Updating the Perth Vehicle Emissions Inventory

2011/2012

Department of Environment and Conservation

Author

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Executive Summary

Emissions from on-road vehicles have been one of the dominating sources of air pollution in Perth. The W.A. Department of Environment Regulation (DER) uses an in-house model to estimate particles, air toxics and photochemical smog emissions. The original inventory was based on the year 1992/1993, with a later update based on the 1998/1999 period. A diffuse emissions study inventory was also developed by a consultant on behalf of DER based on the 2004/2005 period. In 2009, inventories were prepared for 2001/2002 and also 2006/2007. The vehicle emissions inventory results presented in this report are based on 2011/2012 emissions modelling.

The 2011/2012 inventory has estimated total annual emissions of principal pollutants from all vehicle categories for the Perth Airshed and results were compared with 2001/2002 and 2006/2007 inventories. A substantial decrease in annual emissions of CO and VOC was found compared to the last inventory (2006/2007), with slight drop in NO_X emission, notwithstanding the increasing VKT during this period. The estimated annual VOC emissions arise primarily from petrol fuelled vehicles. Passenger vehicles generate the majority of VOC and CO emissions in the Perth accounting for 76.5 percent and 76.2 percent of total emissions respectively. Motor cycles are estimated to account for only 1.7 percent of total NO_X emission, whilst they make up 5 percent of the registered fleet.

The magnitude of evaporative emissions under different situations such as winter, summer and high-oxidant scenarios was examined and evaporative emissions weightings calculated from these scenarios. The total exhaust VOC emissions have decreased by about 38 percent since 2001, while evaporative VOC emissions have decreased by about 46 percent over this period. Total annual emissions of speciated volatile organic compounds (VOCs) from on-road mobile sources in the Perth Airshed were also calculated from total VOC emissions.

1 Introduction

Of the wide range of sources contributing to the pollutant load in the Perth Airshed, the emissions resulting from motor vehicles have been identified as being the single largest contributor, accounting for approximately 75 percent of the oxides of nitrogen (SKM, 2006). As the number of vehicles and the VKT increase, there is a need to ensure that strategies are in place to manage transport emissions, both in the immediate and long term.

The Western Australian Government’s Department of Environment Regulation (DER) has developed local emissions inventories for air toxics and other air pollutants for Perth. These local emissions inventories are used by the DER in air quality modelling programs.

The original inventory was based on the year 1992/1993, with a later update based on the 1998/1999 period. A diffuse emissions study was also undertaken by a consultant on behalf of DER based on the 2004/2005 period. In 2009, an inventory was prepared for 2001/2002 and also 2006/2007. The vehicle emissions inventory results presented in this report are based on 2011/2012 emissions modelling.

1.1 Vehicle Emissions Inventory Years

The vehicle emissions inventory results presented in this report are emissions modelled for the 2011/2012 calendar year based on node-and-link model data of the region's significant roads provided by Main Roads WA. These data represent the road network for the Perth Airshed, for the years 2001, 2006, 2011, 2016, 2021 and 2031.

1.2 Study Region

The Perth Airshed study region measures 90 km east-west by 162 km north-south, which corresponds to a total area of 14,580 km^2 (Figure 1). In order to account for spatial variation in emissions over the region, the region was subdivided into a network of grid cells. Emissions were spatially allocated to grid cells measuring 3 km by 3 km. For the Perth Airshed study region, this approximates to 30 by 54 grid cells or a total of 1620 data points across the spatial domain.

2 Methodology

2.1 Spatial Allocation of Emissions

The vehicle emissions inventory results presented in this report are for emissions modelling of 2011/2012, which are based on a node-and-link model of the region's significant roads using data provided by Main Roads WA. A ‘node’ in this representation is normally a road junction and a ‘link’ is a segment of a road running between nodes.

Road junctions (nodes) and segments of a road running between nodes (links) corresponding to the year to which the road network applies were considered in the inventory modelling. Each link is unidirectional, so that there are two links in the file for any segment of the road network. This matter becomes important when traffic congestion is considered, since a road may experience a morning traffic flow peak in one direction, and an evening peak in the other. In order to use these emission data for the emissions inventory purposes, the road network data was allocated to a grid system where each road link is broken up into sub-links which did not extend beyond the borders of an individual grid square.

2.2 Traffic Volume Variations

Hourly emission variations in an airshed are largely dependent on the hourly variations in behaviour of on-road vehicles, as different vehicle categories have different daily travel patterns. Passenger vehicle numbers generally have dual weekday peaks (morning and afternoon rush hours), while commercial vehicles mainly travel between business hours of the day. One of the limitations in the traffic data used in this study was the lack of sufficient detail on traffic types in the Perth Airshed. The hourly profiles for vehicle activities in the traffic dataset did not differentiate between different vehicle categories. A new method, which facilitates the spectral mixture analysis, was used to extract hourly traffic profiles all vehicle categories from readily available traffic data (Rostampour & Yu, 2009).

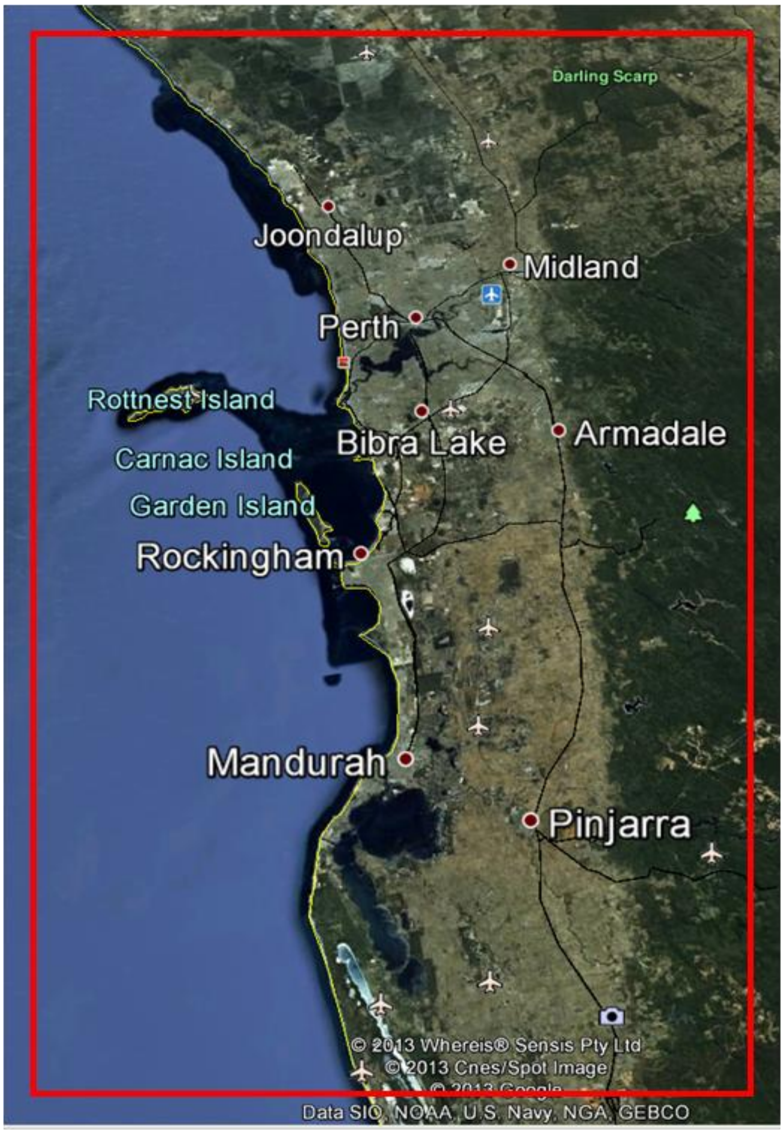

Figure 1: Location of the vehicle emissions inventory study region

2.3 Temporal Variation

Temporal hourly variation data for all fleet categories (i.e. petrol passenger cars; diesel heavy duty commercial vehicles; diesel light duty vehicles; petrol light duty commercial vehicles; and motorcycles) were derived for the Perth Airshed from travel activity data provided by Main Roads WA.

A temporal difference in the vehicle-related emissions was observed for weekdays, Saturdays and Sundays. Significant differences were observed between vehicle emissions on weekends and weekdays due to reduced traffic flow on weekends. The estimated emissions of PM_{10}, NO_X, CO and VOCs (tonne/day) for typical weekday and weekends in the Perth Airshed are illustrated in the Appendix A.

3 Estimated Emissions

3.1 Exhaust emission

Emission factors and VKT are two key parameters required to estimate vehicle emissions. Motor vehicle emissions are estimated from data on spatial VKT by road type and fleet composition, and the relevant emission factors (NPI 2001). Therefore, any increase and decrease in VKT and vehicle emission factors are directly reflected in the vehicle emission estimations.

Five main categories were considered as on-road emission sources: (1) petrol passenger vehicles, (2) petrol light duty commercial vehicles and (3) diesel heavy duty commercial vehicles, (4) diesel light duty vehicles and (5) other vehicles (i.e. motorbikes, campervans, etc). Each category contains several vehicle subcategories based on fuel type and vehicle body code. The composition and behaviour of evaporative emissions for each vehicle and fuel type varies from that of exhaust emissions and as such evaporative emissions are treated as a separate category. The distribution of vehicles based on body type in the Perth Airshed is shown in Figure 2. The percentage change for passenger and commercial vehicles (from total on-road vehicles) between 2007 and 2012 in the Perth Airshed is shown in Figure 3 and Figure 4 (ABS, 2007 and 2012). Statistics shows that since the previous inventory (2006/2007), the number of on-road diesel passenger vehicles has more than doubled and also the number of motorbikes has increased more than 30 percent, whilst the number of petrol commercial and petrol passenger vehicles has decreased 17 percent and 10 percent, respectively. There has been no change in Liquefied Petroleum Gas (LPG) fuelled vehicle numbers

Total estimated annual emissions of CO, NO_X, VOC, SO_2 and PM_{10} from all vehicular categories for the Perth Airshed for 2001/2002, 2006/2007 and 2011/2012 emissions modelling years are shown in Table 1. In the current inventory, a substantial decrease in annual emissions of CO and VOC was found compared to the last inventory (2006/2007), with a slight drop in NO_X emission, notwithstanding the increasing VKT during this period. As shown in Table 1, a small rise occurred in NO_X emissions from 2001 to 2007 (less than six percent) followed by a small change in emissions in 2011/2012. Emissions of SO_2 increased over this period. The reduction in VOC and CO emissions is likely due to newer engine design, where air and combustion temperature increases lead to reduced VOC and CO formation (Reitze 2001). Nevertheless, it should be emphasised that the relationship between VOC, CO and NO_X formation is very complex. It must be noted that more precise estimation of PM_{10} and SO_2 emissions needs to be carried out due to some limitations in the current vehicle emission inventory model and also lack of complete emission information about these pollutants.

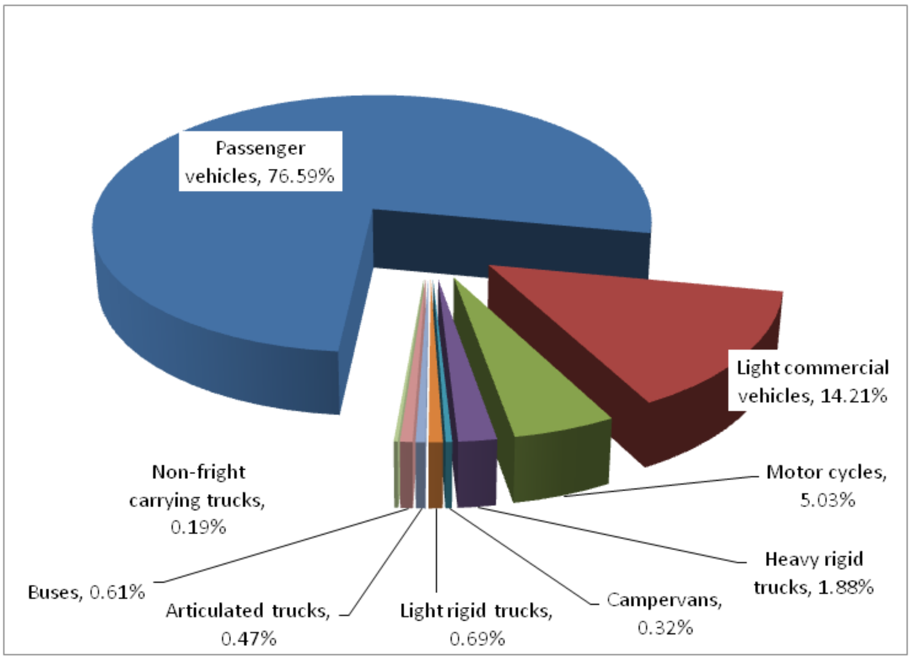

Figure 2: Percentage of total on-road vehicles by body type in the Perth Airshed, 2012

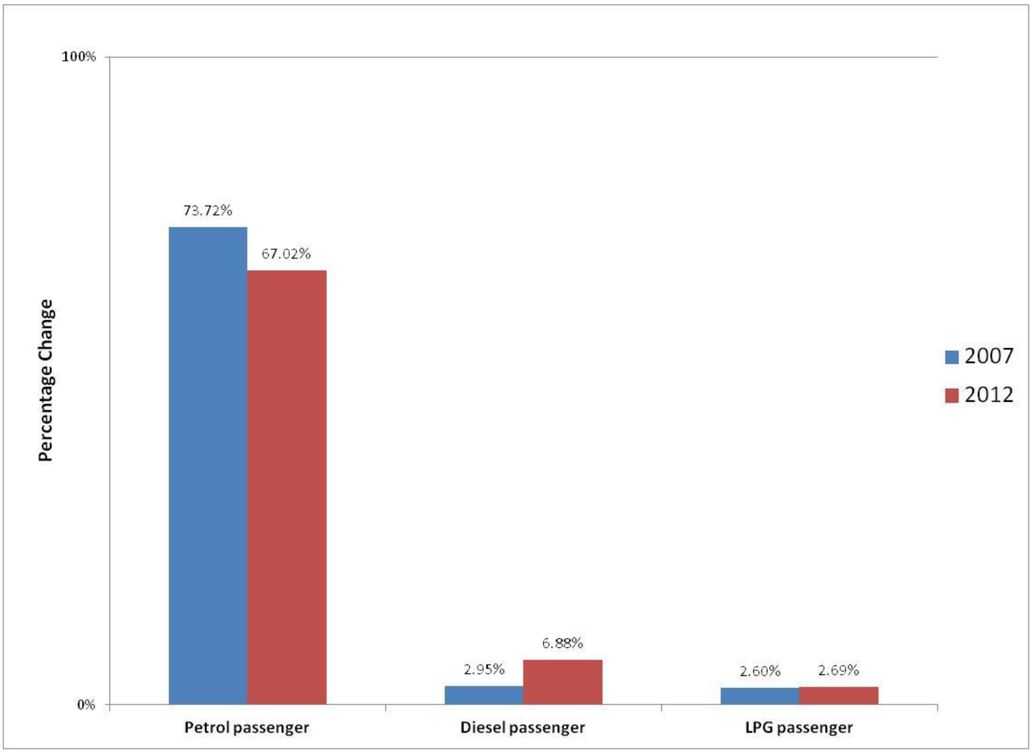

Figure 3: Percentage change for passenger vehicles (from total on-road vehicles) between 2007 and 2012 in the Perth Airshed

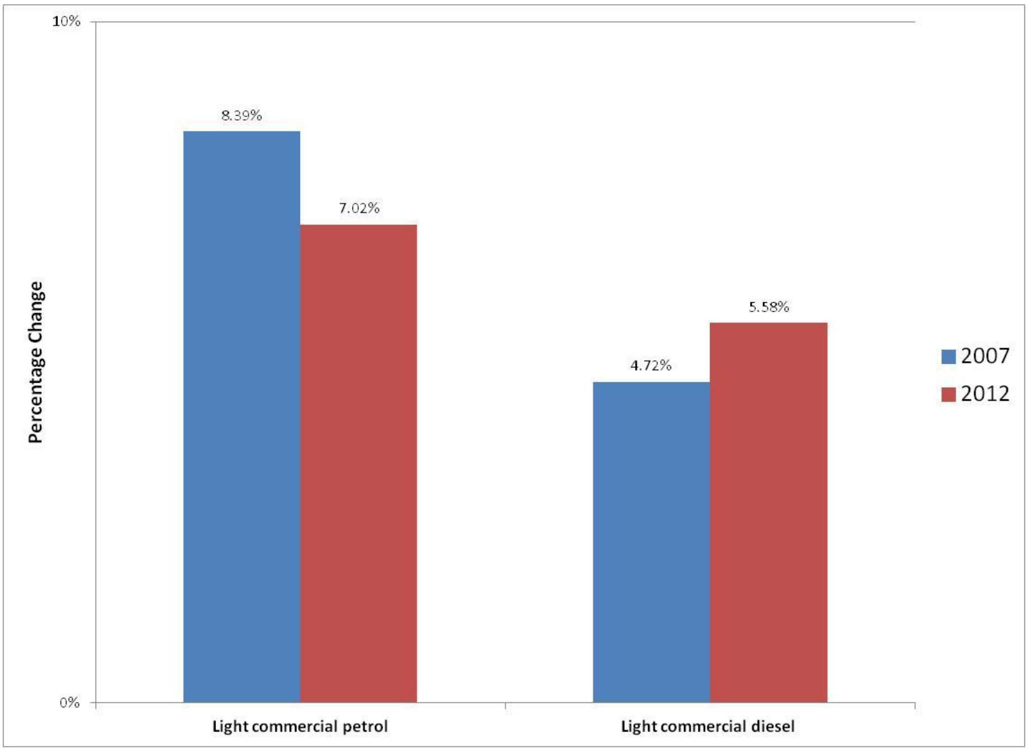

Figure 4: Percentage change for commercial vehicles (from total on-road vehicles) between 2007 and 2012 in the Perth Airshed

Table 1: Annual total emissions of principal pollutants (tonnes/year) from vehicles in the Perth Airshed for 2001/2002, 2006/2007 and 2011 / 2012

	2001/2002	2006/2007	2011/2012
Oxides of nitrogen (NO_X)	15,390	16,302	15,735
Carbon Monoxide (CO)	111,484	100,285	82,108
Sulfur dioxide (SO_2)	164	191	199
Particulate matter (PM_{10})	287	335	204
Total VOCs	16,097	13,404	10,013

3.2 Evaporative Emissions

There are different sources of evaporative (non-exhaust) emissions based on vehicle operating situations such as diurnal, hot soak, running losses, resting losses, refuelling losses and crankcase emissions. Diurnal breathing losses occur as the fuel tank heats up during the day. Resting losses result from vapour permeation and liquid leaks through various parts of the evaporative control system. Hot Soak losses occur after the vehicle has been turned off and result from evaporation of fuel in the engine and fuel delivery system. Running evaporative losses occur as the vehicle is being operated over the road. Refuelling losses are a result of vapour space displacement and spillage. Crankcase losses are primarily the result of defective PCV (Positive Crankcase Ventilation) systems.

Evaporative emissions (except running losses) occur when vehicles are stationary, thus they are not directly VKT-related. In order to quantify diurnal and hot soak losses, some additional vehicular trip data are required including: the number of trip starts, number of trip ends and trip duration information. This information is not currently available for this emission inventory. Therefore, a VKT-based approach, similar to the NSW Metropolitan Air Quality Study inventory, was used to estimate evaporative emission (DECC NSW, 2007).

The magnitude of evaporative emissions under different scenarios was estimated. The evaporative emissions weightings were calculated by determining the average temperature for each day, and comparing this value to averages for winter, summer and high-oxidant scenarios (13°C, 21.5°C and 27°C). A day with an average temperature of 13°C or less added to the sum for the winter day scenario, with an average of 21.5°C added to that for the summer day scenario, and with an average of 27°C or more added to the sum for the high oxidant day scenario. The relationship between temperature and evaporative VOCs is shown in Figure 5. Significant differences were observed between vehicle emissions on typical summer days, winter days and high-oxidant days.

The weighted evaporative emissions, which are calculated from different scenarios, are illustrated in Table 2 for 2001/2002, 2006/2007 and 2011/2012 emissions modelling years. The estimated annual VOC emissions arise almost mostly from petrol fuelled vehicles.

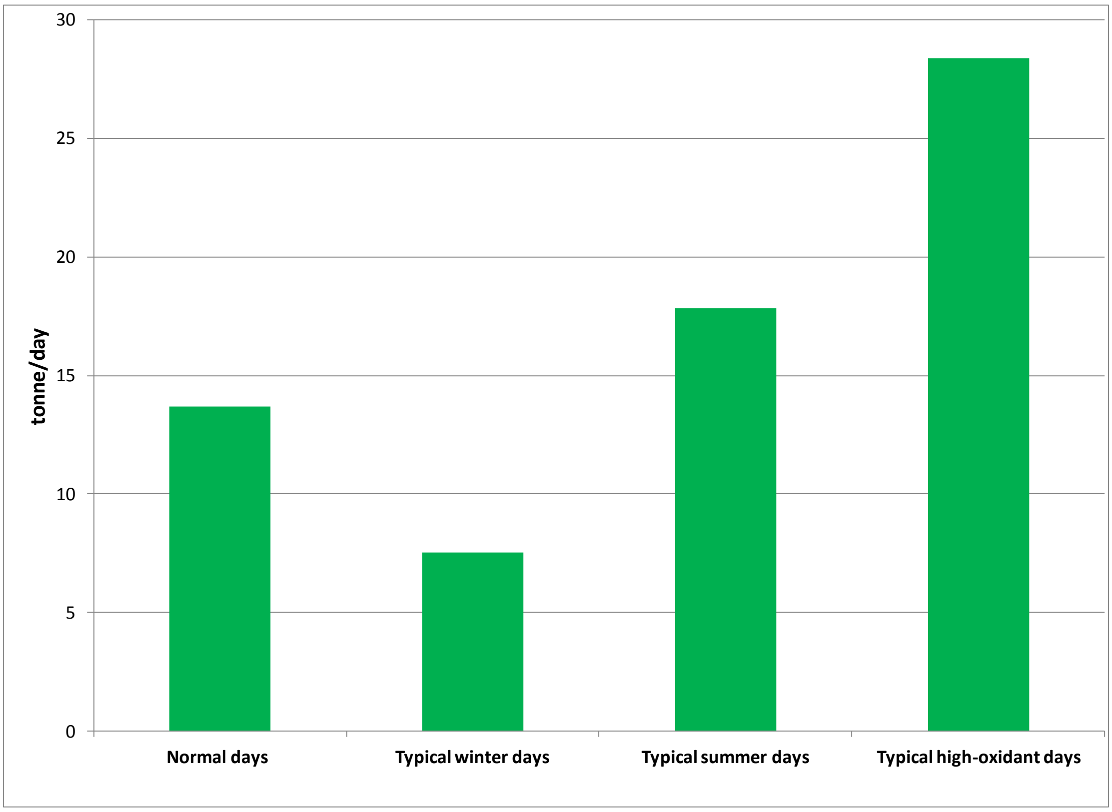

Figure 5: Evaporative VOC emissions (tonne / day) for typical summer, winter, high-oxidant and normal days (2011-2012)

Table 2: Exhaust and evaporative VOC emissions (tonne/year) for 2001/2002, 2006/2007 and 2011 / 2012

	2001/2002	2006/2007	2011/2012
Exhaust VOCs	6,880	6,341	5,023
Evaporative VOCs (weighted annual estimation)	9,218	7,063	4,989
Total VOCs	16,097	13,404	10,013

Speciation of total VOCs emissions is calculated from total estimated VOC emissions. The speciation factors have been adopted from the NSW Environment Protection Authority Technical Report (NSW EPA Technical Report 7, 2012). Table 3 presents total estimated annual emissions for speciation of VOC (selected substances) from on-road mobile sources in the Perth Airshed.

Table 3: Selected VOC speciation of motor vehicle emissions for 2011/2012

	tonne/year
1,3 butadiene	127
Acetaldehyde	48
Benzene	496
Formaldehyde	147
Isomers of xylene	761
Polycyclic aromatic hydrocarbons	56
Toluene	919

3.3 Emission Fractions of the Respective Vehicle Class

Accurate estimation of on-road vehicle emissions is important for policy-making and effective control measures. In order to estimate road emissions, detailed information about on-road vehicles is required such as: emission factors for different vehicles, vehicle class distribution, driving cycles, driving behaviour and traffic data. The relationship between the VKT and pollutant emissions of these categories is presented in the Figure 6.

The graph shows that passenger vehicles make up 76.6 percent of the fleet of registered vehicles, and account for 67.5 percent of total vehicle kilometers traveled. Light commercial vehicles with 14.2 percent of the total registered fleet are the next most significant class to generate VKT (19.3 percent). In addition, passenger vehicles generate the majority of VOC and CO emissions in Perth accounting for 76.5 percent and 76.2 percent of total respective emissions.

Heavy-duty trucks (mainly diesel fueled) account for the majority of NO_X and particulate matter emissions. Passenger Vehicles and Light Commercial Vehicles are the next most significant contributors. Around one-third of the estimated annual PM_{10} emissions are attributed to Heavy-Duty Trucks, which only contribute less than 4 percent of all registered vehicles for the Perth region. Motor cycles are estimated to account for only 1.7 percent of total NO_X emission, whilst they make up 5 percent of the registered fleet.

3.4 Spatial Variation

This inventory provides information on the spatial allocation of emissions across the region. The in-house vehicle emission inventory model was used to estimate temporal (hourly and daily) emission inventories of CO, HC, NO_X and PM_{10}, which were projected onto a 3km x 3km spatial grid of VKT. Figure 7 shows the spatial distribution pattern of the estimated particulate matter for the Perth Airshed from on-road vehicles based on 2011/2012 emissions modelling. The total particulate matter emission is estimated to be 204 tonnes per year. These gridded vehicle emissions inventories can be used in air quality dispersion modelling analysis to determine impacts from motor vehicle emissions and assess the effectiveness of control strategies, which are designed to improve air quality.

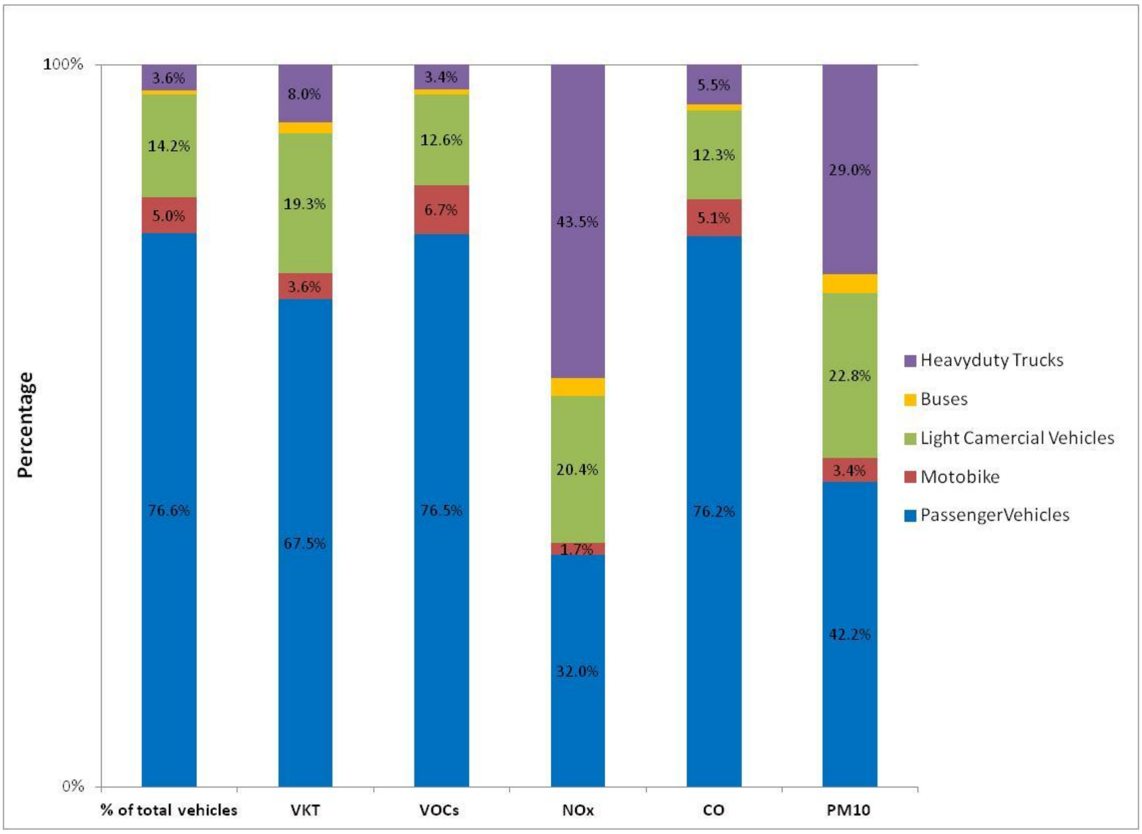

Figure 6: The percentage of total vehicle emissions by vehicle type, 2012

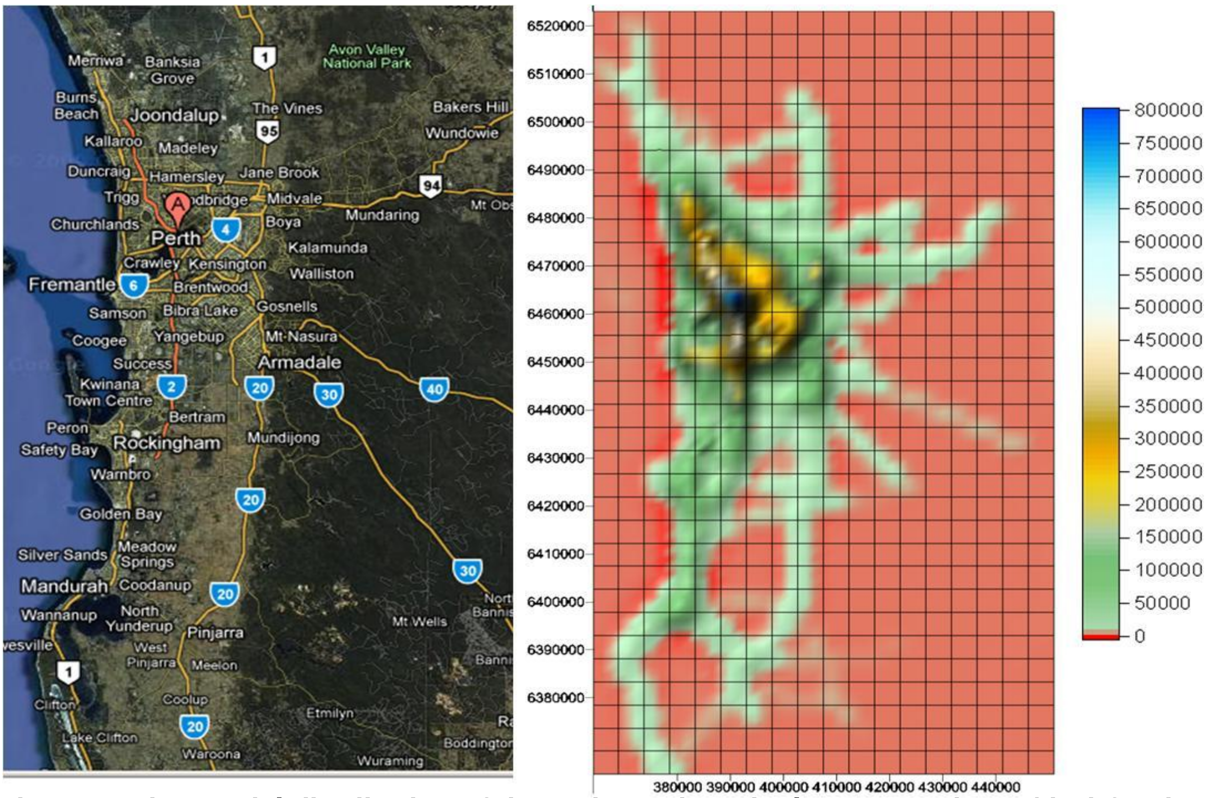

Figure 7: The spatial distribution of the estimated particulate matter (gram/day) for the Perth Airshed from on-road vehicles based on 2011/2012 emissions modelling

4 Conclusion

Emissions from motor vehicles are the single most significant source of air pollution in many Australian urban areas, including Perth. Accurate estimation of on-road vehicle emissions is important for policy and implementing effective control measures.

The current inventory has estimated total annual emissions of principal pollutants for 2001/2002, 2006/2007 and 2011/2012 emissions modelling years. A substantial decrease is observed in annual emissions of CO and VOC is evident when compared to the previous inventory (2006/2007), despite the increasing VKT is shown during this period. The reduction in CO and VOC emissions is likely due to newer engine design, where air and combustion temperature increases lead to reduced VOC and CO formation.

The magnitude of evaporative emissions under different situations such as winter, summer and high-oxidant scenarios has been examined and evaporative emissions weightings calculated from these scenarios. Significant differences were observed between vehicle emissions on typical summer days, winter days and high-oxidant days. Results indicate that the estimated annual VOC emissions arise almost mostly from petrol fuelled vehicles. Total annual emissions for speciation of VOC (selected substances) from on-road mobile sources in the Perth Airshed were also calculated from total VOC emissions.

The findings of this study can be used as an effective tool to generate projections for different pollutants, and to inform air quality policy and the design and delivery of vehicle emissions reduction programs. The output is also useful in the assessment of transport choices and improved public transport, as well as optimising behavioural change programs to reduce vehicle emissions. Vehicle emissions reduction may be best achieved by targeted behavioural change programs in relation to transport choices as well as improved public transport. Vehicle emissions modelling can be an effective tool in informing air quality policy and provide a means of estimating community exposure to vehicle-related air pollutants and of evaluating the effectiveness of air quality policies aimed at reducing vehicle emissions.

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Appendix A: The Emissions for Weekdays and Weekends

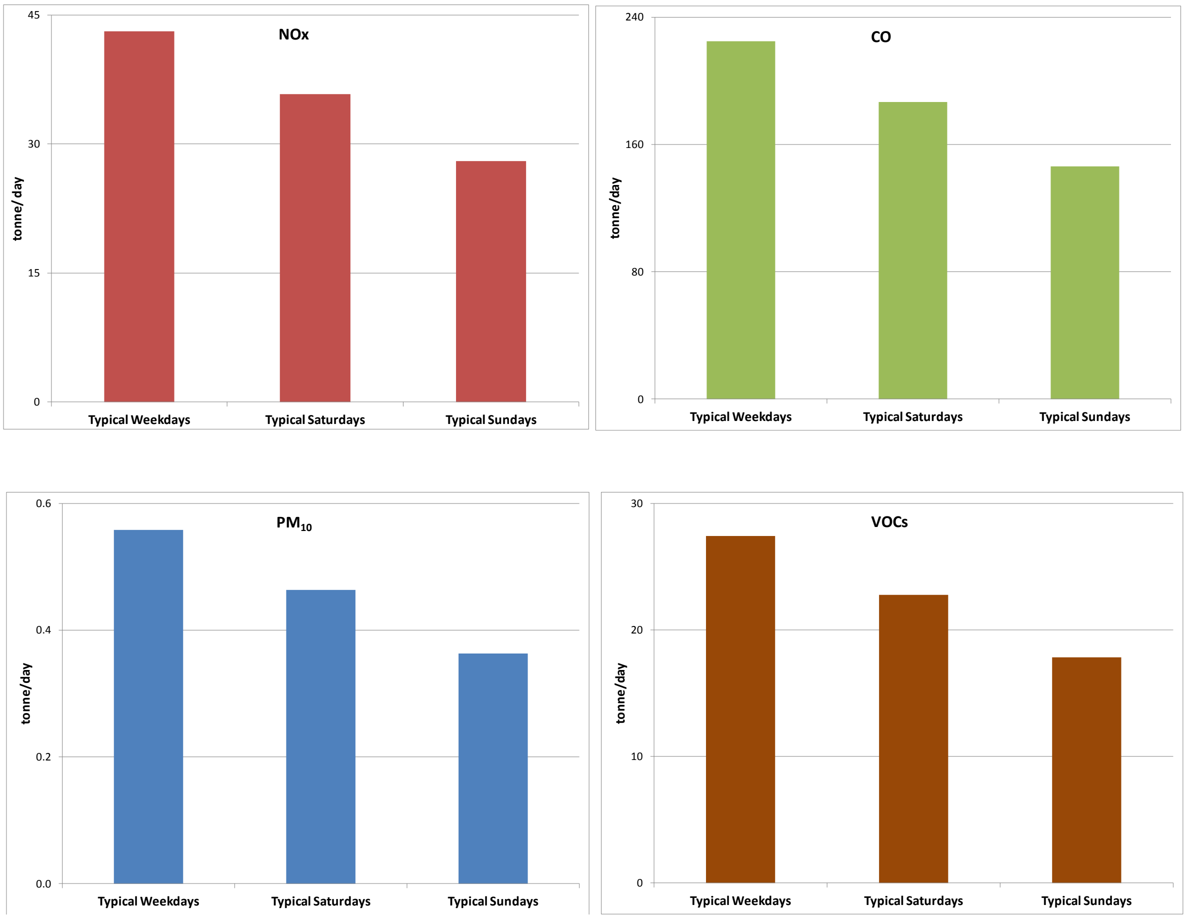

Figure A1: The estimated NO_X, CO, PM_{10} and VOC emissions (tonne/day) in the Perth Airshed for typical weekdays and weekends (2011/12)