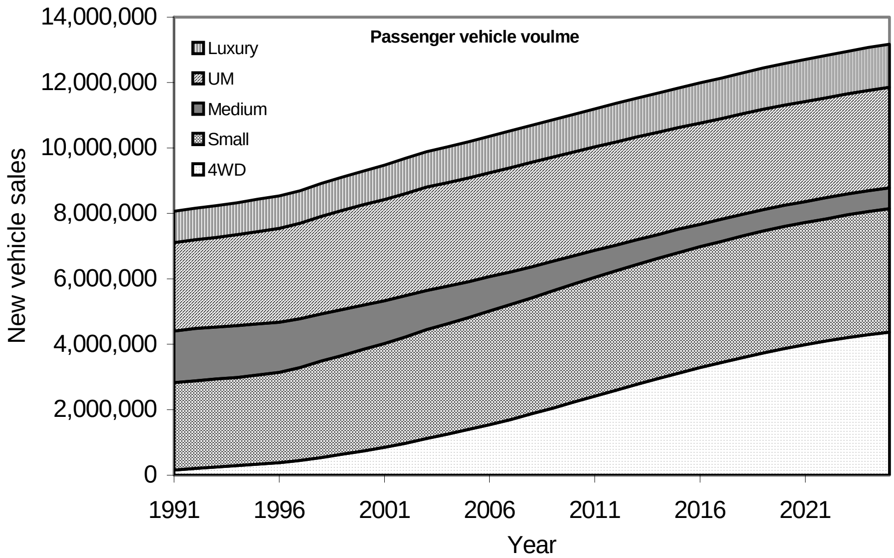

Fig. 4. Projected Passenger vehicles breakdown

Within the light commercial vehicle segment, 4WD pick ups have a significant share. Market share of 4WD pick ups within the light commercial vehicle segment has remained constant at 35% during 1991 to 2002. Therefore for future, same market share has been assumed.

New vehicle sales in a given year are found from the projected vehicle stock and proportion of previous vintages still surviving that year (from the survival function):

$$n_{ij} = N_{ij} - \sum_{k=j-33}^{j-1} n_{ik} S_{ijk}$$

Where, n_{ij}, n_{ik} = number of new vehicles of type i sold in year j, k
N_{ij} = number of vehicles of type i in projected in year j
S_{ijk} = proportion of vehicles of type i, produced in year k, surviving in year j

New vehicle sales and previous vintages still surviving, together, give a complete age wise distribution of vehicles during the modeling horizon (Fig. 5).

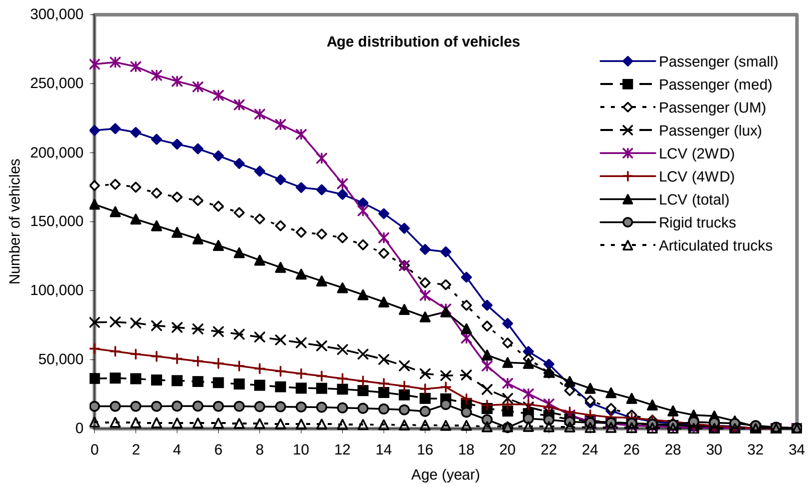

Fig. 5 Age wise distribution of different vehicle classes in 2020

Age wise travel activity of different types of vehicles has been collected from SMVU and other available literature (Commonwealth Scientific and Industrial Research Organization 2003, Cox et al. 1999). The average VKT for passenger vehicles, light commercial vehicles and rigid trucks are not expected to change much in near future. However, articulated truck travel has been ever-increasing, and therefore a linear increase of 1% per year has been assumed (similar to Bureau of Transport and Regional Economics 2002).

Existing information of fuel mix is available within the vehicle segments. Petrol and diesel are still dominant in Australian road transport sector. Passenger vehicles are almost entirely dependent on petrol, whereas articulated trucks mostly use diesel as fuel. As of 2000, 81% of rigid trucks use diesel and 71% of light commercial vehicles use petrol. LPG is currently used by some light commercial vehicles and passenger vehicles, although the proportion of LPG used is still very small in comparison to petrol.

For articulated and rigid trucks, the fuel mix has been assumed to contain only petrol and diesel during the modeling period and Capalad's (Capalad 2000) projections have been used. For light commercial vehicles Capalad's projections have been modified to include a 1% growth in penetration of LPG. By 2025, light commercial vehicles class would thus be fueled by diesel (38%), petrol (42%) and LPG (20%). For passenger vehicles, petrol has been assumed to continue its dominance during the modeling period. Because no data has been available on petrol and diesel use of different size classes, certain assumptions have been made. LPG has been solely assigned to upper medium (UM) classes (7%) maintaining a constant market share. Diesel has been assigned solely to 4WD vehicles. The penetration of diesel in the 4WD market would follow the same as in the light commercial vehicles.

For fuel economy projections of cars, the NAFC target of 6.7 l/100 km by 2010 (Environment Australia 2003) has been modeled for passenger vehicles. A modification factor of 1.06 has been used to account for on-road performance. For commercial vehicles, it is assumed that the improvements in fuel efficiency due to technological innovations would be balanced by increasing payloads. Although some reports consider fuel efficiency deterioration with age of the vehicles, there has not been any strong proof for this assumption (Dynamic Transport Management Pty 1996), therefore we neglected the any deterioration of fuel consumption performance with age.

Emission intensities of local pollutants for current Australian vehicles have been derived from the available literature (National Environment Pollution Council 2000, Department of Transport and Regional Services 2001, Federal Office of Road Safety 1996, Watson et al. 2000, Watson 2001). For future emissions of passenger vehicles, it is assumed that new vehicles would emit 50% of the specified standard and will emit as much as 90% of the standard at the specified 80,000 km odometer reading with deterioration in emissions performance. It has also been found that the Federal Test Procedure test cycle results prescribed by the Australian Design Rules to measure emissions from motor vehicles do not simulate well real life city driving. AUC conversion factors (Watson 2001) have been used to get the real emission picture. For commercial vehicles MOBILE 6 factors (USEPA 2003) have been used. Effects of the proposed ADRs to be implemented have been modeled as well. While deterioration in emissions performance is a key feature of petrol vehicles, NEPC reported that no such deterioration is observable in the diesel-fueled vehicles.

Emissions of N_2O and CH_4 from passenger vehicles have been difficult to estimate [20]. A constant N_2O and CH_4 emission factors as suggested by the NGGIC (National Greenhouse Gas Inventory Committee 1996) would lead to unnecessarily high emissions. Again, N_2O and CH_4 emission to be expressed as a ratio of NO_x and HC would lead to too small emissions, because NO_x and HC emission standards would go down with new ADR standards, but N_2O and CH_4 may not go down as much. In the end it has been assumed that N_2O and CH_4 would vary as a proportion of NO_x and HC respectively, but that proportion would increase as NO_x and HC emissions decrease. Detail of the model methodology is available in Wadud (2003).

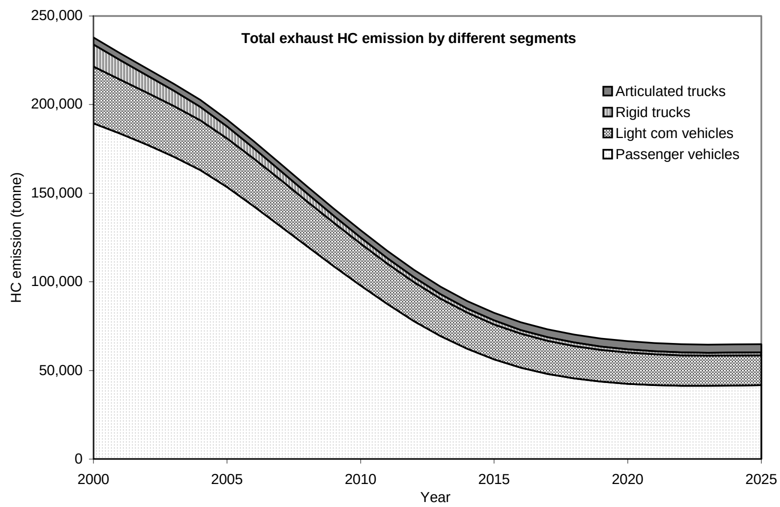

Fig. 6. Exhaust HC emission from all vehicle classes

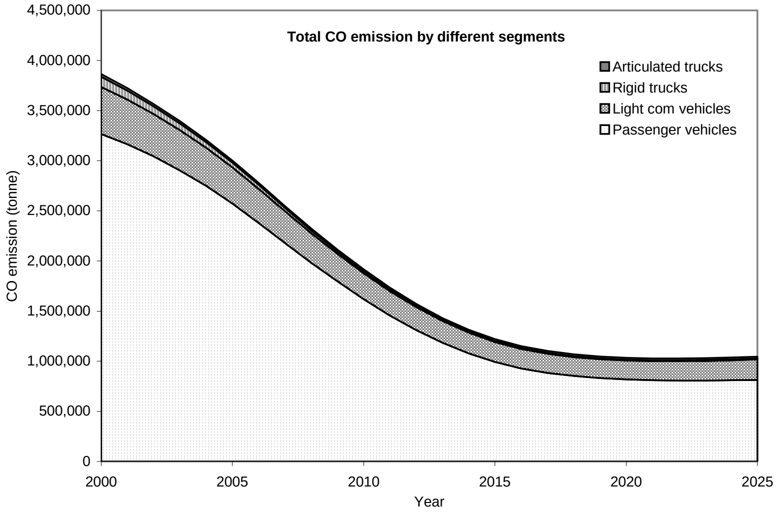

Fig. 7. CO emission from all vehicle classes

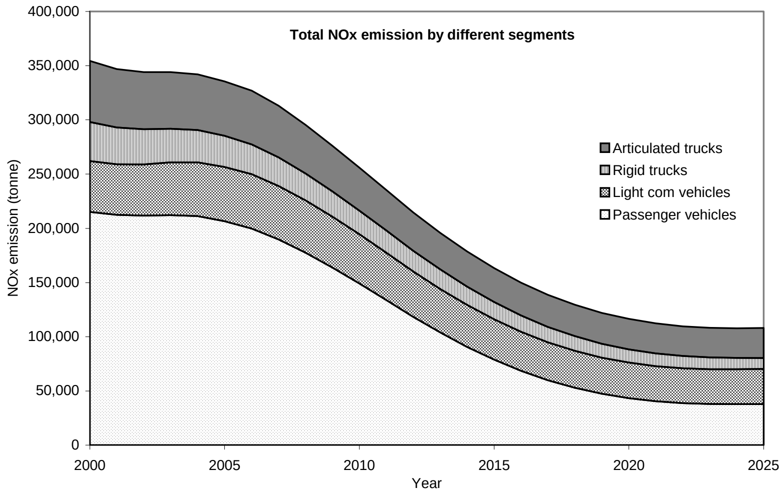

Fig. 8. NO_x emission from all vehicle classes

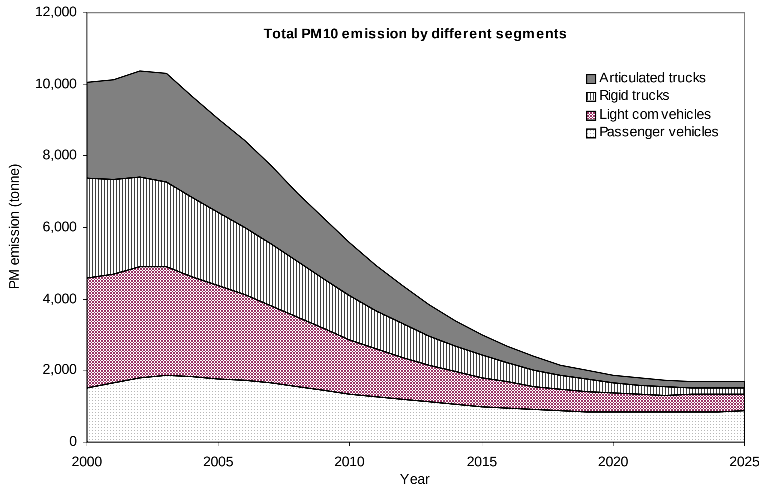

Fig. 9. PM_{10} emission from all vehicle classes

3. Results

Figs. 6 through 13 present the emissions of different pollutants from the motor vehicles by different segments. For criteria air pollutants, it is predicted that the emissions will decrease significantly (around 70%) during the modeling period. This is the expected outcome of the proposed new emission standards to be implemented in Australia till 2007. Any stricter emission standard to be implemented after 2007 would reduce the emissions even further. Passenger vehicles would continue to be the major emitter, although commercial vehicles' share would increase in the emissions of HC, CO and NO_x (Figs. 6-8). Because diesel vehicles contribute to emission of PM_{10}, and 4WD vehicles are increasing (which run more on diesel), passenger vehicles would increase its share in total PM_{10} emission (Fig. 9).

The emissions of greenhouse gases are expected to increase initially but then stabilize at the end of the modeling period. The CH_4 emission would decrease significantly (54%, Fig. 10), so would N_2O (53%, Fig. 11). The contribution of N_2O and CH_4 to total greenhouse gases will not be much, even after considering the global warming potential of these two gases (310 and 21 respectively). In fact, their total contribution to greenhouse gases would decline from 7.5% in 2000 to 3% in 2025.

Because of fuel efficiency improvement measures for passenger vehicles, CO_2 emission is expected to be in balance with the increased vehicle volume. However, for commercial vehicles, the CO_2 emission is projected to be increasing (Fig. 12). It is likely that total CO_2 emission would decrease if fuel consumption pattern for commercial vehicles can be reduced by the same amount as passenger vehicles. Because CO_2 emission dominates the greenhouse gas scenario, overall, greenhouse gas emissions are expected to stabilize or rise very slowly by 2025 (Fig. 13). An increase of 14% over 2000 emissions is projected. Majority of this increase takes place before year 2008.

Petrol continues to be the dominant contributor to emissions from passenger vehicle class, although diesel will have its dominating share in commercial vehicles. Penetration of CNG and alternate fuel vehicles has not been considered at this stage.

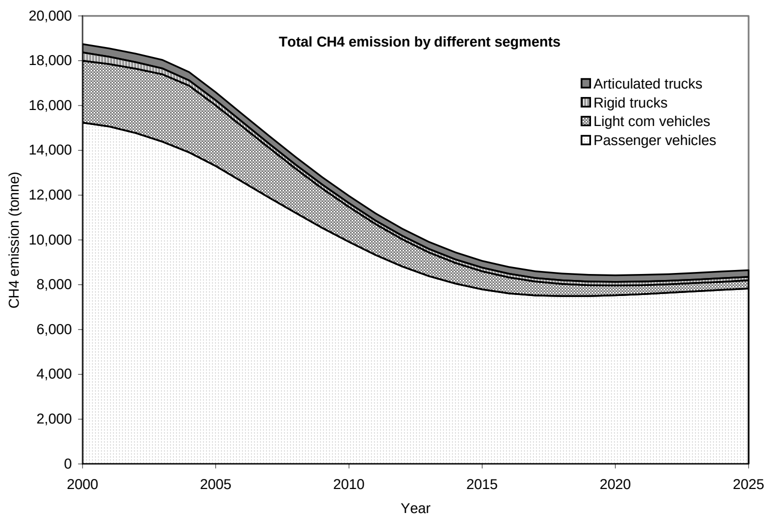

Fig. 10. CH_4 emission from all vehicle classes

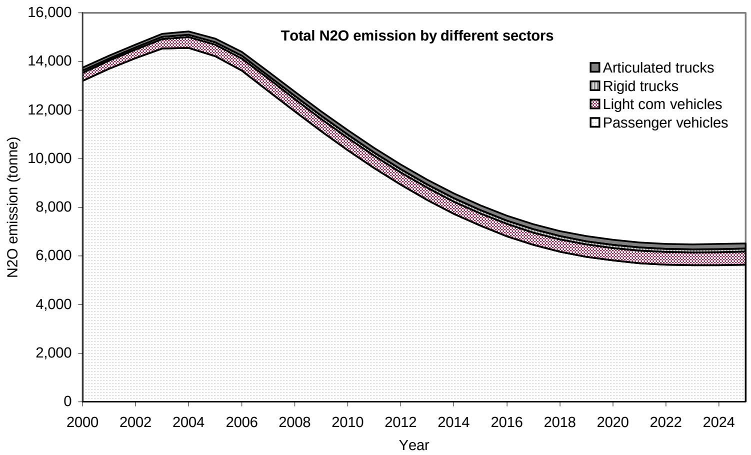

Fig. 11. N_2O emission from all vehicle classes

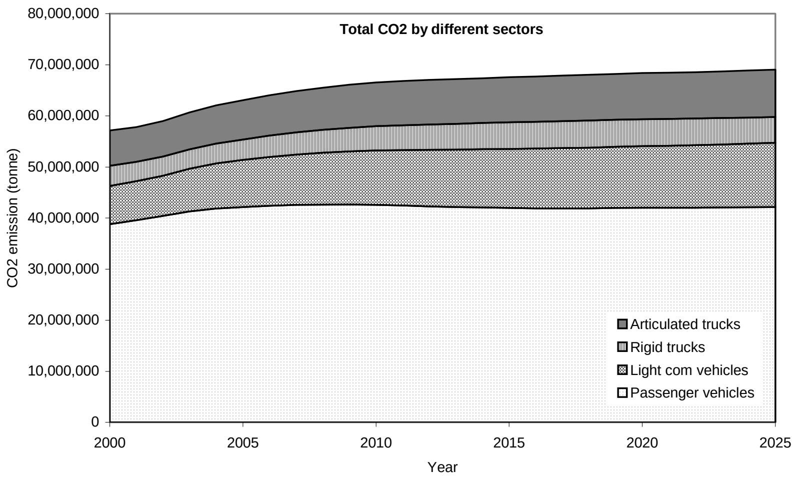

Fig. 12. CO_2 emission from all vehicle classes

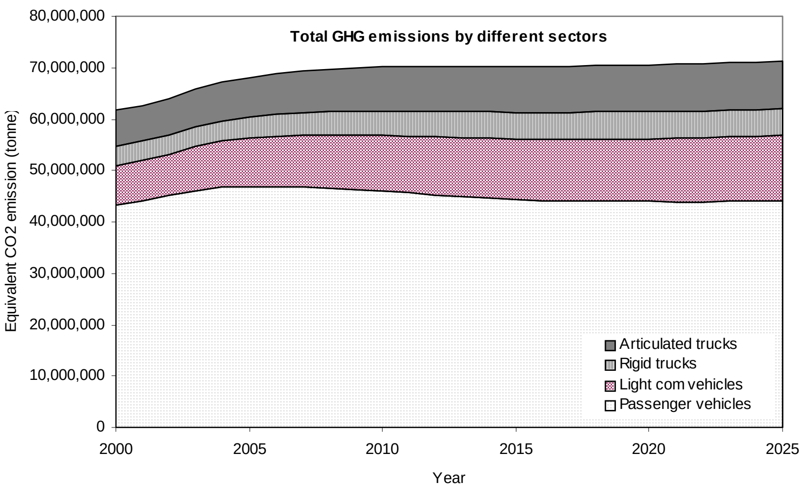

Fig. 13. GHG emission from all vehicle classes

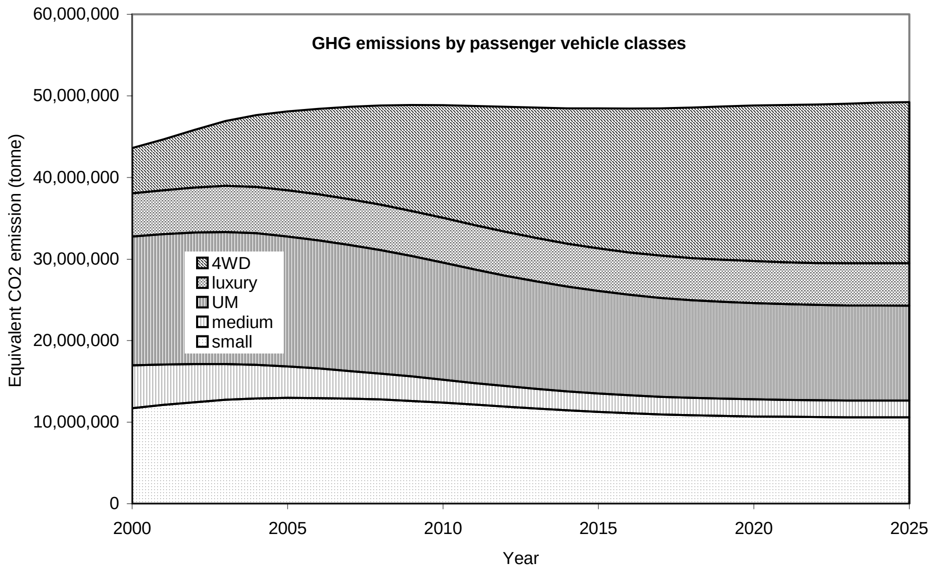

Fig. 14. GHG emission from passenger vehicle classes

Within passenger vehicle class, the 4WD vehicle stock is expected to increase at the expense of other passenger vehicles. This translates into increasing share of emissions attributed to 4WD passenger vehicles. Also, because 4WD vehicles are more fuel intensive, the CO_2 emission increases more than proportionally (Fig. 14).

Table 2.
Emissions comparison between 2000 and 2025

Pollutant	Emission (tonne)		Change (%)
	2000	2025	
HC	237858	64875	-73
CO	3864907	1045723	-73
NO_x	354451	107922	-70
PM_{10}	10062	2936	-71
CH_4	18744	8654	-54
N_2O	13742	6515	-53
CO_2	57136034	69071110	+21
GHG	61789584	71272478	+15

Table 3.
Passenger and commercial vehicles' share in emissions

Polt.	Passenger vehicles share (%)			Commercial vehicles share (%)		
	2000	2025	change	2000	2025	change
HC	80	64	-	20	36	+
CO	84	78	-	16	22	+
NO_x	60	35	-	40	65	+
PM_{10}	15	30	+	85	70	-
CH_4	81	91	+	19	9	-
N_2O	96	87	-	4	13	+
CO_2	68	61	-	32	39	+
GHG	70	62	-	30	38	+

4. Conclusions

Exhaust emissions of criteria air pollutants HC, CO, NO_x and PM_{10} from Australian road transport sector are expected to decrease significantly by year 2025, as a result of new emissions standards to be implemented till 2007. More stringent emissions standards beyond 2007 would decrease the emissions even further. Emission of CO_2 is expected to increase, primarily as a result of increasing vehicle stock, although two other greenhouse gases, CH_4 and N_2O would decrease significantly. 4WD passenger vehicles would continue to increase its share in emissions of all type of pollutants, despite the improvement of emission performance. Table 2 summarizes the emission level of different pollutants in 2000 and 2025. The change in share of emissions of passenger and commercial vehicles is given in Table 3. Improvement in the fuel efficiency of commercial vehicles and rapid penetration of alternate fuel vehicles would possibly bring down the greenhouse gas emissions further. It is important to recognize that the model does not predict the level of congestion that may occur in city roads resulting from the predicted increased number of vehicles on the roads. Increased congestion may lead to higher emissions through higher travel time and the stop-and-go nature of traffic, yet it may decrease emissions as congestion would encourage people to forego some leisure travel. Modeling future congestion and its effect on emissions is left as an avenue for further research.

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Acronyms

4WD	Four Wheel Drive
ADR	Australian Design Rule
AUC	Australian Urban Cycle
BTRE	Bureau of Transport and Regional Economics
CH_4	Methane
CO	Carbon-mono-oxide
CO_2	Carbon-di-oxide
FTP	Federal Test Procedure
GHG	Greenhouse gases
HC	Hydrocarbons
NAFC	National Average Fuel Consumption
NEPC	National Environment Protection Council
N_2O	Nitrous Oxide
NO_x	Nitrogen Oxide
PM_{10}	Particulate matter less than 10 μg
SMVU	Survey of Motor Vehicle Use
UM	Upper Medium