EPA VICTORIA

2016 Victorian air pollution emissions inventory

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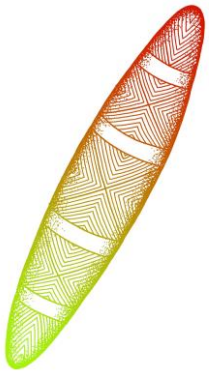

EPA acknowledges Aboriginal people as the first peoples and Traditional custodians of the land and water on which we live, work and depend. We pay respect to Aboriginal Elders, past and present.

As Victoria's environmental regulator, we pay respect to how Country has been protected and cared for by Aboriginal people over many tens of thousands of years.

We acknowledge the unique spiritual and cultural significance of land, water and all that is in the environment to Traditional Owners, and recognise their continuing connection to, and aspirations for Country.

Contents

Message from Victoria's Chief Environmental Scientist

As Victoria's Chief Environmental Scientist my role is to ensure Victorians have access to robust, science-based information about their environment. With the right information and knowledge, we can develop new and innovative ways for government, industry and community to protect the environment from the effects of pollution and waste.

There are numerous sources of air pollution in Victoria and managing the impacts from emissions requires a range of approaches and strategies. Air pollution emission inventories are one tool that can be used to help identify, inform and guide how air pollution emissions and impacts can be better managed. These inventories provide an understanding of where and how much air pollution is emitted and the data can be incorporated in modelling to determine how and where emissions are transported and dispersed. Modelling can complement air monitoring to fill data gaps of where data is not available to better estimate regional air pollution levels and human health exposure. Thus, modelling can be extended to other applications to enable air pollution forecasting, inform human health impact assessment, evaluate the efficacy of air pollution management strategies and emission reduction initiatives.

This Victorian Air Pollution Emission Inventory provides a comprehensive assessment of the major air pollution sources in the calendar year of 2016, which draws on the most recent census data available for this analysis.

Professor Mark Patrick Taylor
Chief Environmental Scientist

List of tables and figures

Tables

Figures

Acronyms and abbreviations

AAQ NEPM	Ambient Air Quality National Environment Protection Measure
ABCGEM	Australian Biogenic Canopy and Grass Emissions Model
ABS	Australian Bureau of Statistics
AMSA	Australian Maritime Safety Authority
ANNG	Australia National Nested Grid
ANZSIC	Australian and New Zealand Standard Industrial Classification
APEI	Air pollution emissions inventory
APS	Annual performance statements
BITRE	Bureau of Infrastructure, Transport and Regional Economics
BVOCs	Biogenic volatile organic compounds
CO	Carbon monoxide
CTM	Chemical transport model
DELWP	Department of Environment, Land, Water and Planning
ECODEV	Economic Development Jobs Transport and Resources
GTK	Gross tonne kilometres
LGA	Local government areas
LV	Latrobe Valley
MM	Metropolitan Melbourne
NPI	National Pollutant Inventory
NO_x	Oxides of nitrogen
O_3	Ozone
PM_{10}	Particles with an aerodynamic diameter equal or less than 10 µm
$PM_{2.5}$	Particles with an aerodynamic diameter equal or less than 2.5 µm

PPR	Port Phillip Region
SEPP (AQM)	State Environment Protection Policy (Air Quality Management)
SO_2	Sulfur dioxide
VITM	Victorian Integrated Transport Model
VKT	Vehicle kilometre travelled
VOC	Volatile organic compounds
WGS84	World Geodetic System 1984

Executive summary

A state-wide air pollution emissions inventory (APEI) for six major air pollutants has been developed for Victoria for the 2016 calendar year. In addition to this Victoria (VIC) wide emissions inventory, separate emissions inventory has also been determined for the Latrobe Valley (LV), Port Phillip Region (PPR) and metropolitan Melbourne (MM) areas. The PPR and LV inventory areas are based on the control regions for management of air pollution and air quality defined in the SEPP (AQM). In this report, PPR is defined to include Greater Geelong and MM. The emission estimates in MM area have also been included as a seperate control region because of the high density of population residing in this area less likely to be impacted from the high industrial emissions from Geelong and Latrobe Valley.

The purpose for preparing the 2016 air pollution inventory was to:

1. Estimate the annual quantities and locations of emissions for five national criteria air pollutants and VOCs for the 2016 calendar year in Victoria comprising:
    - carbon monoxide (CO)
    - oxides of nitrogen (NO_x)
    - particulate matter smaller than 2.5 μm ($PM_{2.5}$)
    - particulate matter smaller than 10 μm (PM_{10})
    - sulfur dioxide (SO_2)
    - total volatile organic compounds (VOC).
2. Identify and better understand the major sources and locations of the six air pollutants in Victoria.
3. Compile the data into a spatial grid platform that can readily be uploaded into air pollution dispersion models and other modelling applications. These modelling applications can better support air pollution forecasting, population exposure, health impact assessment and assist in guiding air pollution management strategies.

Compared to the previous APEI (2008), this 2016 inventory is different in three fundamental ways:

- it incorporates updated 2016 industry and Victorian population data and changes in activities generating air pollution emissions
- some of the methods used to estimate the emissions have been modified and updated to improve modelling accuracy
- the 2016 APEI has been modified to be consistent with the NSW APEI in order to promote greater national consistency of emissions source assessment. The air pollution emission sources used in this inventory are aligned with those used in NSW. These sources comprise natural, commercial, domestic-commercial, industrial, on-road mobile and off-road mobile sources.

Across Victoria, sources of emissions comprise a mixture of natural and anthropogenic sources. In regional Victoria the landscape is characterised by natural vegetation and low population. In these locations, natural emission sources from bushfires, dust and vegetation result in elevated releases of $PM_{2.5}$, PM_{10} and VOCs, respectively (**Figure E1**).

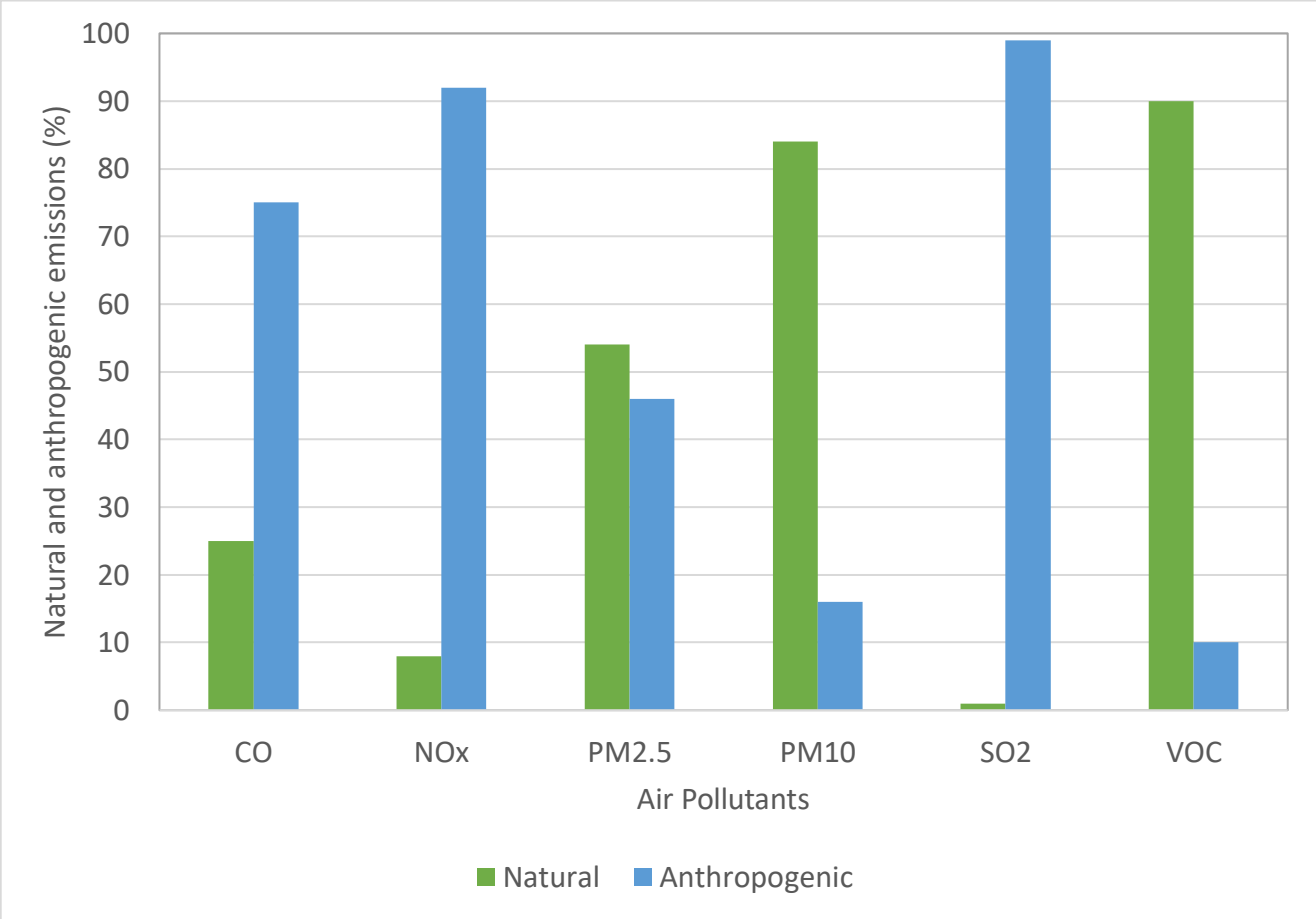

Figure E1: Proportions of natural and anthropogenic emissions for Victoria.

In terms of anthropogenic emissions, the main sources are from motor vehicles, wood heaters and fossil fuel electricity power generation. With respect to motor vehicles and wood heater emissions, the sources are from the most populated regions of Victoria, that is. PPR and MM (**Figure E2**). With respect to fossil fuel electricity power generation, the primary source of these emissions is the LV region.

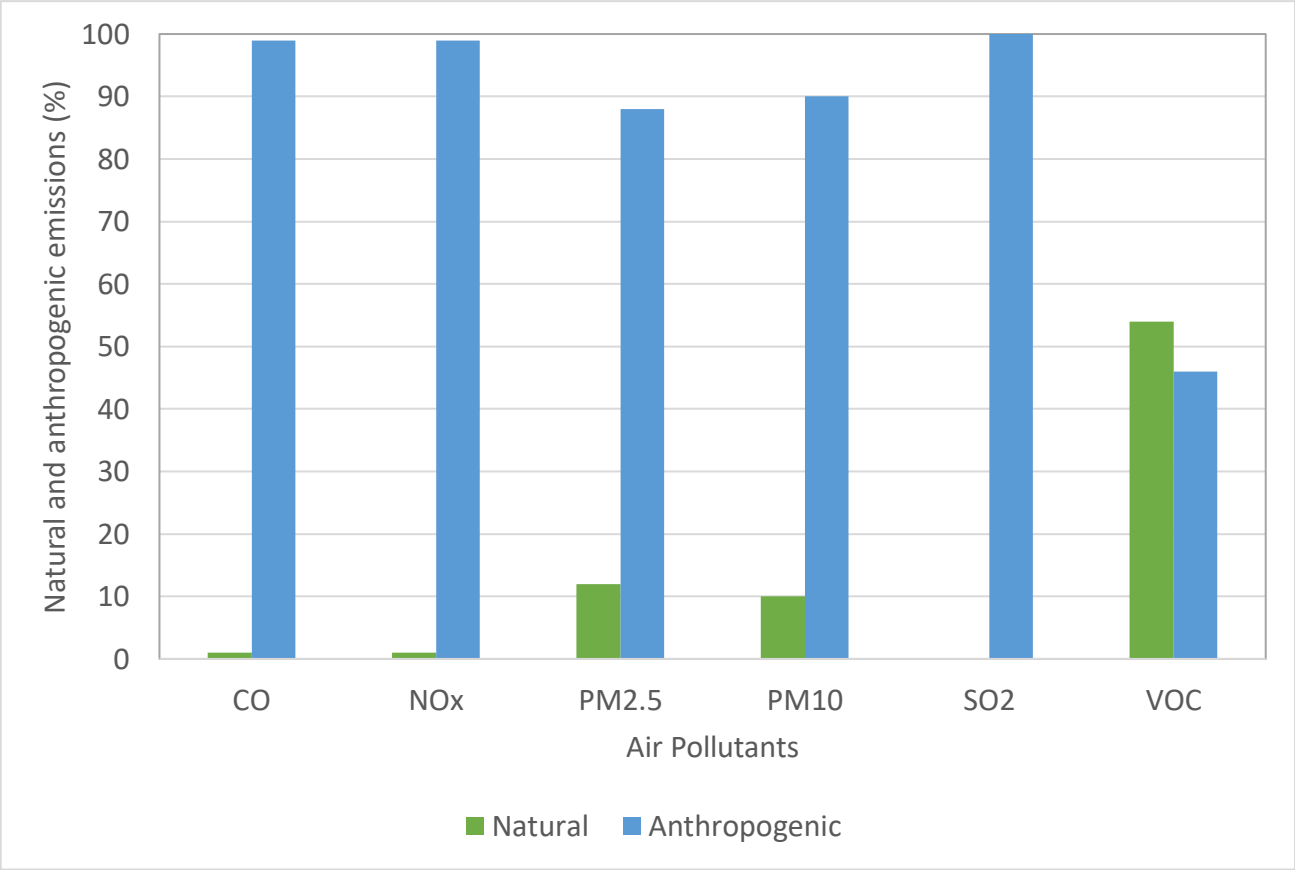

Figure E2: Proportions of natural and anthropogenic emissions for PPR.

The 2016 APEI report of the sources contributing to anthropogenic and natural emissions resulted in the following **key findings**:

(1) **Anthropogenic emissions of carbon monoxide, oxides of nitrogen, and sulfur dioxide** are significantly higher than natural emissions across regional Victoria (MM, PPR and LV) and the state as a whole.

(2) **$PM_{2.5}$ and PM_{10} anthropogenic sources** are higher than natural sources in MM, PPR and LV.

(3) **$PM_{2.5}$ and PM_{10} natural emissions** across Victoria are higher than anthropogenic sources due to bushfires and dust sources, respectively.

(4) **$PM_{2.5}$ anthropogenic emission sources** are greatest from domestic wood heaters in MM (50.9%), PPR (50%) VIC (37.9%); fossil fuel electricity generation is the highest source in LV (87.8%).

(5) **PM_{10} anthropogenic emission sources** are greatest from on-road motor vehicles in MM (71.6%), VIC (51.8%), PPR (70.9%), fossil fuel electricity generation is the highest source in LV (86.0%).

(6) **Oxides of nitrogen anthropogenic sources** are greatest from on-road motor vehicle emissions for MM (68.6%), PPR (69%), VIC (48%) and fossil fuel electricity generation is highest source for LV (93%).

(7) **Carbon monoxide anthropogenic sources** are greatest from on-road motor vehicle emissions in MM (58.9%) PPR (58.1%), VIC (89.6%), fossil fuel electricity generation is highest source in LV (98.5%).
(8) **Sulfur dioxide anthropogenic sources** are greatest from fossil fuel electricity generation for PPR (49.2%), LV (98.5%), VIC (VIC (89.6%), petroleum refining and petroleum fuel manufacturing for MM (63.4%).
(9) **VOC anthropogenic sources** are greatest from domestic solvents for MM (32.3%), PPR (31.1%), VIC (27.1), oil and gas extraction for LV (30.1%).

This report makes the following **recommendations** for reducing anthropogenic emissions:

(1) Reduce wood heater emissions, given that they comprise half of all $PM_{2.5}$ emissions in MM and PPR, and a significant proportion (37.9%) across VIC.
(2) Efforts should also be directed at reducing motor vehicles as they make up significant anthropogenic sources of carbon monoxide (58.9%), oxides of nitrogen (69.6%), $PM_{2.5}$ (29.1%) and PM_{10} (71.6%) in MM and PPR.
(3) Reduction programs for sulfur dioxide should focus on LV as it produces 87% of the sulfur dioxide emissions for Victoria
(4) Future emission inventories need to be compiled yearly or bi-yearly using a nationally consistent methods to give greater insight into the efficacy of intervention actions. More frequent and nationally consistent inventory data can be integrated into air pollution dispersion modelling to develop better and more targeted programs for the reduction of anthropogenic emissions.

A brief summary of the data is presented below, which should be read in conjunction with the full report for complete context.

Natural emissions by region

Table E1 shows the total natural emissions by region. Given that emissions are from natural sources, most emissions (80-98%) occur in areas outside of major urban areas of MM, PPR and LV.

Table E1: Total estimated natural emissions of carbon monoxide, oxides of nitrogen, $PM_{2.5}$, PM_{10}, sulfur dioxide and VOC for each region

Region	Emissions (tonnes/year)					
	CO	NO_x	$PM_{2.5}$	PM_{10}	SO_2	VOC
MM	2,254	466	331	1,479	20.52	60,709
PPR	2,786	792	630	2,624	25.36	98,632
LV	1,647	283	146	320	14.99	54,786
VIC	123,056	14,801	12,396	292,017	1,120	1,065,178

Anthropogenic emissions by region

Table E2 summarises the total anthropogenic emissions by region. The regional contribution to anthropogenic emissions varies from pollutant to pollutant. Most carbon monoxide comes from PPR (50%) and MM (43%) due to large presence of traffic sources in these regions. Most oxides of nitrogen comes from LV (51%) due to presence of power generation sources. $PM_{2.5}$ sources are evenly distributed across the regions, in PPR (44%) and MM (37%) due to large presence of domestic and on-road sources and LV (23%) due to power generation sources. Similarly, for PM_{10}, the contribution is evenly distributed between the regions with PPR (42%) and MM (36%) mainly from on-road sources and LV (21%) from power generation sources. Most sulfur dioxide emissions come from LV (87%) due to power generation sources. Most VOC emissions come from PPR (71%) and MM (64%) due to large presence of domestic sources.

Table E2:Total estimated anthropogenic emissions of carbon monoxide, oxides of nitrogen, $PM_{2.5}$, PM_{10}, sulfur dioxide and VOC for each region

Region	Emissions (tonnes/year)					
	CO	NO_x	$PM_{2.5}$	PM_{10}	SO_2	VOC
MM	159,681	45,694	3,883	23,235	4,408	74,960
PPR	185,502	52,523	4,687	27,071	11,964	83,002
LV	38,630	83,628	3,167	13,282	124,826	6,264
VIC	368,155	165,261	10,637	64,320	143,734	116,860

Relative proportions of anthropogenic and natural emissions by region

Table E3 shows the contribution of anthropogenic emissions versus natural emissions. The relative proportions are dependent on the local presence or absence of the various emission sources in that region. For most pollutants (except for VOCs), the dominant (88-99%) contribution to total emission is from anthropogenic emissions in MM, PPR and LV. For VOCs, anthropogenic emissions contribute a larger proportion (55%) in MM only due to domestic sources, with lesser contributions in PPR (46%) and LV (10%). For VIC, anthropogenic emissions make a larger share of total emissions for carbon monoxide (75%), oxides of nitrogen (92%) and sulfur dioxide (99%), but contribute lesser share for $PM_{2.5}$ (46%), PM_{10} (16%) and VOC (10%). On a state-wide level, the contributions from natural sources dominate for $PM_{2.5}$ (for example bushfires), PM_{10} (from dust in the northwest) and VOC (from vegetation).

Table E3: Proportion of anthropogenic (versus natural) emissions of carbon monoxide, oxides of nitrogen, $PM_{2.5}$, PM_{10}, sulfur dioxide and VOC for each region (%)

Region	Anthropogenic emissions (%)					
	CO	NO_x	$PM_{2.5}$	PM_{10}	SO_2	VOC
MM	99	99	92	93	>99	55
PPR	99	99	88	90	>99	46
LV	96	>99	96	98	>99	10
VIC	75	92	46	16	99	10

Relative proportions of emission sources by region

Emission results have also been analysed for the relative proportions of the five anthropogenic emission sources (commercial, domestic-commercial, industrial, off-road mobile and on-road mobile emissions) including total natural emissions for each region.

For carbon monoxide emissions, except for LV, the largest contributing sector to total carbon monoxide emissions is motor vehicles (on-road mobile sources), contributing as much as 58% for both MM and PPR and 38% for VIC. In LV, industrial sources (mainly power generation) make up the largest (59%) contribution to carbon monoxide emissions. The domestic-commercial sector is the second largest contributor to carbon monoxide emissions in MM (34%) and PPR (35%) whereas on-road and natural sources make the second largest contributions for LV (20%) and VIC (25%), respectively.

For oxides of nitrogen, MM and PPR have similar oxides of nitrogen profiles with the largest contribution from on-road sources (68%), followed by industrial sources (25%). Industrial sources make the largest contribution to oxides of nitrogen emissions in LV (97%) and VIC (54%), seconded by on-road sources contributing 3% and 35% for LV and VIC, respectively.

Domestic-commercial sources are the largest source of $PM_{2.5}$ in MM (47%) and PPR (44%). Industrial sources contribute 88% of $PM_{2.5}$ emissions in LV followed by domestic-commercial (5%) and natural (4%). Across VIC, natural emissions are the largest source of $PM_{2.5}$ emissions (53%) followed by domestic-commercial (17%) and industrial (16%) sources.

For PM_{10}, the largest emission sector in MM and PPR are on-road mobile sources, contributing as much as 72% and 71%, respectively. Industry is again the largest source of PM_{10} in LV (86%), whereas natural sources make the largest contribution across VIC (83%). The bulk of these emissions are from windblown dust in the north-west region of the state.

Sulfur dioxide is largely an industrial pollutant with industry making up 91% in MM, 96% in PPR, over 99% in LV and 99% across VIC.

The largest contributor to total VOC emissions is natural sources from vegetation, contributing 45% in MM, 54% in PPR and 90% in both LV and across the whole state of VIC. The domestic-commercial sector is the second largest source of VOC emissions in MM (37%) and PPR (31%).

Top three contributing anthropogenic emission sources by region

Looking at anthropogenic emissions exclusively and further breaking down the industry emissions into their Australia and New Zealand Standard Industrial Classification (ANZSIC) codes, tables of the top 10 contributing sources have been complied for each pollutant and for each region (refer to the main report). The focus here is on the top three pollutants contributing anthropogenic sources shown in **Tables E4-E9**:

Table E4: Top three contributing sources to anthropogenic emissions of carbon monoxide for each region

Region	Top CO anthropogenic emission contributors		
	1st	2nd	3rd
MM	Motor vehicle (59%)	Wood heater (34%)	Aircraft (2%)
PPR	Motor vehicle (58%)	Wood heater (36%)	Aircraft (2%)
LV	Fossil fuel generation (55%)	Motor vehicle (21%)	Wood heater (17%)
VIC	Motor vehicle (51%)	Wood heater (31%)	Aluminum smelting (8%)

Table E5: Top three contributing sources to anthropogenic emissions of oxides of nitrogen for each region

Region	Top NOx anthropogenic emission contributors		
	1st	2nd	3rd
MM	Motor vehicle (69%)	Gas supply (6%)	Aircraft (4%)
PPR	Motor vehicle (70%)	Gas supply (5%)	Aircraft (3%)
LV	Fossil fuel generation (93%)	Motor vehicle (3%)	Oil and gas extraction (2%)
VIC	Fossil fuel generation (48%)	Motor vehicle (38%)	Oil and gas extraction (3%)

Table E6: Top three contributing sources to anthropogenic emissions of $PM_{2.5}$ for each region

Region	Top $PM_{2.5}$ anthropogenic emission contributors		
	1st	2nd	3rd
MM	Wood heaters (51%)	Motor vehicles (30%)	Aircraft (7%)
PPR	Wood heaters (50%)	Motor vehicles (29%)	Aircraft (6%)
LV	Fossil fuel generation (88%)	Wood heaters (6%)	Motor vehicles (3%)
VIC	Wood heaters (38%)	Fossil fuel generation (27%)	Motor vehicles (22%)

Table E7: Top three contributing sources to anthropogenic emissions of PM_{10} for each region

Region	Top PM_{10} anthropogenic emission contributors		
	1st	2nd	3rd
MM	Motor vehicles (72%)	Wood heaters (14%)	Other construction mining (6%)
PPR	Motor vehicles (71%)	Wood heaters (14%)	Other construction mining (5%)
LV	Fossil fuel generation (86%)	Motor vehicles (9%)	Wood heaters (2%)
VIC	Motor vehicles (52%)	Fossil fuel generation (18%)	Mineral sand mining (10%)

Table E8: Top three contributing sources to anthropogenic emissions of sulfur dioxide for each region

Region	Top SO_2 anthropogenic emission contributors		
	1st	2nd	3rd
MM	Petroleum manufacturing (63%)	Glass manufacturing (10%)	Oil and gas extraction (6%)
PPR	Fossil fuel generation (49%)	Petroleum manufacturing (35%)	Glass manufacturing (4%)
LV	Fossil fuel generation (99%)	Pulp paper manufacturing (0.8%)	Oil and gas extraction (0.7%)
VIC	Fossil fuel generation (90%)	Aluminium smelting (5%)	Petroleum manufacturing (3%)

Table E9: Top three contributing sources to anthropogenic emissions of VOC for each region

Region	Top VOC anthropogenic emission contributors		
	1st	2nd	3rd
MM	Domestic solvents (32%)	Architect coating (18%)	Wood heaters (14%)
PPR	Domestic solvents (31%)	Architect coating (18%)	Wood heaters (16%)
LV	Oil and gas extract (30%)	Wood heaters (18%)	Fossil fuel generation (13%)
VIC	Domestic solvents (27%)	Wood heaters (18%)	Architect coating (17%)

1 Introduction

An air pollution emissions inventory is a database that compiles estimates of the amount of air pollutants discharged into the atmosphere from different sources across a geographical area or location during a year or other period. Estimates provided by an air pollution emissions inventory enable an understanding of what, where and how much air pollution is discharged. Inventory emissions combined with air monitoring, pollution modelling and other information associated with air pollution impacts guide and inform management controls and strategies.

Environment Protection Authority Victoria (EPA) has produced this air pollution emissions inventory from natural and anthropogenic sources covering the whole state of Victoria. The inventory is a database that consists of a matrix that has the data organised into a series of geographical grids (digital spatial rasters) calculated and produced to a resolution of 1 km by 1 km for the calendar year 2016.

The emissions presented in this report are for the national criteria pollutants except for lead and photochemical oxidants (ozone), which are listed in Table ATM4[1] in the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM). Volatile organic compounds (VOCs) are also included in this inventory as they are an important precursor for secondary air pollution such as ozone. The air pollutants assessed in this emissions inventory include:

- carbon monoxide (CO)
- oxides of nitrogen (NOx)
- particulate matter ≤2.5 μm ($PM_{2.5}$)
- particulate matter ≤ 10 μm (PM_{10})
- sulfur dioxide (SO_2)
- total volatile organic compounds (VOC).

[1]https://soe.environment.gov.au/theme/ambient-air-quality/topic/2016/national-air-quality-standards

For each pollutant listed above, the emissions are grouped into six emission sources:

- **Natural** - vegetation, marine aerosols and bushfires.
- **Industry** – comprising those industries that usually need an EPA licence to operate, such as power stations, petroleum refineries, chemical manufacturing and processing plants.
- **Commercial** –non-EPA licensed sources such as service stations and dry cleaners.
- **Domestic-commercial** – residential domestic activities (such as wood heaters) or public facility–based commercial sources such gas leaks.
- **On-road mobile** – road traffic sources such as cars, trucks and buses.
- **Off-road mobile** –off-road sources such as locomotives, aviation and shipping activities.

The purpose of this report is to provide an assessment of Victoria's emissions inventory for 2016. The report is structured as follows:

- Emissions inventory specification. This includes:
    - inventory calendar year (section **2.1**)
    - inventory region and subregions (section **2.2**)
    - method (section **3**)
- Emission sector results, including:
    - natural and anthropogenic pollutant emission summary for metropolitan Melbourne (MM), Port Phillip Region (PPR), Latrobe Valley (LV) and the whole of Victoria (VIC) (section **4.1)**
    - natural and anthropogenic (presented by source-type) pollutant emission summary for MM, PPR, LV and VIC (section **4.2**)
    - anthropogenic (presented by source-type) pollutant emission summary for MM, PPR, LV and VIC (section **4.3**)
    - tables of top 10 contributing sources to anthropogenic emissions of each pollutant in MM, PPR, LV and VIC (section **4.4**)
- spatial distribution of emissions (section **5**)
- comparison with emissions inventories from other states (section **6**)
- conclusions (section **7**).

[1]https://soe.environment.gov.au/theme/ambient-air-quality/topic/2016/national-air-quality-standards

2 Specification of emission inventory

2.1 Inventory year

This report presents the Victorian emission inventory for the 2016 calendar year which is the most current census data available before the next census in 2021.

2.2 Inventory region and subregions

In addition to VIC, emissions have also been estimated separately for MM, PPR and LV. A map showing the four emissions regions in Victoria is shown in **Figure 2-1**. The area for estimating air pollution emissions in Victoria has been guided by the State Environment Protection Policy (Air Quality Management) 2001 (SEPP(AQM)).

The SEPP(AQM) establishes and defines control regions for management of air pollution and air quality[1]. The air quality and air pollution control regions are defined as Port Phillip Air Quality Region (PPR) and Latrobe Valley Air Quality Region (LV) with the relevant geospatial coordinates and local government areas (LGA) specified for 2001. Air pollution estimates in MM area has also been included a separate control region because of high population density residing in this area away from industrial emissions from Geelong and Latrobe Valley.

It is noted that due to on-going growth of MM, a small part of MM extends outside of SEPP (AQM) defined coordinates for PPR.

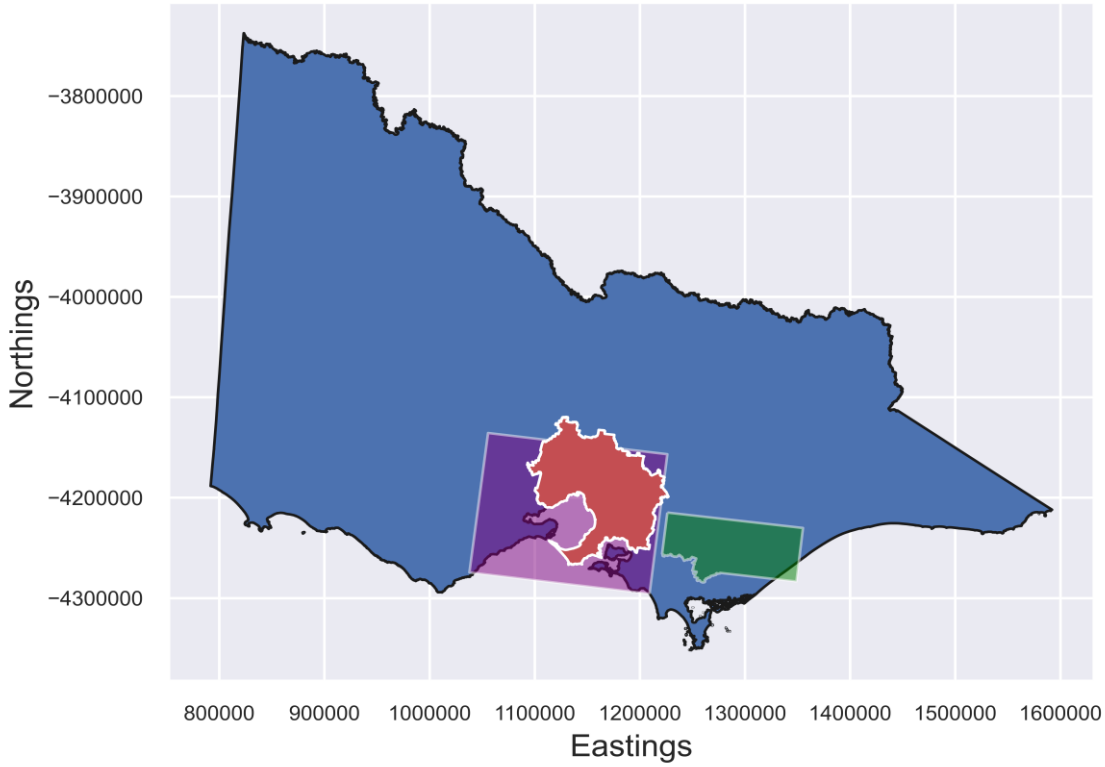

Figure 2-1: Map of the state of Victoria showing inventory regions: metropolitan Melbourne (red), Port Phillip Region (purple), Latrobe Valley (green) and the whole state of Victoria (blue)

3 Methods and approach

Emissions are usually estimated as a product of activity data and emission factors. The general equation for emission estimation is (USEPA, 1995):

$$E_{i,j} = A_j \times EF_{i,j} \times (1-ER_{i,j}/100) \quad (1)$$

Where:

- $E_{i,j}$ = emissions of substance i from source j (units of kg/annum)
- A_j = activity rate for source j (units of activity unit/annum)
- $EF_{i,j}$ = emission factor (unit of kg/activity unit)
- $ER_{i,j}$ = overall reduction efficiency for substance i for source j (as a percentage)

For the 2016 Victoria emission inventory, the calculated emissions have been gridded to the spatial resolution of 1 km by 1 km across the whole state of Victoria.

A description of the method of emission estimation for each source category is presented below.

3.1 Natural emissions

There are three types of sources of natural emissions that are considered in this emission inventory:

- biogenic emissions (from vegetation)
- windblown dust (from soil)
- fires (natural or prescribed burning of vegetation).

3.1.1 Biogenic sources

Biogenic emissions were estimated using Australian Biogenic Canopy and Grass Emissions Model (ABCGEM), which was run in CSIRO's Chemical Transport Model (CTM) for calendar year 2016. Developed in 2003 at CSIRO, the ABCGEM calculates temperature and light dependent emissions of biogenic volatile organic compounds (BVOCs) from a 10-layer tree canopy. A detailed description of the model is provided by Emmerson et al. (2018).

3.1.2 Windblown dust

Dust emissions were calculated using a windblown dust emissions module in CSIRO's CTM model (for example Cope et al., 2009). Based on a sand-saltating mechanism, a detailed description of the method is provided by Lu and Shao (1999).

3.1.3 Emissions from fires

Emissions from bushfires and prescribed burning were estimated using the equation (NPI, 1999):

$$E_{i,j} = A_j \times FL_j \times Z_j \times EF_{i,j}$$

Where:

$E_{i,j}$	=	Emission of substance i from fire type j	(kg/year)
A_j	=	Annual area burned by fire type j	(ha/year)
FL_j	=	Fuel loading for fire type j	(tonne dry vegetation burned / ha vegetation)
Z_j	=	Vegetation burning efficiency for fire type j	(kg vegetation burned / kg vegetation)
$EF_{i,j}$	=	Emission factor for substance i from fire type j	(kg/tonne)
i	=	Substance (either "criteria pollutants", "speciated NO_x", "speciated VOC", "organic air toxics", "metal air toxics", "PAH", "PCDD and PCDF", "ammonia" or "greenhouse gases"	
j	=	Fire type (either "bushfires" or "prescribed burning")	

Vegetation burning efficiency and emission factors for each substance and fire types are shown in **Table 3-1** and **Table 3-2**:

Table 3-1: Vegetation burning efficiency and emission factors for bushfires

	Bushfires			
	FL (tonne dry vegetation burned / ha)	Z (kg vegetation burned / kg vegetation)	Emission factors (kg/tonne)	Total emission (kg/ha/year)
Oxides of nitrogen	36.4	0.72	3.68	96.44544
Sulfur dioxide			1.134	29.71987
PM_{10}			12.55	328.9104
$PM_{2.5}$			10.65	279.1152
VOC			8.72	228.5338
Carbon monoxide			124.57	3264.731

Table 3-2: Vegetation burning efficiency and emission factors for prescribed burning

Prescribed burning				
	FL (tonne dry vegetation burned / ha)	Z (kg vegetation burned / kg vegetation)	Emission factors (kg/tonne)	Total emission (kg/ha/year)
Oxides of nitrogen	18.2	0.42	3.68	28.130
Sulfur dioxide			1.134	8.668
PM_{10}			12.55	95.932
$PM_{2.5}$			10.65	81.409
VOC			8.72	66.656
Carbon monoxide			124.57	952.213

3.2 Industrial sources

Industrial emissions were compiled from three datasets:

- annual performance statements (APS) from industrial premises licensed by EPA
- 2015-2016 annual emissions from the National Pollutant Inventory (NPI)
- information from EPA's previous air emissions inventories (2006 and 2011).

As the NPI data does not provide information about stack discharge parameters, it was necessary to match the NPI emissions with stack information from previous emission inventories. This was accomplished by grouping stack diameters, stack heights, stack exit temperatures and discharge velocities from the 2006 and 2011 Victorian emission inventories according to ANZSIC codes and matching these with ANZSIC codes from the 2015-2016 NPI data.

It was found that 30 ANZSIC industry categories in the 2015-2016 set of facilities were not present in the earlier inventories. The 25th percentile of the discharge characteristics from all industry categories in the earlier inventories were applied for these facilities.

3.3 Commercial sources

Commercial sources of emissions in the 2016 emissions inventory include bakeries, crematoria, dry cleaning, eateries, printing services and service stations. For each commercial emission source, the list of pollutant(s) and references for method and emission factor sources are listed in **Table 3-3**. The method for estimating emissions from commercial premises involved four main steps:

- business names and addresses of commercial sources were taken from appropriate sources such as Worksafe Victoria
- checking of names and addresses against the industry database entries for duplication
- geocoding of names and addresses to WGS84 using ggmap library (Kahle and Wickham, 2013) in R (R Core Team, 2020)
- using emission factors either from NPI or other sources such as from literature.

Table 3-3: Methodologies and emission factors for commercial emission sources

Emission source	Pollutant	Method and emission factor source
Bakeries	VOC	- *Emission estimation techniques for bread manufacturing* Commonwealth of Australia, Canberra (NPI 1999a) - *Survey of small and medium commercial baking establishments to estimate average VOC emission factors*. Unpublished report. Markham (ON): Cheminfo. Prepared for Environment Canada (Cheminfo Services, 2005) - VOC / PM Speciation Data System (USEPA. 1992)
Crematoria	Carbon monoxide, $_{oxides}$ of nitrogen, PM_{10}, $PM_{2.5}$, sulfur dixode, VOC	- *Emissions estimation technique for crematoria* (NPI 2011). - *Victorian cremation industry viability report* (Marsden Jacob Associates,2002).
Dry cleaning	VOC	- Emissions Estimation Technique Manual for Dry Cleaning (NPI 1999b). - Survey of dry-cleaning facilities in Victoria.

Eateries	$PM_{2.5}$, VOC	- Data for the addresses of charcoal chicken and wood fired pizza outlets were taken from the Tripadviser website. - Weight of chicken per week taken from average of several charcoal chicken businesses for sale on (https://www.commercialrealestate.com.au/business-for-sale/vic/). - $PM_{2.5}$ emission factor (McDonald et al., 2003). - VOC emission factor (Whynot et al., 1999).
Printing services	VOC	- *Emissions estimation technique manual for aggregated emissions from printing and graphic arts* (NPI, 1999c) - Survey of commercial printing services from WorkSafe Victoria minus those already included in NPI industry inventory.
Service stations	VOC	- *Emissions estimation technique manual for fuel and organic liquid storage* (NPI, 2012) - Total petrol, LPG and diesel sales from annual reporting for 2016 from Australian Petroleum Statistics (APS, 2016) - Names and addresses of service stations from combining results from business names and addresses from WorkSafe Victoria. Duplicates were removed.

3.4 Domestic-commercial sources

Domestic-commercial emissions sources include architectural coatings, cutback bitumen, domestic solvents, gas leaks and wood heaters. The methodologies and emission factors references are shown in **Table 3-4**.

Table 3-4: Methodologies and emission factors references for domestic-commercial emission sources

Emission source	Pollutant	Method and emission factor source
Architectural coatings	VOCs	- *Emission estimation technique manual for aggregated emissions from architectural surface coatings* (NPI, 2003) - ABS population grid for 2016.
Cutback bitumen	VOC	- Australian Petroleum Statistics (APS, 2016) - *Guide to the Australian energy statistics* 2017 (AES, 2017) - *Emission estimation technique manual for aggregated emissions from cutback bitumen* (NPI, 1999e)
Domestic solvents	VOC	- *Emissions estimation technique manual for aggregated emissions from domestic/commercial solvent and aerosol use* (NPI, 1999d) - ABS population grid for 2016.
Gas leaks	VOC	- *Emission estimation technique manual for gas supply* (NPI, 2011a) - ABS population grid for 2016.
Wood heaters	Carbon monoxide, oxides of nitrogen, PM_{10}, $PM_{2.5}$, sulfur dioxide, VOC	- *Victorian wood heater inventory report* – Parts 1 and 2, Produced for EPA Victoria (Williamson and O'Sullivan, 2018). - Modelling PM_{10} concentrations and carrying capacity associated with wood heater emissions in Launceston (Luhar et al., 2006)

3.5 On-road mobile sources

On-road mobile sources of emissions in the Victoria emissions inventory refer to motor vehicles on its roads. The following data sources were used to estimate air emissions from motor vehicles:

- Victorian Integrated Transport Model (VITM) from the Department of Transport, 2016
- shapefile of extent of VITM (referred to as on-network)
- shapefile of the rest of Victoria, excluding the VITM extent (referred to as off-network)
- shapefile of the road network for Victoria (from Department of Environment Land Water and Planning, DELWP)
- Australian Bureau of Statistics (ABS) Survey of Motor Vehicle Use 2015-16.

The VITM, provided by Economic Development, Jobs, Transport and Resources (ECODEV), contains traffic volumes on freeways, arterials and a small fraction of residential streets. The extent of the VITM network is about the same as the ABS boundary for the Melbourne statistical division, so it does not include all the roads for regional Victoria.

The method of estimating vehicle emissions involved first estimating the vehicle kilometre travelled (VKT) for each road type and then converting these to emissions by multiplying by emission factors.

3.5.1 Estimating VKT by road location

VKTs were estimated by splitting the road network into three separate sections:

- the VITM roads in the on-network
- the non-VITM roads in the on-network (dominated by quieter residential roads)
- the non-VITM roads in the off-network (most of the roads in the off-network).

Firstly, for VITM roads, the VKTs were estimated based on traffic volumes in VITM. Small adjustments were made to convert the weekday data to annual data. Adjustment factors from previous inventories were used to convert the weekday VKTs to Saturday and Sunday VKTs.

After calculating the VKTs for the VITM on-network, data from *ABS survey of motor vehicle use* was used to determine the 'leftover' VKTs in Melbourne metropolitan area. These VKTs were allocated to residential roads not included in VITM based on a spatial weighting of the population density area where the roads were located.

Finally, for the VKTs for non-VITM off-network, again the *ABS survey of motor vehicle use* data was used to determine total VKTs for this category of roads. A population density weighting was also applied using data from ABS Statistical Area Level 3 (SA3) as well as ratios of freeways, arterials and residential roads in the on-network.

3.5.2 Estimating motor vehicle emissions from VKTs

The shapefile lines were rasterised using the raster package in R (Hijmans, 2020; R Core Team, 2020) to create the sum of VKT for each 1 km x 1 km raster cell in the Australian National Nested Grid projection. The rasterised VKTs were then converted to annual emissions of pollutant per grid by multiplying with emissions factors taken from Smit (2014).

3.6 Off-road mobile sources

Off-road mobile sources refer to emission sources from rail, airports and shipping.

3.6.1 Rail emissions

The following data sources have been used to estimate air emissions from locomotives:

- Gross tonne kilometres (GTK) summary by line provided by the Australian Rail Track Corporation (ARTC)
- shapefile of the interstate rail network within Victoria
- emission factors from EPA NSW 2008 Emissions technical report 6 (EPA NSW, 2012).

The GTK data was joined to the rail network shapefile in the Australia National Nested Grid (ANNG) projection. The GTK data (in metres) was then converted to litres of fuel use per kilometre using a value of 3.89 L/GKT (ARTC, 2010). Emissions from rail were then calculated as kilograms per annum for each line segment in the shape file using the locomotive emission factors from *EPA NSW 2008 emissions inventory* (EPA NSW, 2012). Finally, emissions were rasterised in the ANNG projection to give pollutant emissions per square kilometre per annum.

3.6.2 Aircraft emissions

Data regarding airport emissions was obtained from the following sources:

- published aviation statistics from the Australian Government Department of Infrastructure, Regional Development and Cities, 2016: The Bureau of Infrastructure, Transport and Regional Economics (BITRE)
- landing/takeoff (LTO) data from Air Services Australia
- emissions factors from the *National Pollutant Inventory: Emissions Estimations Technique Manual for Aggregated Emissions from Aircraft* (NPI, 2003a)
- polygons for each airport line from DELWP
- raster to produce 1-km grid of Victoria was sourced from ABS (ABS, 2014).

Aircraft movements are expressed as LTO which incorporate all of the normal flight and ground operation modes including descent/approach from a reference height above ground level, touchdown, landing run, taxi in, idle and shutdown, start-up and idle, checkout, taxi out, take-off and climb out to the reference height.

Auxiliary power units (APU) were scaled up from the 2006 data by the change in aircraft movements. As was done in the 2006 emissions inventory, only APU data for the domestic/international airports at Melbourne and Avalon was used.

Ground support equipment (GSE) was also scaled up from the 2006 data by the change in aircraft movement. GSE data was used only for the more frequently used airports: Avalon, Essendon, Melbourne, Mildura, Moorabbin and Portland.

3.6.3 Shipping emissions

Shipping emissions for the 2016 Victoria emissions inventory were compiled by the Australian Maritime College Search (AMCS) a commercial arm of the Australian Maritime College.

The following data sources were used to estimate emissions from shipping:

- activity data from the ship based Automatic Identification System (AIS) provided by the Australian Maritime Safety Authority (AMSA)
- fuel consumption data from International Maritime Organisation (IMO 2014) and Starcrest Consulting Group (PoLA 2016 and PoLB 2016).
- emission factors from Cooper and Gustaffson (2004).

The shipping emission estimation method used is provided in Goldsworthy and Goldsworthy (2015) and is based on tracking ship movements from high-resolution temporally and spatially resolved ship activity data from ship based AIS and assigning engine loads. The Goldsworthy and Goldsworthy (2018) report detailing the method can be obtained upon request from EPA Victoria.

4 Emissions summary

In this section, summaries of each pollutant's total natural and total anthropogenic emissions are presented as well as their relative contributions (natural vs anthropogenic) for each of the emission regions (**subsection 4.1**). This is followed (**subsection 4.2**) by a further break-down of the anthropogenic emission sources and their relative contributions to total emissions (including natural emissions). The contributions of each anthropogenic emission sector to total anthropogenic emissions are presented in **subsection 4.3**, followed by tables of top 10 contributing sources to total anthropogenic emissions in **subsection 4.4.**

4.1 Totals and relative contribution of natural and anthropogenic emissions for each pollutant

4.1.1 Carbon monoxide

Table 4-1 is a summary of the total natural and anthropogenic emissions of carbon monoxide for the four regions. For the state of VIC, 491,211 tonnes of carbon monoxide were emitted in 2016, with MM, PPR and LV contributing 33%, 38% and 8%, respectively.

Table 4-1: Total estimated natural and anthropogenic emissions of carbon monoxide for each region

Pollutant	Region	Emissions (tonnes/year)		
		Natural	Anthropogenic	Total
Carbon monoxide	MM	2,254	159,681	161,935
	PPR	2,786	185,502	188,288
	LV	1,647	38,630	40,277
	VIC	123,056	368,155	491,211

Out of the 123,056 tonnes of natural carbon monoxide emitted in VIC, 2% came from MM, with PPR and LV accounting for 2.2% and 1.3%, respectively. Thus, the majority of natural emissions of carbon monoxide, which are predominantly from vegetation and bushfires, came from regions outside MM and outside PPR. On the contrary, half of the 368,154 tonnes of anthropogenic carbon monoxide emissions for VIC came from PPR, with MM and LV regions contributing 43% and 10%, respectively.

Shown in **Figure 4-1** are pie charts of the relative contributions of natural versus anthropogenic emissions of carbon monoxide for the four emission regions. The origin of carbon monoxide emissions is overwhelmingly anthropogenic for all regions: MM (99%), PPR (99%), LV (96%) and VIC (75%).

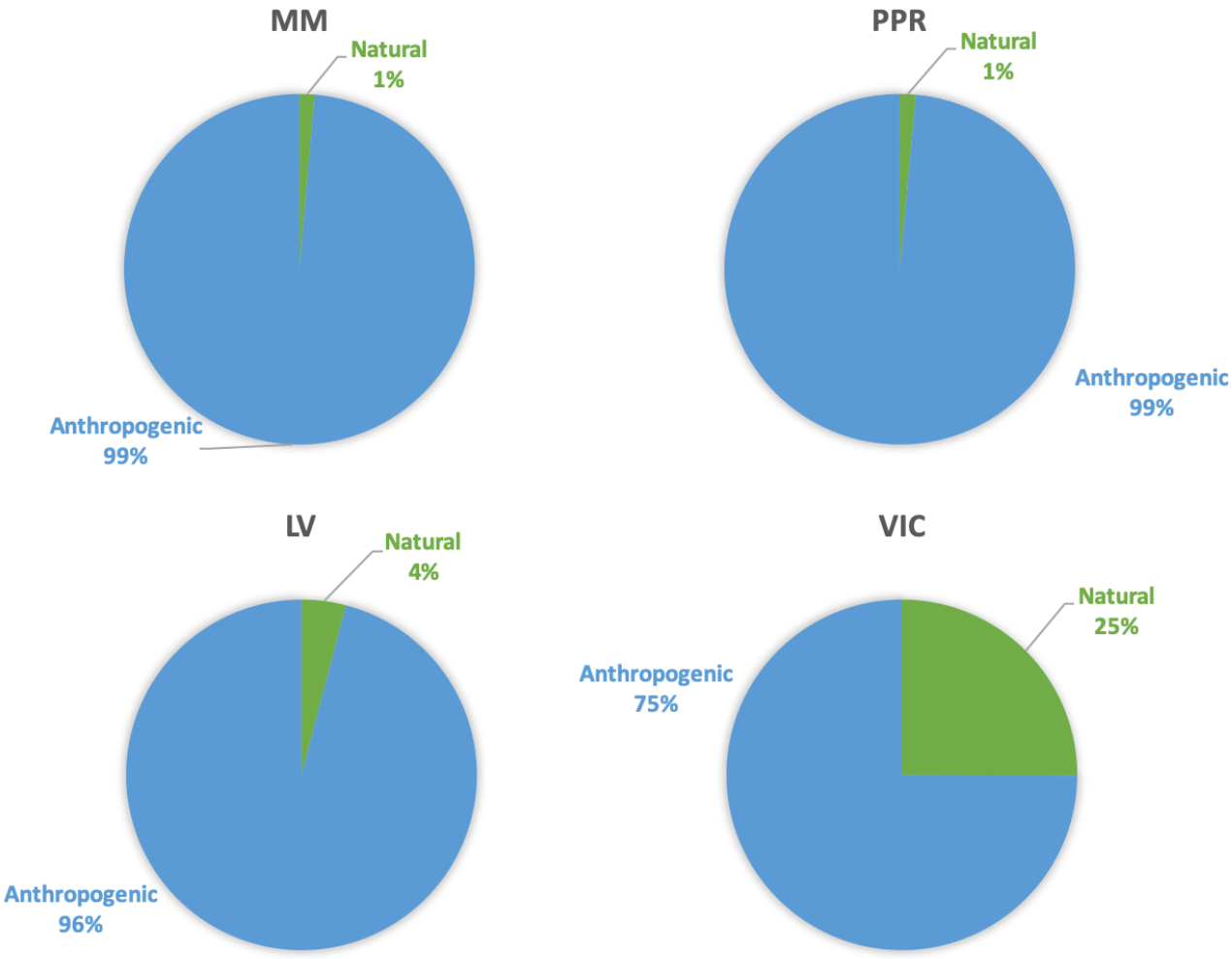

Figure 4-1: Proportions of natural and anthropogenic carbon monoxide emissions for MM, PPR, LV and VIC.

4.1.2 Oxides of nitrogen

Table 4-2 is a summary of the total natural and anthropogenic emissions of oxides of nitrogen for the four emission regions. There was a total of 180,062 tonnes of oxides of nitrogen emitted from VIC. Almost half (47%) came from LV, with 30% and 26% from PPR and MM, respectively.

Table 4-2: Total estimated natural and anthropogenic emissions of oxides of nitrogen for each region

Pollutant	Region	Emissions (tonnes/year)		
		Natural	Anthropogenic	Total
Oxides of nitrogen	MM	466	45,694	46,160
	PPR	792	52,523	53,315
	LV	283	83,628	83,911
	VIC	14,801	165,261	180,062

For natural oxides of nitrogen emissions, 14,801 tonnes were emitted in VIC, with MM and PPR and LV accounting for only 3%, 5% and 2%, respectively, so most of natural oxides of nitrogen emissions were outside these sub-regions. A total of 165,261 tonnes of anthropogenic oxides of nitrogen was emitted from VIC, half of which came from LV (51%), with MM and PPR accounting for 28% and 32%, respectively.

The pie charts in **Figures 4-2** show the relative contribution of natural versus anthropogenic emissions to the total oxides of nitrogen emissions. Anthropogenic emissions made the bulk of oxides of nitrogen emissions contributing to 99% for MM and PPR, over 99% for LV and 92% for VIC.

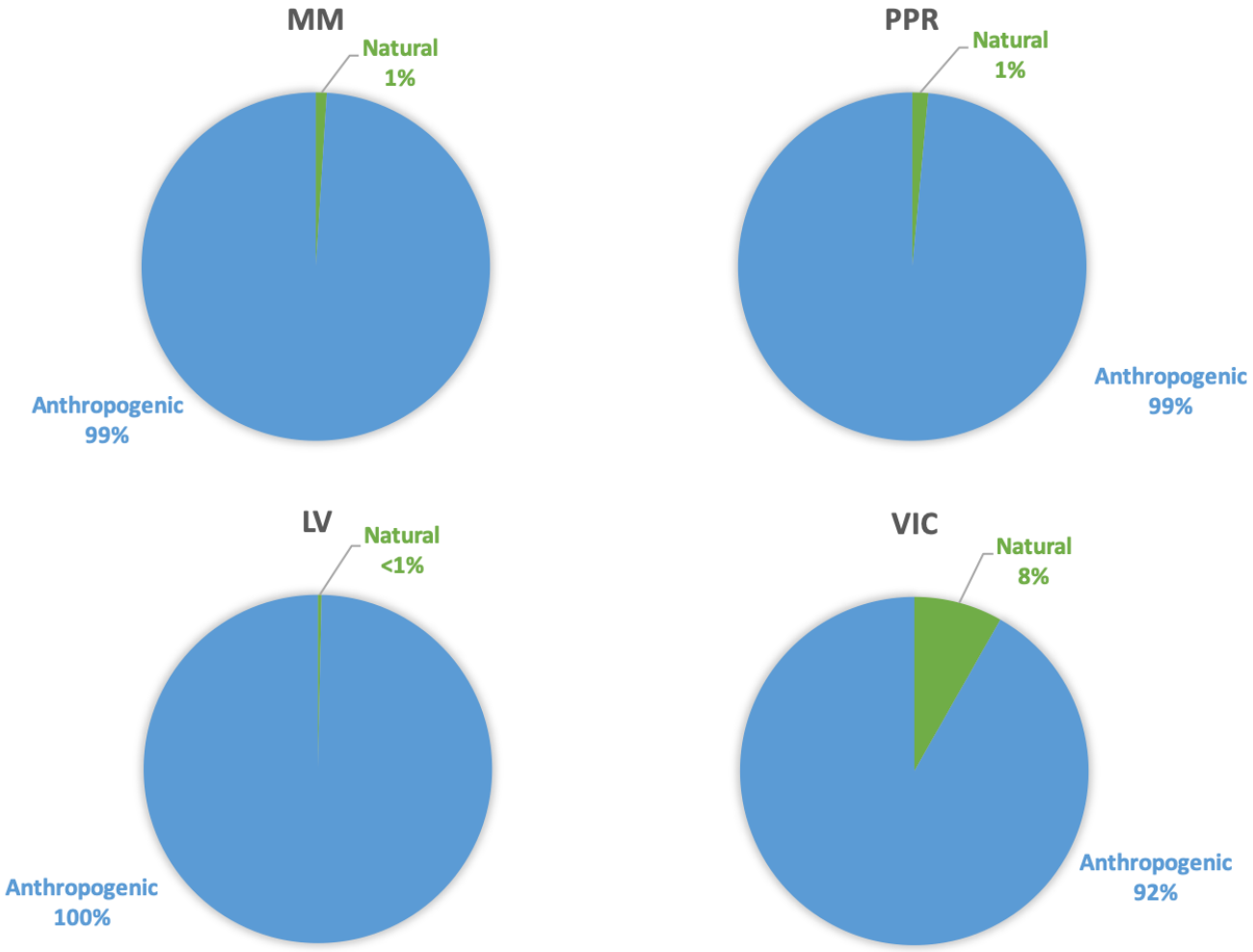

Figure 4-2: Proportions of natural and anthropogenic oxides of nitrogen emissions for MM, PPR, LV and VIC.

4.1.3 Particulate matter ≤ 2.5 μm

Table 4-3 is a summary of the total natural and anthropogenic emissions of $PM_{2.5}$ for the four regions. In 2016, there was 23,033 tonnes of total $PM_{2.5}$ emitted from VIC, with MM, PPR and LV each accounting for 18%, 23% and 14% of total emissions, respectively. There was a total of 12,396 tonnes of natural emissions for VIC. Only 3%, 5% and 1% of these were emitted in MM, PPR and LV, respectively. Anthropogenic emissions of $PM_{2.5}$ amounted to 10,637 tonnes for VIC, with the 37%, 44% and 30% from MM, PPR and LV, respectively.

Table 4-3: Total estimated natural and anthropogenic emissions of $PM_{2.5}$ for each region

Pollutant	Region	Emissions (tonnes/year)		
		Natural	Anthropogenic	Total
$PM_{2.5}$	MM	331	3,883	4,214
	PPR	630	4,687	5,317
	LV	146	3,167	3,313
	VIC	12,396	10,637	23,033

The pie charts in **Figure 4-3** show the relative contribution of natural versus anthropogenic emissions to the total $PM_{2.5}$ emissions. Anthropogenic emissions make the majority contribution to total emissions in MM (92%), PPR (88%) and LV (96%). However, for the whole state of VIC, there are slightly more natural emissions (54%) than anthropogenic emissions (46%). The natural sources of $PM_{2.5}$ include bushfires, sea-spray.

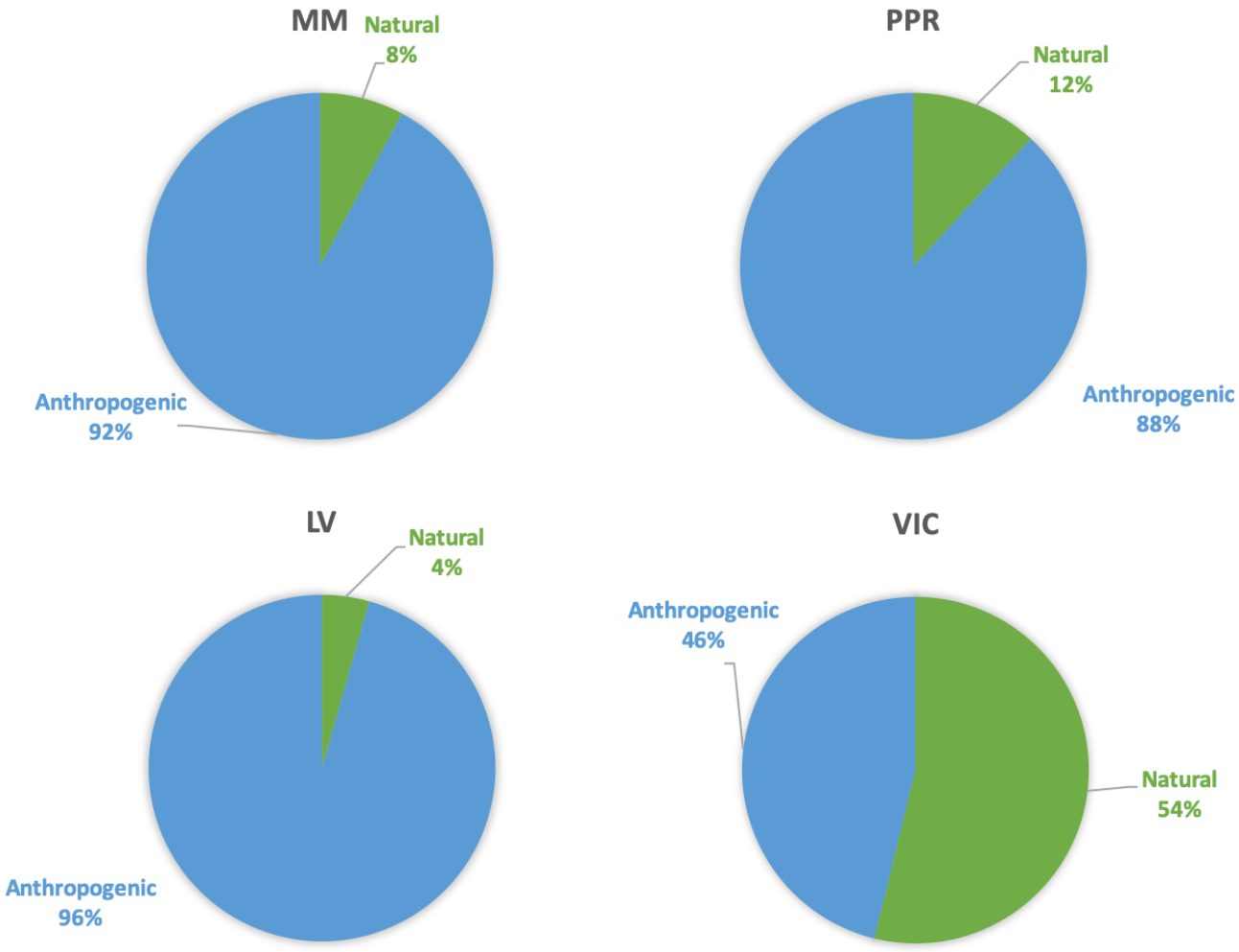

Figure 4-3: Proportions of natural and anthropogenic $PM_{2.5}$ emissions for MM, PPR, LV and VIC.

4.1.4 Particulate matter ≤ 10 μm

Table 4-4 is a summary of the total natural and anthropogenic emissions of PM_{10} for the four regions. In 2016, there was a total of 356,337 tonnes of PM_{10} emitted from VIC, most of which came from natural emissions from areas outside MM, PPR and LV. Indeed, the state totals were dominated by windblown dust emissions from deflated soils from northwest part of VIC Anthropogenic emissions of PM_{10} amounted to 64,320 tonnes for VIC, with the 42%, 36% and 21% of the emissions coming from PPR, MM and LV, respectively.

Table 4-4: Total estimated natural and anthropogenic emissions of PM_{10} for each region

Pollutant	Region	Emissions (tonnes/year)		
		Natural	Anthropogenic	Total
PM_{10}	MM	1,479	23,235	24,714
	PPR	2,624	27,071	29,695
	LV	320	13,282	13,602
	VIC	292,017	64,320	356,337

The pie charts in **Figure 4-4** show the relative contribution of natural versus anthropogenic emissions to the total PM_{10} emissions. Like $PM_{2.5}$, anthropogenic emissions of PM_{10} make the bulk of emissions for MM (94%), PPR (91%) and LV (98%). This is reversed for VIC, with natural emissions significantly greater (83%) than anthropogenic emissions (17%), which, as already mentioned above, is due to natural contribution by windblown dust in the northwest regions of VIC.

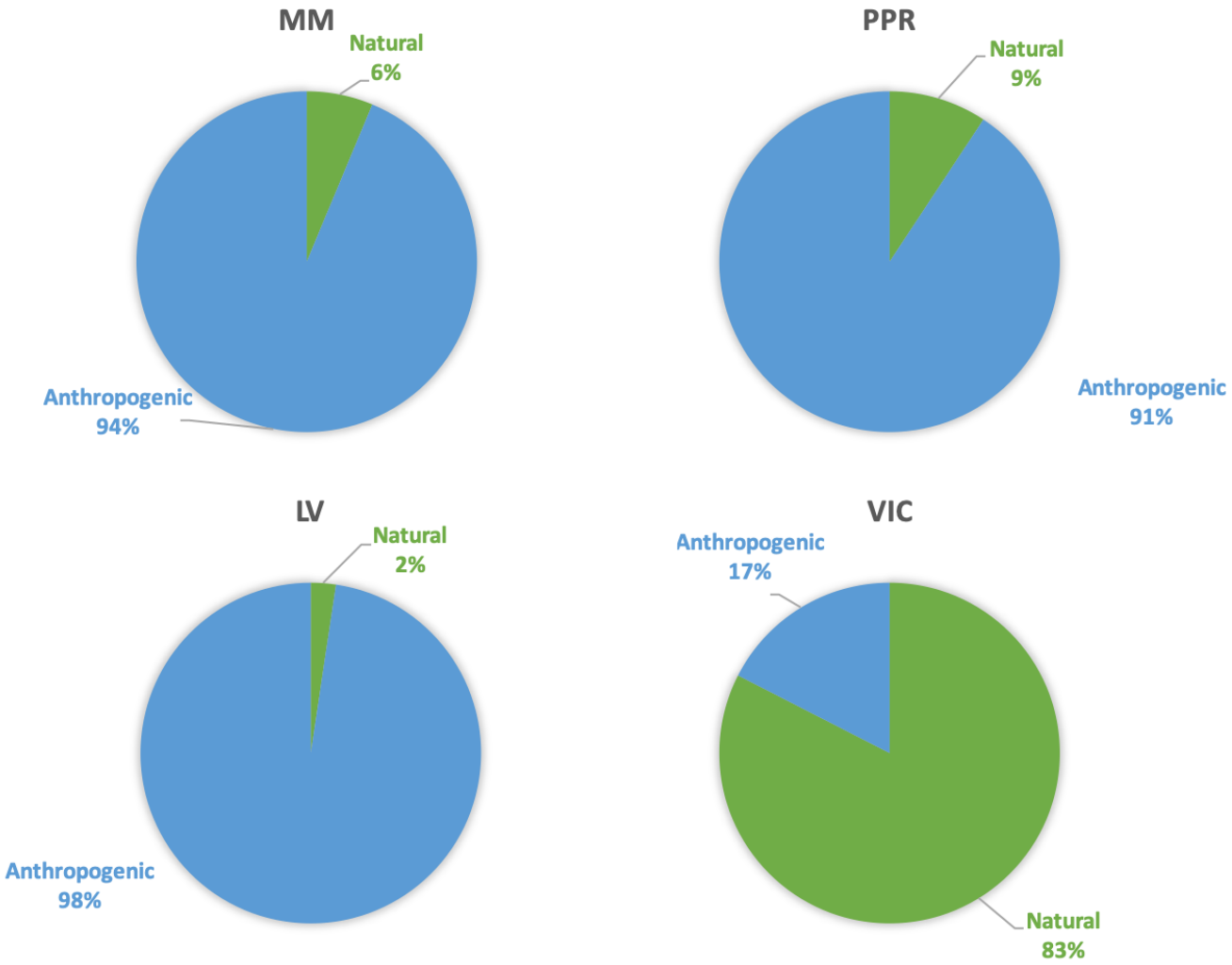

Figure 4-4: Proportions of natural and anthropogenic PM_{10} emissions for MM, PPR, LV and VIC.

4.1.4 Sulfur dioxide

Table 4-5 is a summary of the total natural and anthropogenic emissions of sulfur dioxide for the four regions. For the state of Victoria, 144,853 tonnes of sulfur dioxide was emitted in 2016. Most of these emissions were from the LV (86%), with PPR and MM contributing only 8% and 3%, respectively. The dominance of LV as a source of sulfur dioxide shows that sulfur dioxide is an industrial pollutant, with only 1120 tonnes (less than 1%) being generated by natural sources.

Table 4-5: Total estimated natural and anthropogenic emissions of sulfur dioxide for each region

Pollutant	Region	Emissions (tonnes/year)		
		Natural	Anthropogenic	Total
Sulfur dioxide	MM	20.52	4,408	4,429
	PPR	25.36	11,964	11,989
	LV	14.99	124,826	124,841
	VIC	1,120	143,734	144,854

And as shown in **Figure 4-5**, the anthropogenic contribution of sulfur dioxide emissions is greater than 98% for all the four regions.

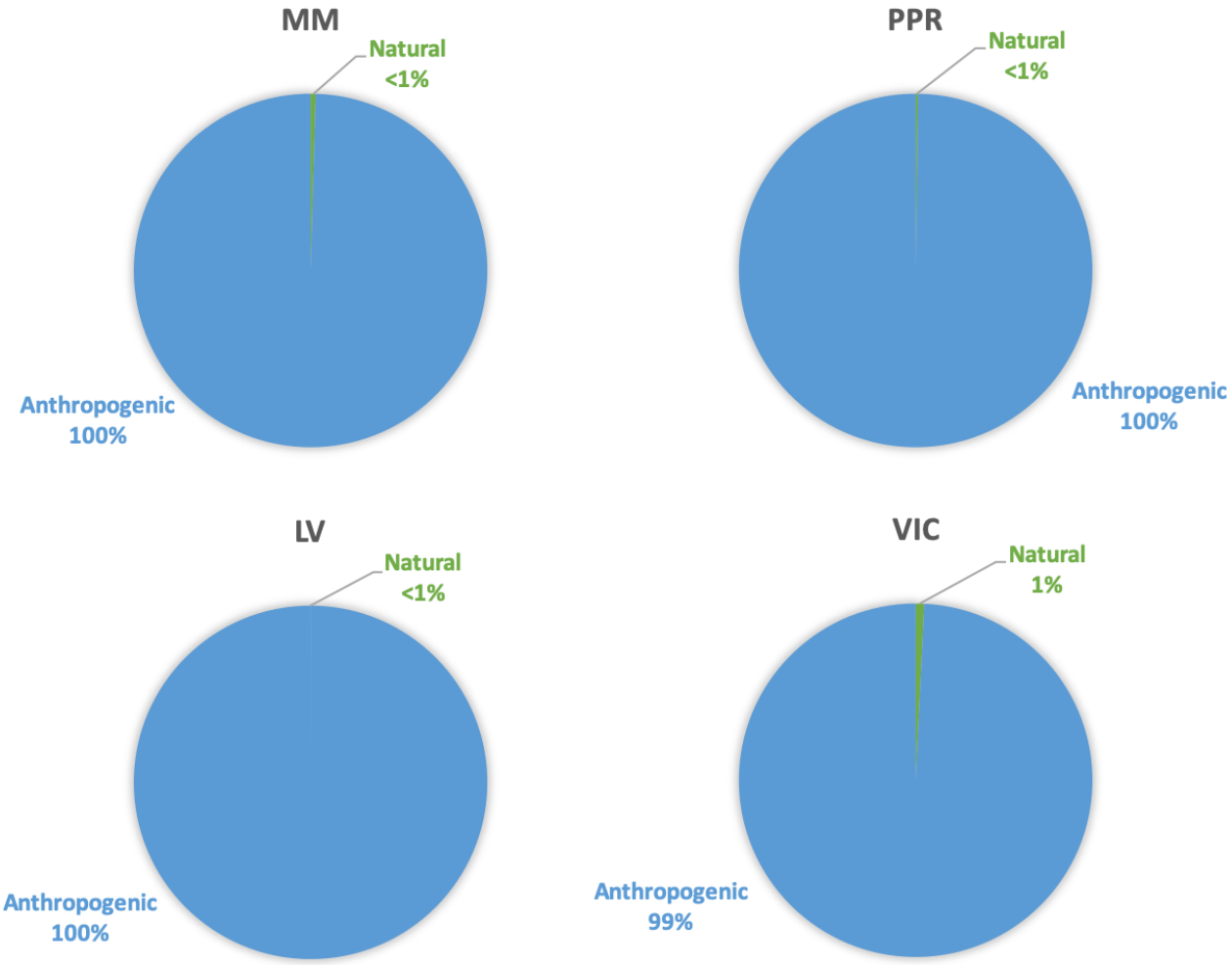

Figure 4-5: Proportions of natural and anthropogenic sulfur dioxide emissions for MM, PPR, LV and VIC.

4.1.4 Total VOCs

Table 4-6 is a summary of the total natural and anthropogenic emissions of total VOC for the four regions. For the state of Victoria, 1,182,039 tonnes of total VOC was emitted in 2016. Out of these, only 15%, 11% and 5% came from PPR, MM and LV, respectively. Thus, most of the emissions were outside these sub-regions which points to a natural source. There were 1,065,178 tonnes of natural VOC emitted in VIC with sub-regions contributing to a combined total of 3.6%. From anthropogenic sources, there were 116,860 tonnes of VOC emissions for VIC with 71%, 64% and 5% from PPR, MM and LV, respectively.

Table 4-6: Total estimated natural and anthropogenic emissions of total VOC for each region

Pollutant	Region	Emissions (tonnes/year)		
		Natural	Anthropogenic	Total
Total VOC	MM	60,709	74,960	135,669
	PPR	98,632	83,002	181,634
	LV	54,786	6,264	61,051
	VIC	1,065,178	116,860	1,182,039

The pie charts in **Figure 4-6** show the relative contribution of natural versus anthropogenic emissions to the total VOC emissions. There are more VOC emissions from anthropogenic sources (55%) than natural sources in MM. This is reversed for PPR with more VOC emissions from natural sources (54%). For LV and across the state of VIC, the natural sources (90%) dominate the contribution to total VOC emissions.

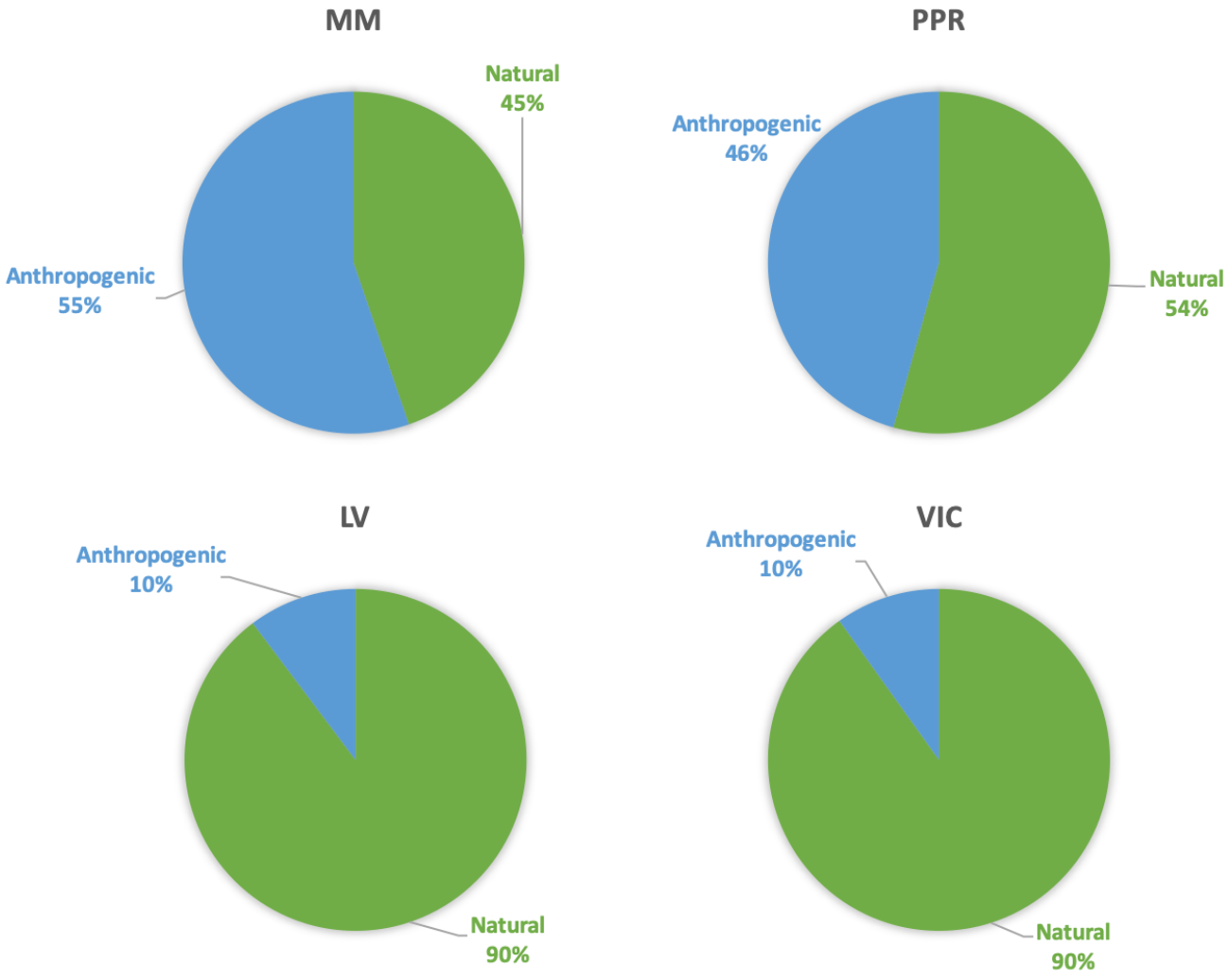

Figure 4-6: Proportions of natural and anthropogenic VOC emissions for MM, PPR, LV and VIC

4.2 Pollutant emissions from anthropogenic and natural sources for each region

In this section, the relative contributions of emission sources are presented. The anthropogenic sources are presented as commercial, domestic-commercial, industrial, off-road mobile, and on-road mobile whereas natural sources, are presented as total natural sources.

4.2.1 Carbon monoxide

Table 4-7 is a summary of the total emissions of carbon monoxide from each of the five anthropogenic emission sources as well as natural emissions for MM, PPR, LV and VIC.

Table 4-7: Estimated sectoral anthropogenic and natural emissions of carbon monoxide for each region

Pollutant	Region	Emissions (tonnes/year)						
		Commercial	Domestic-commercial	Industrial	Off-road mobile	On-road mobile	Natural	Total
Carbon monoxide	MM	2.65	54,315	7,483	3,823	94,057	2,254	161,935
	PPR	3.12	65,085	7,927	3,888	108,599	2,786	188,288
	LV	0.28	6,695	23,751	33	8,150	1,647	40,277
	VIC	4.07	112,322	62,495	4,811	188,522	123,056	491,211

The relative contributions by each sector for the four regions are shown in pie charts in **Figure 4-7**. With the exception of LV, the largest contributing sector to carbon monoxide emissions is motor vehicles (on-road mobile sources), contributing as much as 58% for both MM and PPR and 38% for VIC. In LV, industrial sources (mainly power stations) make up the largest (59%) contribution to total carbon monoxide emissions. The domestic-commercial sector is the second largest contributing sector to carbon monoxide emissions in MM (34%) and PPR (35%) whereas on-road (20%) and natural (25%) sources make the second largest contributions for LV and VIC, respectively.

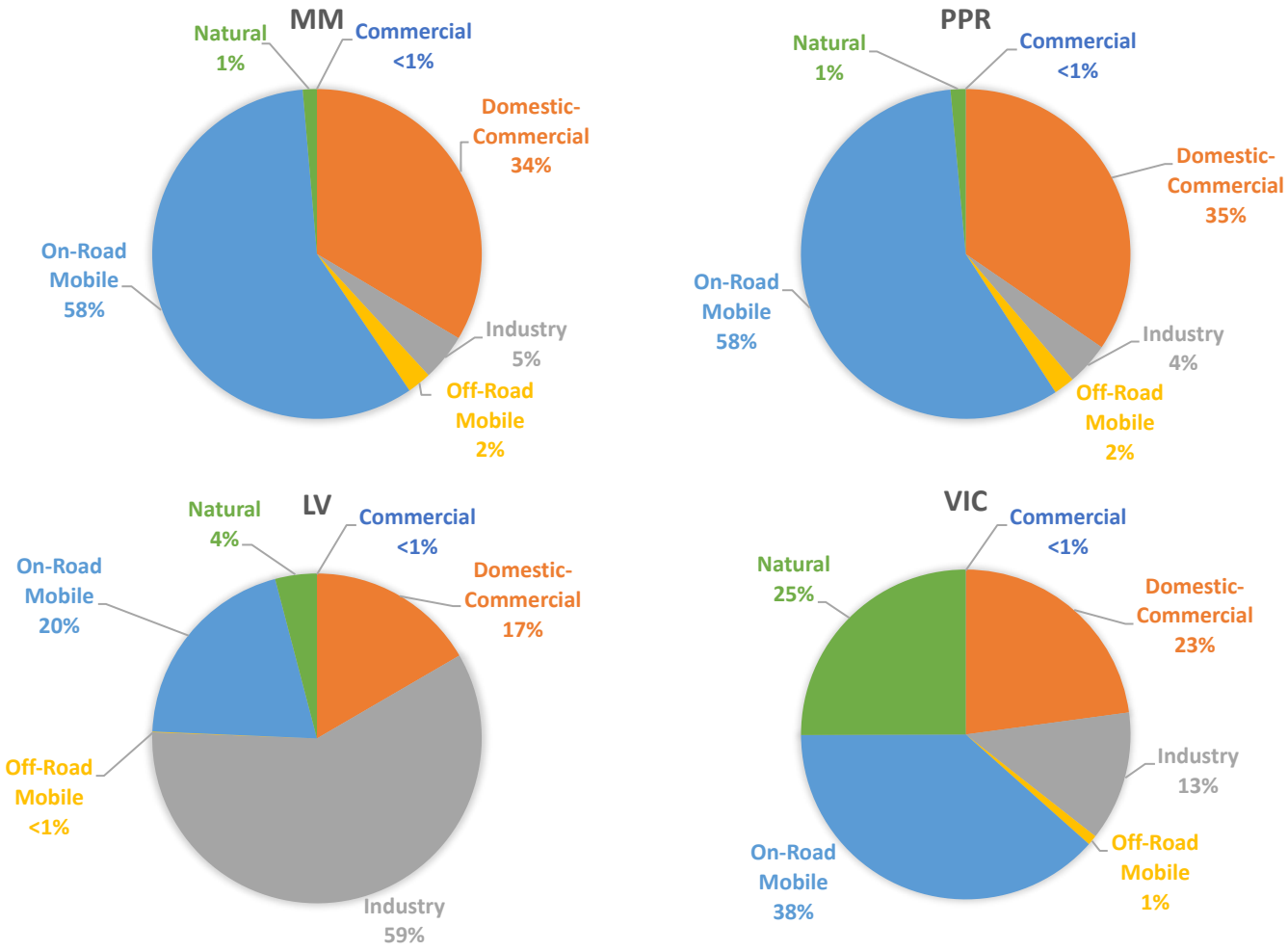

Figure 4-7: Relative proportions of anthropogenic sectoral and natural carbon monoxide emissions for MM, PPR, LV and VIC.

4.2.2 Oxides of nitrogen

Table 4-8 is a summary of the total emissions of oxides of nitrogen from each of the five anthropogenic emission sources as well as natural emissions for MM, PPR, LV and VIC. In general, the least contribution anthropogenic sector is the commercial sector followed by the domestic-commercial sector. As shown in **Figure 4-8,** MM and PPR have similar oxides of nitrogen profiles with the largest contribution from on-road sources (68%), followed by industrial sources (25%). Industrial sources make the largest contributor to oxides of nitrogen emissions in LV (97%) and VIC (54%), seconded by on-road sources at 3% and 35%, respectively.

Table 4-8: Estimated sectoral anthropogenic and natural emissions of oxides of nitrogen for each region

Pollutant	Region	Emissions (tonnes/year)						
		Commercial	Domestic-commercial	Industrial	off-road mobile	On-road mobile	Natural	Total
Oxides of nitrogen	MM	4.21	686	11,562	2,089	31352	466	46160
	PPR	5.01	824	13,303	2,191	36,200	792	53,315
	LV	0.34	63	81,363	0.33	2,301	283	83,911
	VIC	6.49	1,431	97,593	3,389	62,841	14,801	180,062

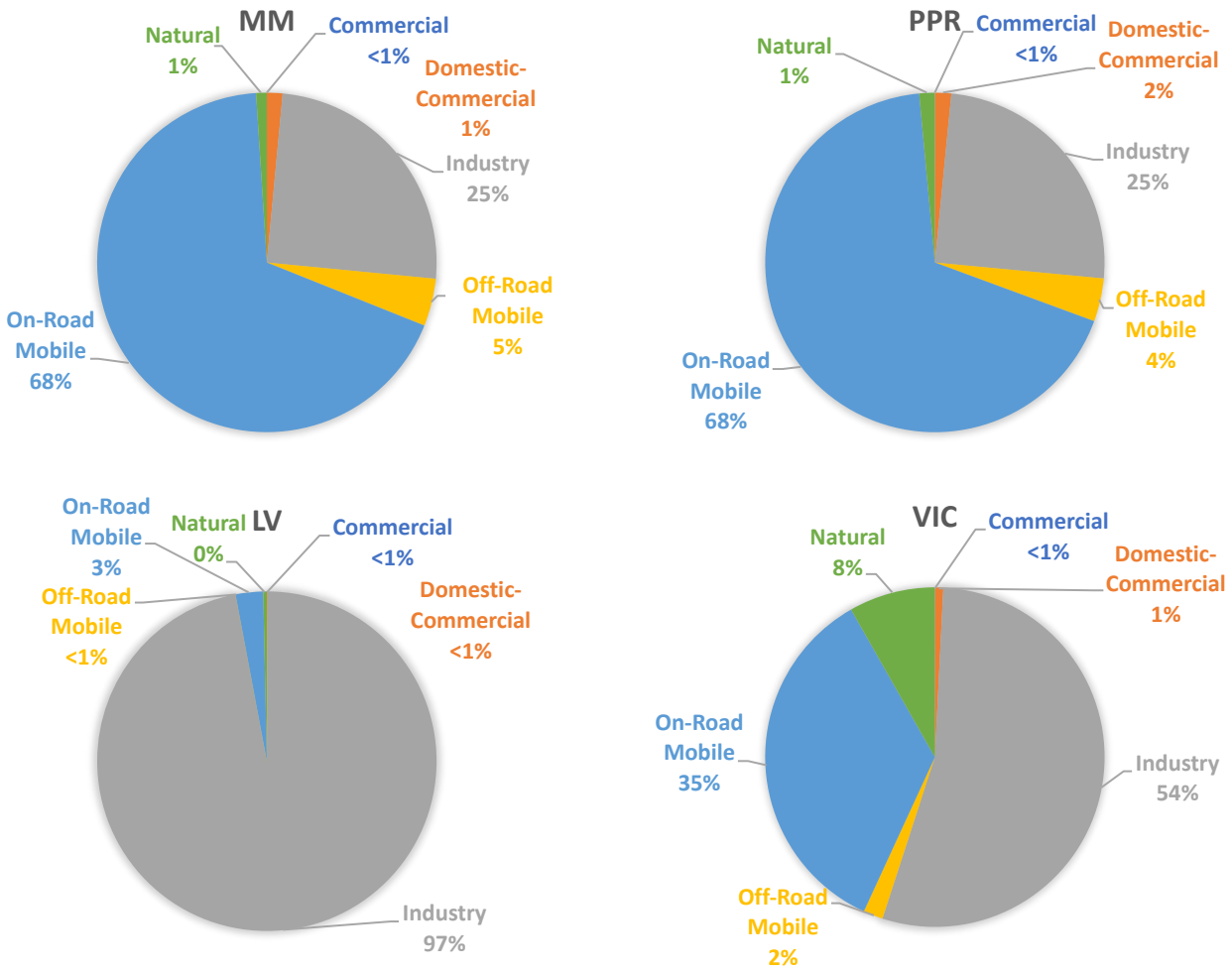

Figure 4-8: Relative proportions of sectoral anthropogenic and natural oxides of nitrogen emissions for MM, PPR, LV and VIC.

4.2.3 Particulate matter ≤ 2.5 μm

Table 4-9 is a summary of the total emissions of $PM_{2.5}$ from each of the five anthropogenic emission sources as well as from the natural emission sector for MM, PPR, LV and VIC.

Table 4-9: Estimated sectoral anthropogenic and total natural emissions of $PM_{2.5}$ for each region

Pollutant	Region	Emissions (tonnes/year)						
		Commercial	Domestic-commercial	Industrial	Off-road mobile	On-road mobile	Natural	Total
$PM_{2.5}$	MM	140	1,978	325	259	1,182	331	4,214
	PPR	150	2,343	558	272	1,364	630	5,317
	LV	1.5	173	2,905	4.79	83	146	3,313
	VIC	165	4,030	3,629	444	2,369	12,396	23,033

Domestic-commercial sources are the largest source of $PM_{2.5}$ emissions in MM and PPR, contributing as much as 47% and 44% of all $PM_{2.5}$ emissions, respectively (**Figure 4-9**). Industrial sources contribute 88% of $PM_{2.5}$ emissions in LV followed by domestic-commercial and natural at 5% and 4%, respectively. Across VIC, natural emissions are the largest source of $PM_{2.5}$ emissions (53%) followed by domestic-commercial (17%) and industrial (16%) sources.

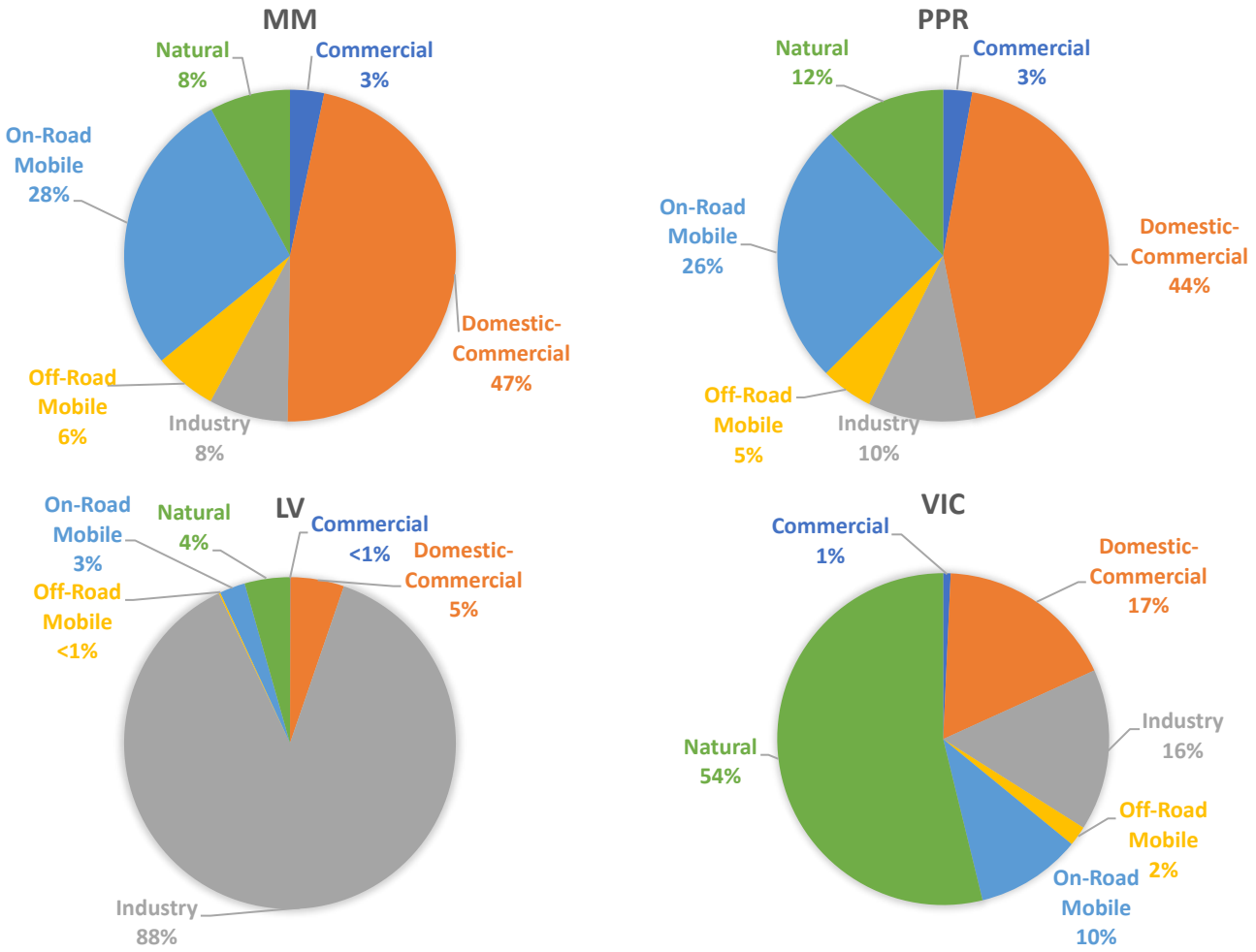

Figure 4-9: Relative proportions of anthropogenic (sectoral) and natural $PM_{2.5}$ emissions for MM, PPR, LV and VIC.

4.2.3 Particulate matter ≤ 10 μm

Table 4-10 is a summary of the total emissions of PM_{10} from each of the five anthropogenic emission sources as well as from the natural emission source for MM, PPR and VIC.

Table 4-10: Estimated sectoral anthropogenic and natural emissions of PM_{10} for each region

Pollutant	Region	Emissions (tonnes/year)						
		Commercial	Domestic-Commercial	Industrial	Off-road mobile	On-road mobile	Natural	Total
PM_{10}	MM	0.87	3,296	3,040	272	16,626	1,479	24,714
	PPR	1.05	3,904	3,685	285	19,196	2,624	29,695
	LV	0.03	289	11,821	5.02	1,167	320	13,602
	VIC	1.34	6,717	23,813	466	33,323	292,017	356,337

Pie charts showing various emission sectoral contributions are shown in **Figure 4-10.** The largest emission sectoral source in MM and PPR are on-road mobile sources, contributing as much as 67% and 65% of all PM_{10} emissions (natural sources included), respectively. Industry is again the largest source of PM_{10} in LV (87%) whereas natural sources make the largest contribution across VIC (82%). The bulk of these emissions are from windblown dust in the northwest region of the state.

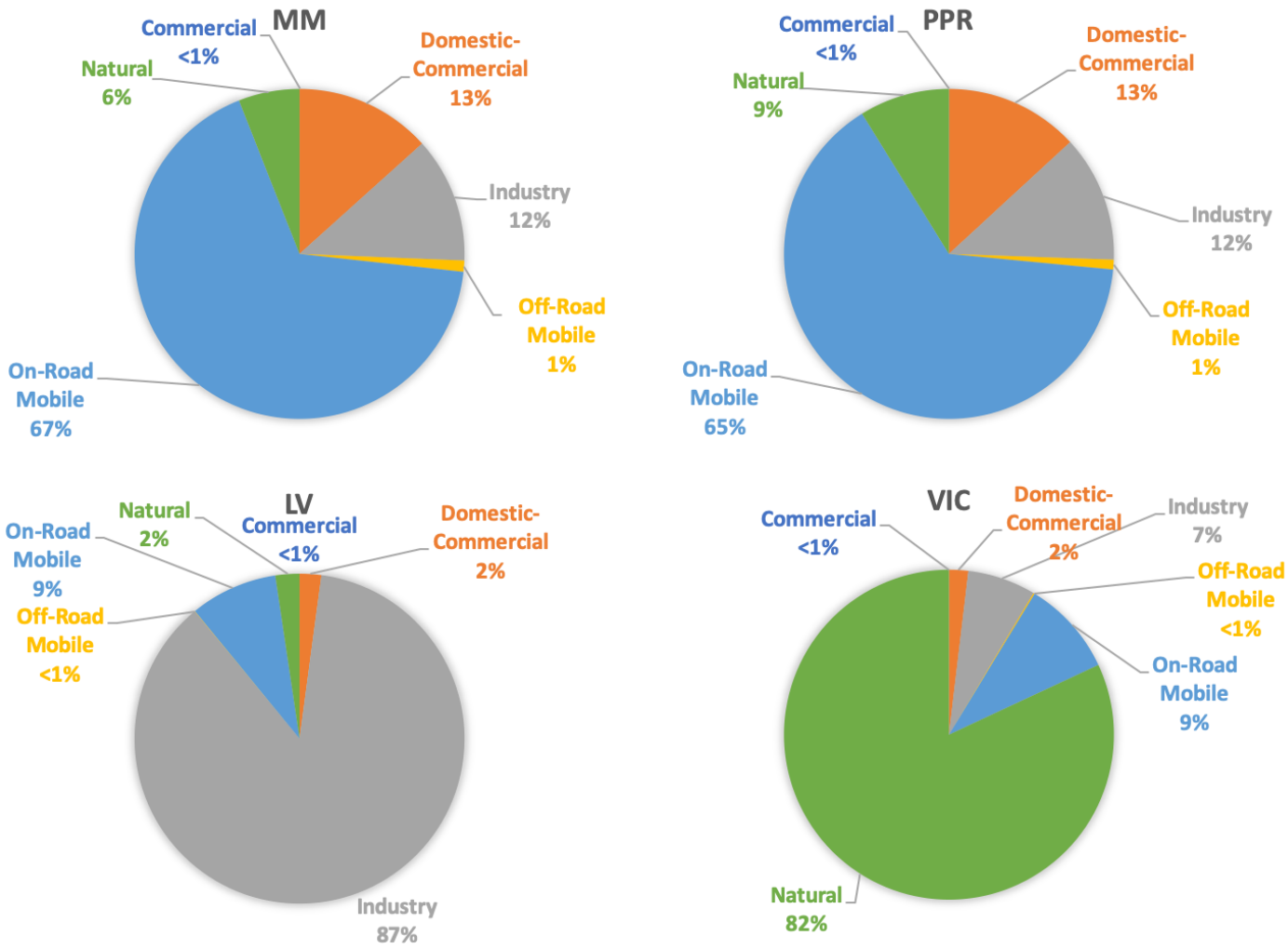

Figure 4-10: Relative proportions of sectoral anthropogenic and natural PM_{10} emissions for MM, PPR, LV and VIC.

4.2.3 Sulfur dioxide

Table 4-11 is a summary of the total emissions of sulfur dioxide from each of the five anthropogenic emission sources as well as from the natural emission source for MM, PPR, LV and VIC.

Table 4-11: Estimated sectoral anthropogenic and natural emissions of sulfur dioxide for each region

Pollutant	Region	Emissions (tonnes/year)						
		Commercial	Domestic-commercial	Industrial	Off-road mobile	On-road mobile	Natural	Total
Sulfur dioxide	MM	1.25	109	4,017	136	145	20.5	4,429
	PPR	1.51	131	11,525	139	167	25.4	11,989
	LV	0.04	10.3	124,806	0.03	10.2	15.0	124,841
	VIC	1.94	231	143,038	172	291	1,120	144,854

Sulfur dioxide is largely an industrial pollutant with industry making up 91% in MM, 96% in PPR, over 99% in LV and 99% across VIC (**Figure 4-11**).

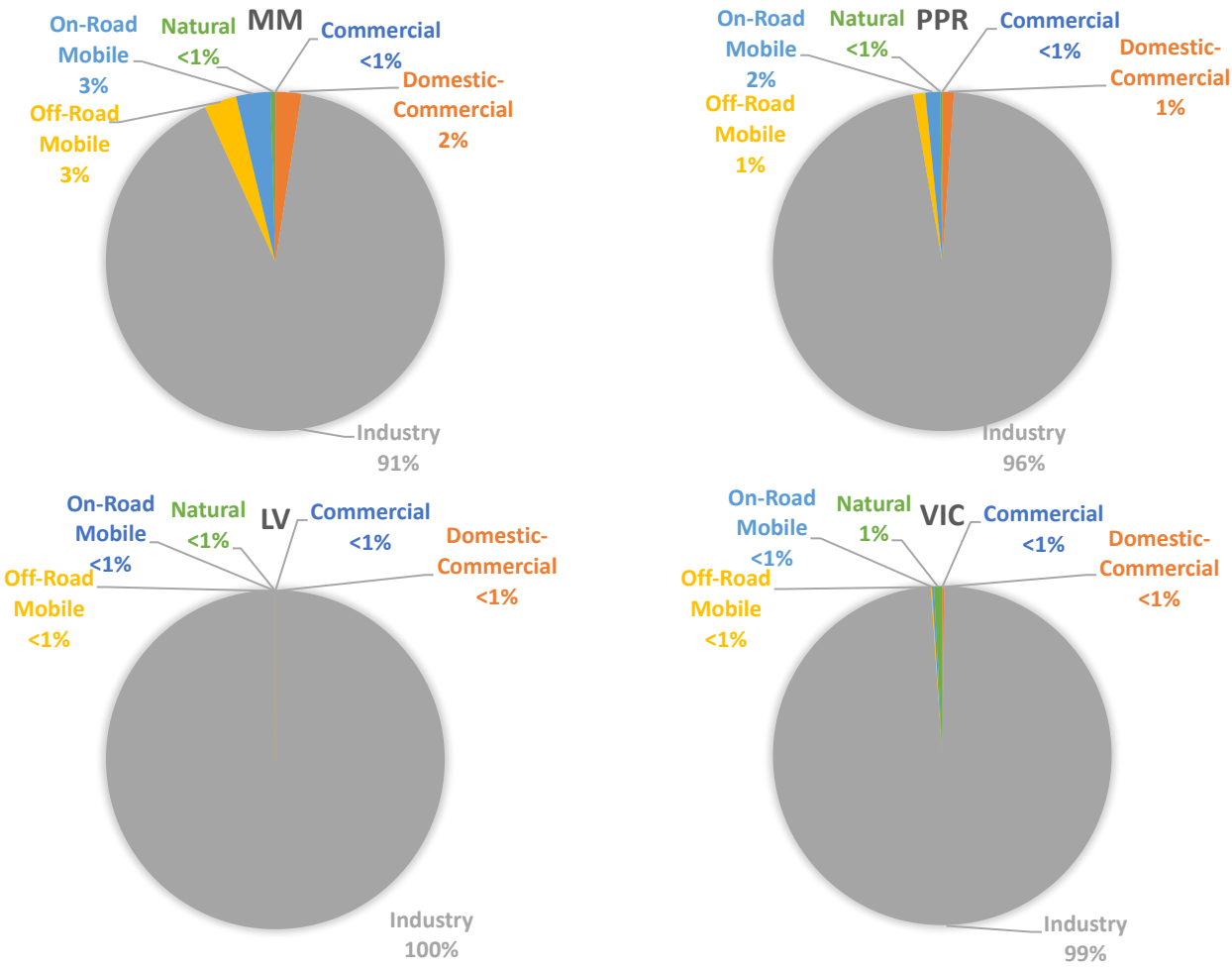

Figure 4-11: Relative proportions of sectoral anthropogenic and natural sulfur dioxide emissions for MM, PPR, LV and VIC.

4.2.4 Total VOC

Table 4-12 is a summary of the total emissions of sulfur dioxide from each of the five anthropogenic emission sources as well as from the natural emission source for MM, PPR, LV and VIC.

Table 4-12: Estimated sectoral anthropogenic and natural emissions of total VOC for each region

Pollutant	Region	Emissions (tonnes/year)						
		Commercial	Domestic-commercial	Industrial	Off-road mobile	On-road mobile	Natural	Total
VOC	MM	7,559	50,652	6,720	382	9,647	60,709	135,669
	PPR	7,958	55,985	7,533	388	11,138	98,632	181,634
	LV	242	2,232	3,112	0.57	677	54,786	61,051
	VIC	10,002	75,427	11,602	493	19,336	1,065,178	1,182,039

As shown in **Figure 4-12,** the largest contributing emission sector to total VOC emissions is made by natural sources, with 45% in MM, 54% in PPR and 90% in both LV and across the whole state of VIC. The domestic-commercial source is the second largest source of VOC emissions in MM (37%) and PPR (31%).

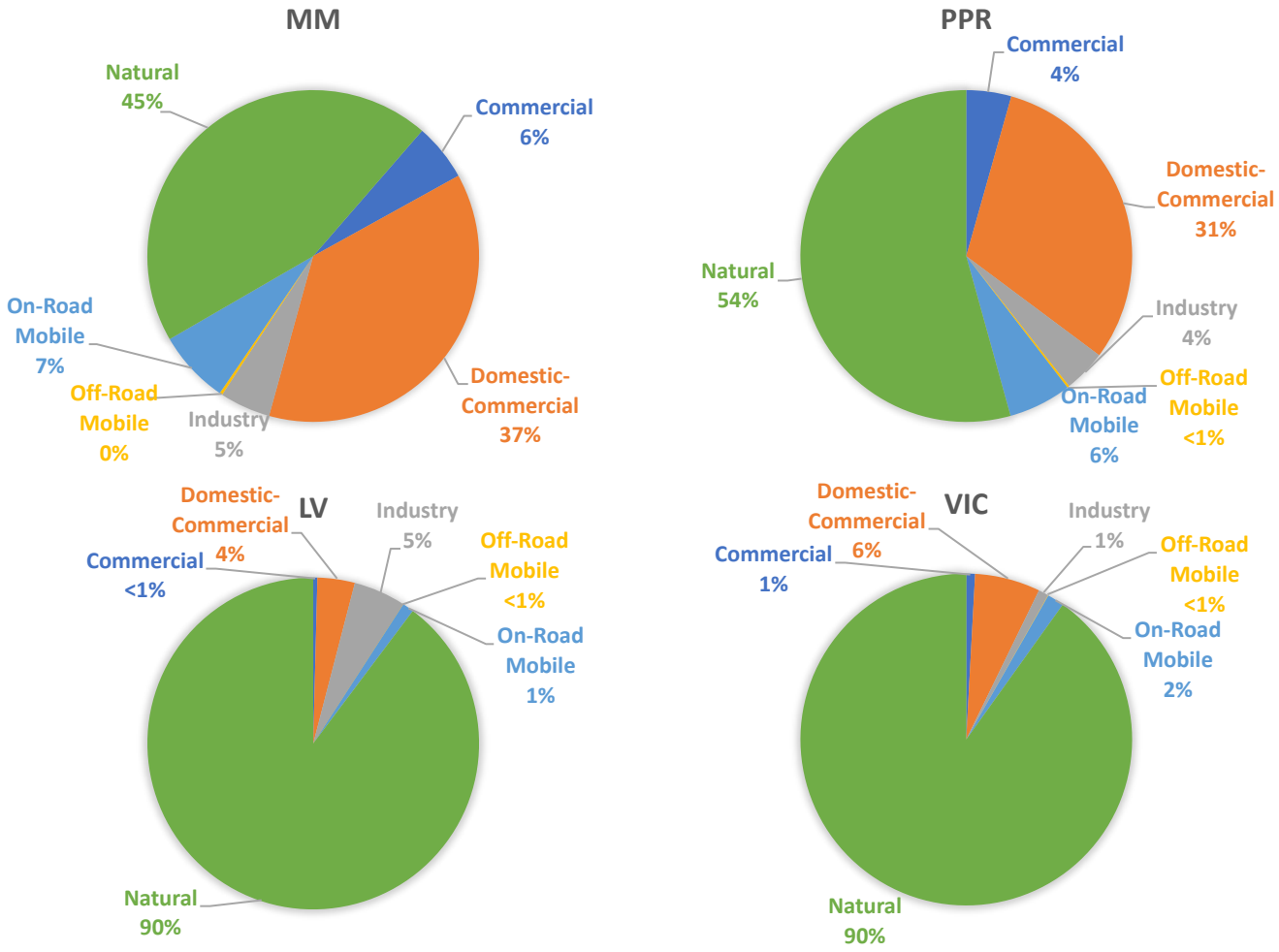

Figure 4-12: Relative proportions of anthropogenic emission sources and natural emissions of total VOC for MM, PPR, LV and VIC.

4.3 Pollutant emissions from anthropogenic sources for each region

In Section 4.2 above, relative contributions of anthropogenic emission sources to total emissions (that is including natural sources) were presented. In this section, only a summary of the relative contribution of anthropogenic emission sources to total anthropogenic sources are presented as pie charts. The results are similar to those presented in the previous section, the only difference being the relative contributions from the various anthropogenic sources are increased with the removal of the natural source from the emissions totals.

4.3.1 Carbon monoxide anthropogenic sources only

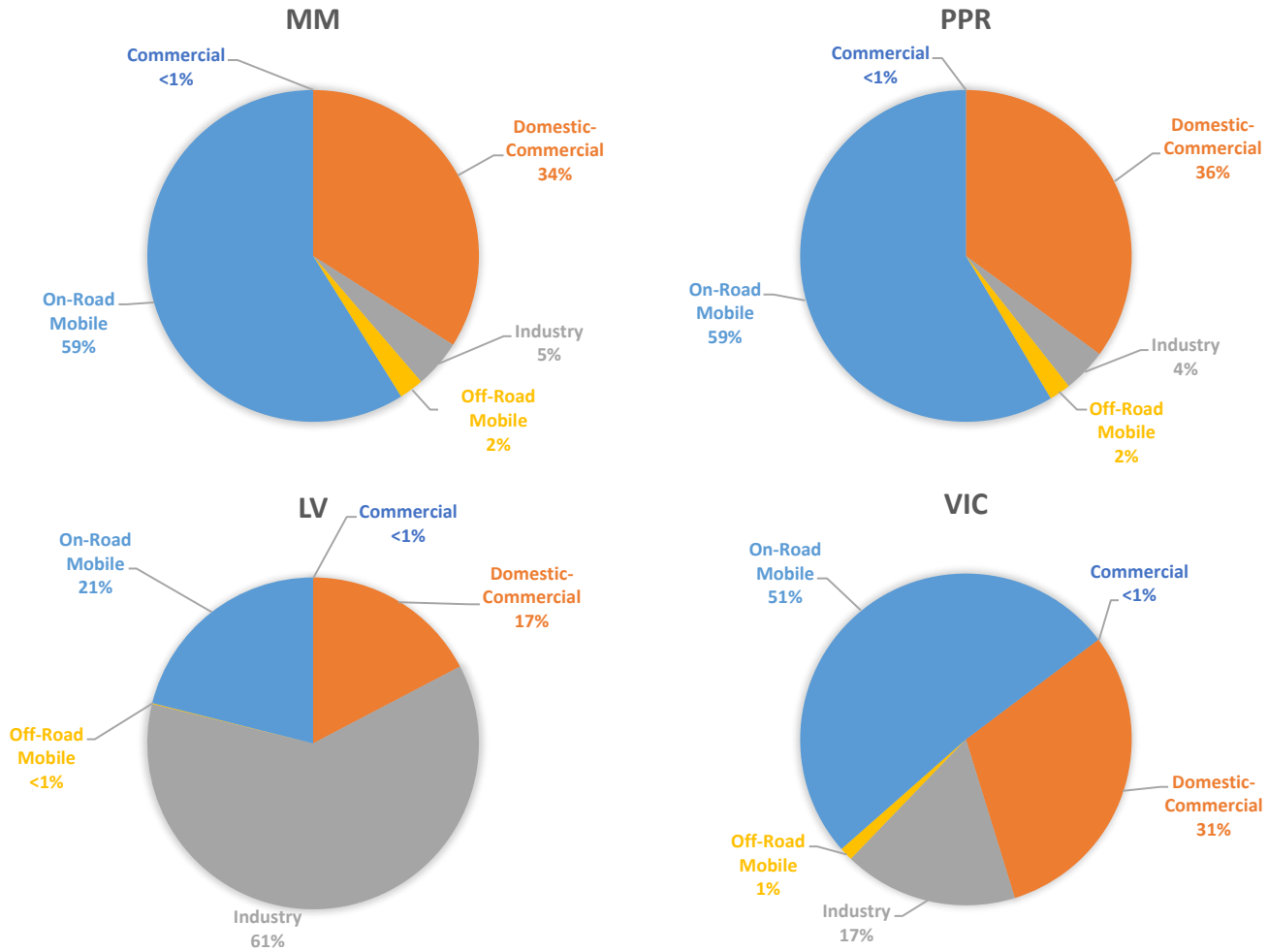

Figure 4-13: Relative contribution of anthropogenic emission sources to total anthropogenic emissions of carbon monoxide for MM, PPR, LV and VIC.

4.3.2 Oxides of nitrogen- anthropogenic sources only

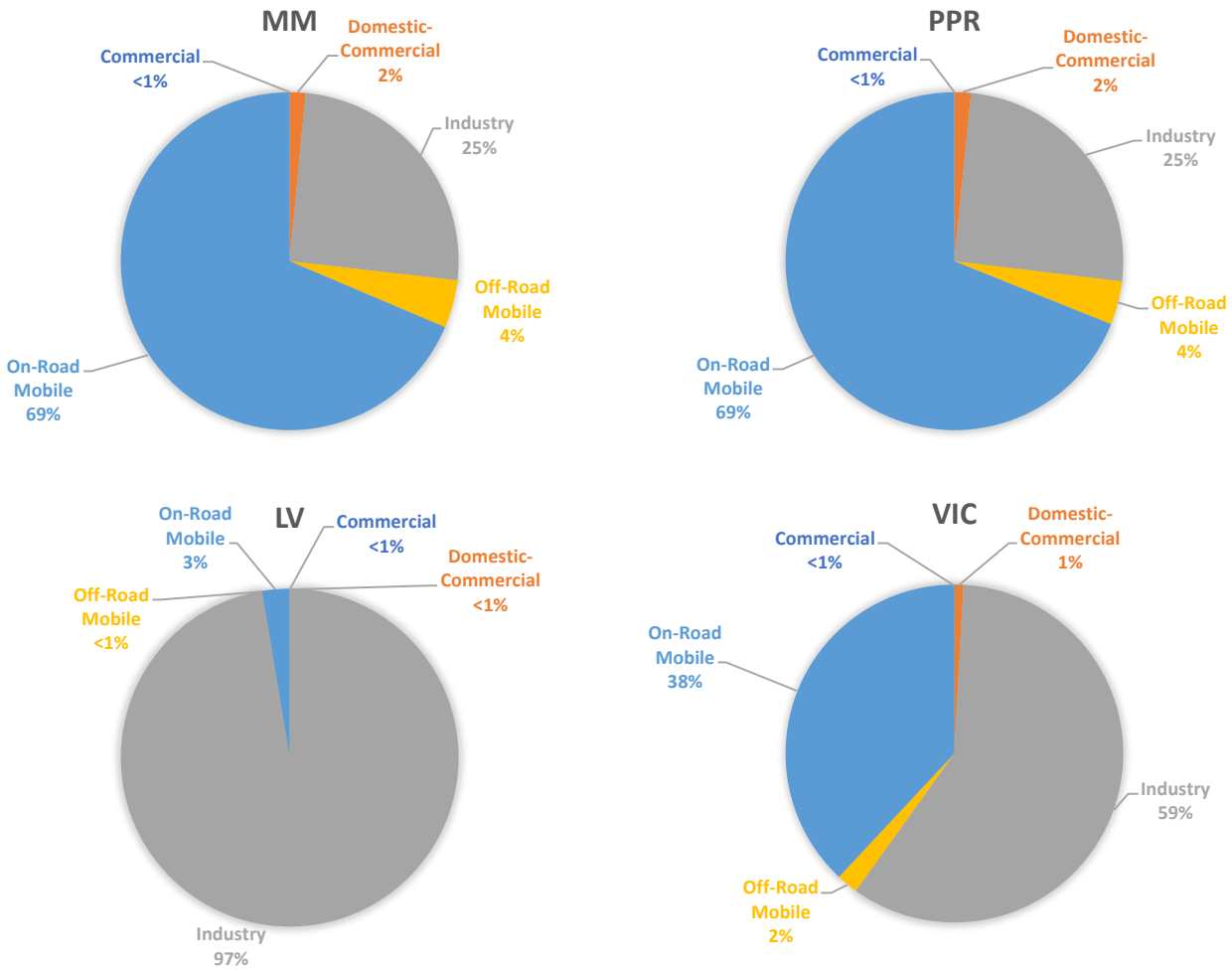

Figure 4-14: Relative contribution of anthropogenic emission sources to total anthropogenic emissions of oxides of nitrogen for MM, PPR, LV and VIC.

4.3.3 Particulate matter ≤ 2.5 μm - anthropogenic sources only

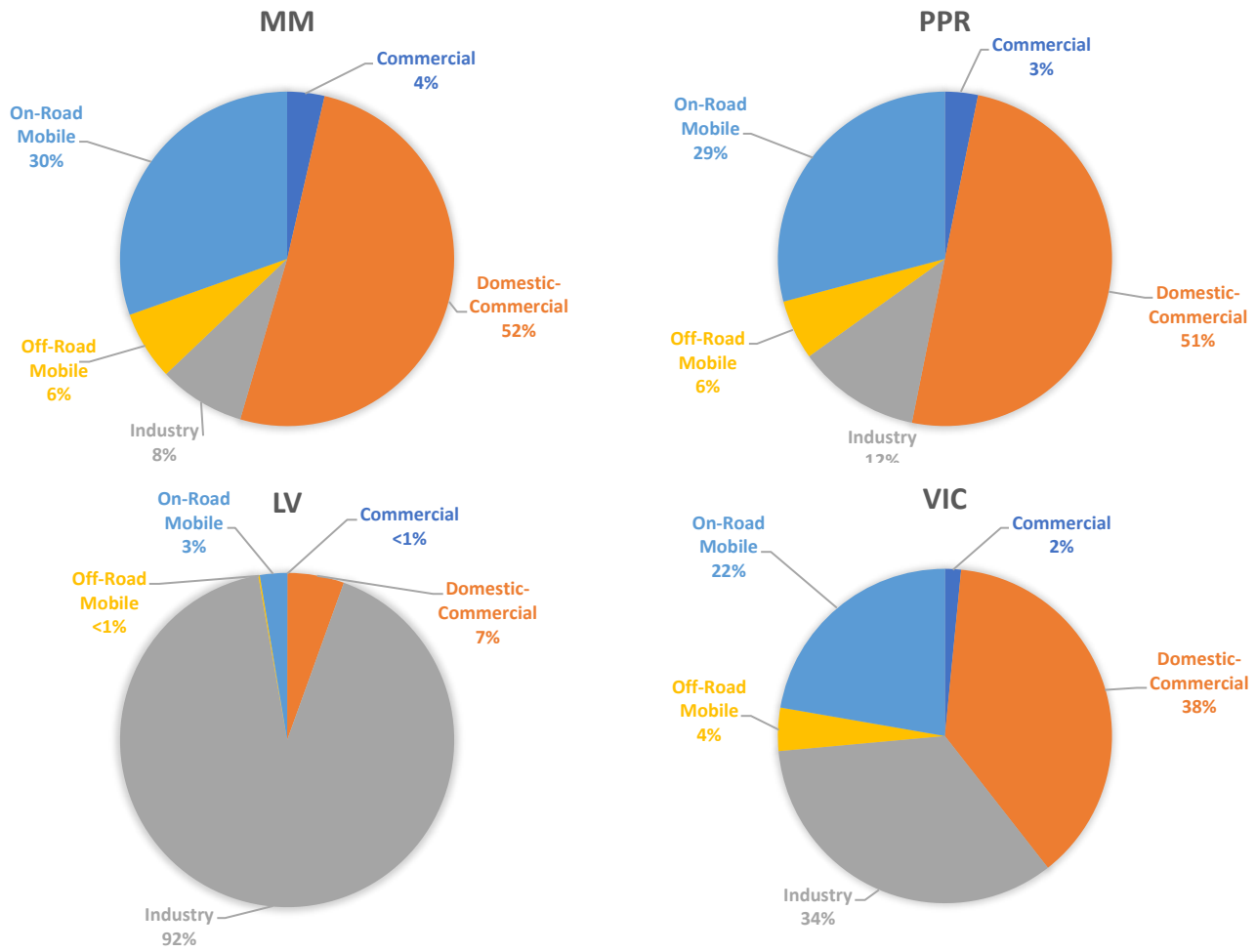

Figure 4-15: Relative contribution of anthropogenic emission sources to total anthropogenic emissions of $PM_{2.5}$ for MM, PPR, LV and VIC.

4.3.4 Particulate matter ≤ 10.0 μm - anthropogenic sources only

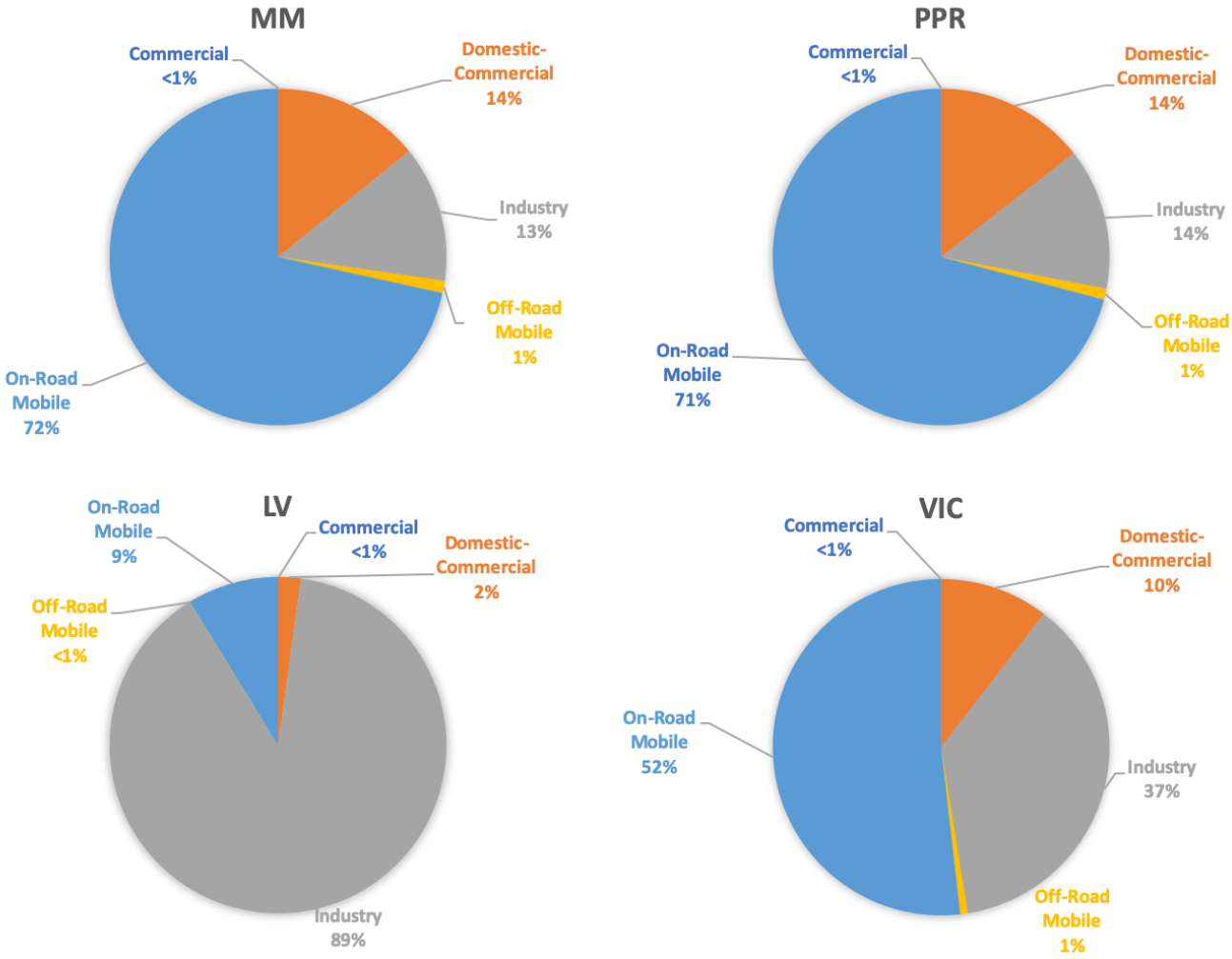

Figure 4-16: Relative contribution of anthropogenic emission sources to total anthropogenic emissions of PM_{10} for MM, PPR, LV and VIC.

4.3.5 Sulfur dioxide - anthropogenic sources only

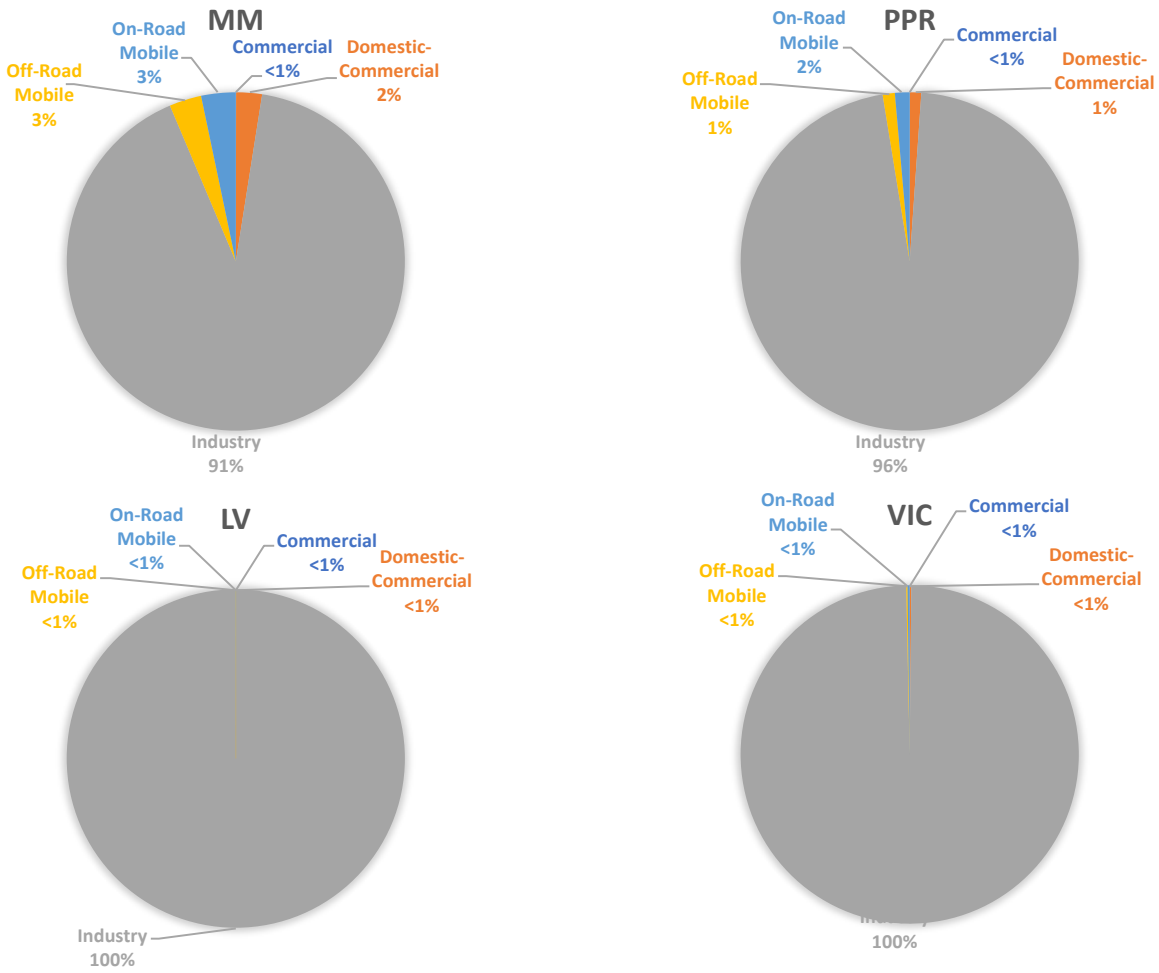

Figure 4-17: Relative contribution of anthropogenic emission sources to total anthropogenic emissions of sulfur dioxide for MM, PPR, LV and VIC.

4.3.6 Total VOC - anthropogenic sources only

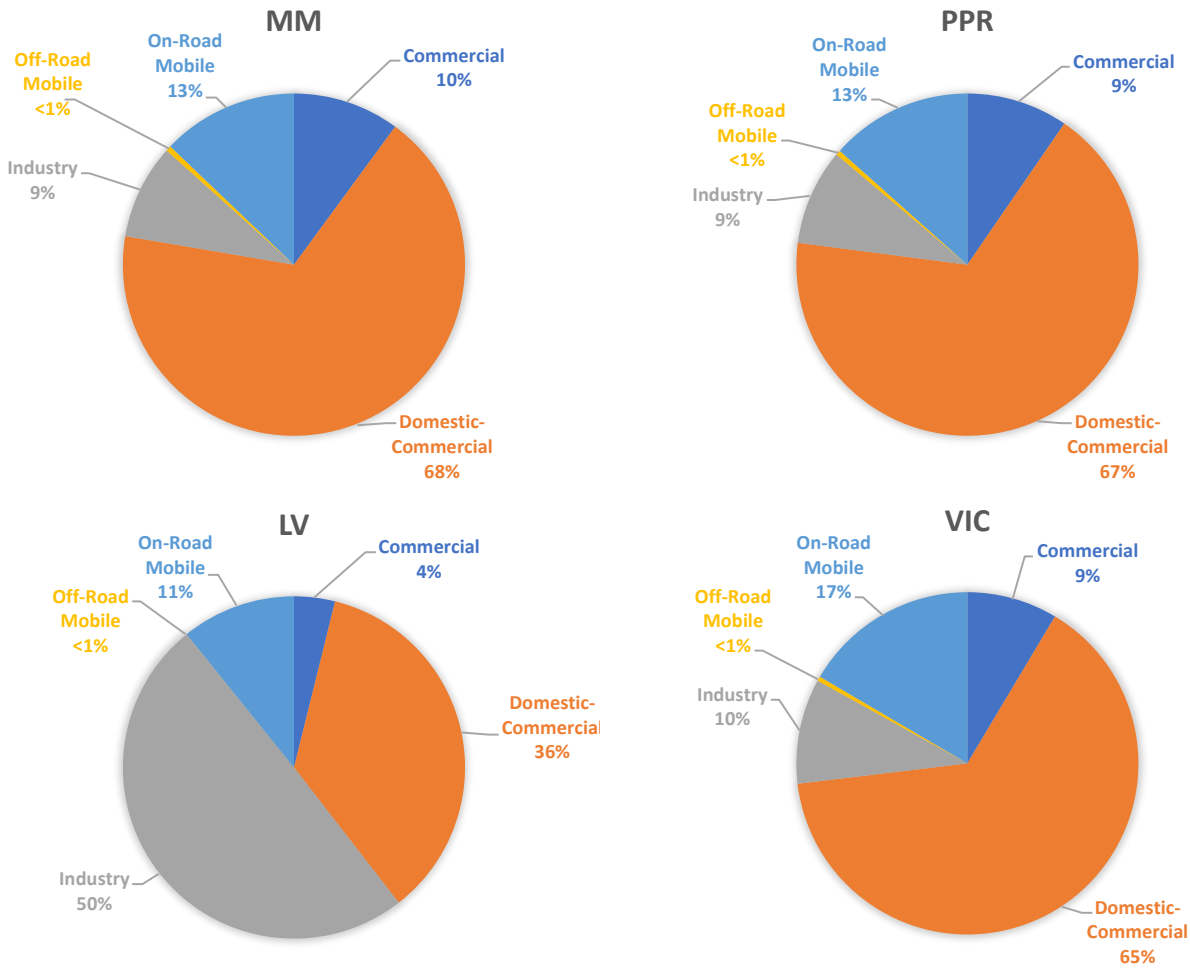

Figure 4-18: Relative contribution of anthropogenic emission sources to total anthropogenic emissions of total VOC for MM, PPR, LV and VIC.

4.4 Tables of top 10 contributing sources to anthropogenic emissions

Top 10 contributing sources to anthropogenic emissions are presented for each pollutant in the tables below. The contributions from the industrial sector have been further categorised into their respective Australian and New Zealand Standard Industrial Classification (ANZSIC) classifications. Also shown are both the proportion that each sector makes to total anthropogenic emission as well as combined cumulative proportions for the top 10 contributing sources. The last row in each table shows the contribution of remaining sources outside the top 10.

4.4.1 Carbon monoxide

Table 4-13: Total estimated annual emissions, proportion and cumulative proportion of carbon monoxide for MM

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
On-road mobile	Motor vehicles	94057.5	58.9	58.9
Domestic	Wood heaters	54314.7	34	92.9
Off-road mobile	Aircraft	3791.4	2.4	95.3
Industry	Other electricity generation	1259.1	0.8	96.1
Industry	Oil and fat manufacturing	771.9	0.5	96.6
Industry	Metal coating and finishing	753.3	0.5	97
Industry	Gas supply	742.9	0.5	97.5
Industry	Oil and gas extraction	653.5	0.4	97.9
Industry	Iron and steel casting	525.5	0.3	98.2
Industry	Plaster product manufacturing	418.6	0.3	98.5
Industry	Other	2392.84	1.5	100

Table 4-14: Total estimated annual emissions, proportion and cumulative proportion of carbon monoxide for PPR

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
On-road mobile	Motor vehicles	114274.8	58.1	58.1
Domestic	Wood heaters	70286.6	35.7	93.8
Off-road mobile	Aircraft	3869.4	2	95.8
Industry	Other electricity generation	1297.7	0.7	96.5
Industry	Oil and fat manufacturing	771.9	0.4	96.9
Industry	Metal coating and finishing	758.1	0.4	97.2
Industry	Gas supply	742.9	0.4	97.6
Industry	Oil and gas extraction	653.5	0.3	98
Industry	Iron and steel casting	525.5	0.3	98.2
Industry	Plaster product manufacturing	418.6	0.2	98.4
Industry	Other	3074.43	1.56	100

Table 4-15: Total estimated annual emissions, proportion and cumulative proportion of carbon monoxide for LV

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Industry	Fossil fuel electricity generation	21239.7	55	55
On-road mobile	Motor vehicle	8149.8	21.1	76.1
Domestic	Wood heater	6695.5	17.3	93.4
Industry	Oil and gas extraction	1716.2	4.4	97.9
Industry	Pulp, paper and paperboard manufacturing	391.1	1	98.9
Industry	Cement and lime manufacturing	201.3	0.5	99.4
Industry	Log sawmilling	119.2	0.3	99.7
Off-road mobile	Aircraft	32.8	0.1	99.8
Industry	Milk and cream processing	27.6	0.1	99.9
Industry	Gas supply	16.4	0	99.9
Industry	Other	40.32	0.1	100

Table 4-16: Total estimated annual emissions, proportion and cumulative proportion of carbon monoxide for VIC

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
On-road mobile	Motor vehicles	188522.41	51.2	51.2
Domestic	Wood heaters	112321.95	30.5	81.7
Industry	Aluminium smelting	28888.76	7.8	89.6
Industry	Fossil fuel electricity generation	21347.6	5.8	95.4
Off-road mobile	Aircraft	4587.72	1.2	96.6
Industry	Oil and gas extraction	3301.75	0.9	97.5
Industry	Other electricity generation	1360.96	0.4	97.9
Industry	Oil and fat manufacturing	779.85	0.2	98.1
Industry	Gas supply	775.61	0.2	98.3
Industry	Metal coating and finishing	758.12	0.2	98.5
Industry	Other	5509.8	1.5	100

4.4.2 Oxides of nitrogen

Table 4-17: Total estimated annual emissions, proportion and cumulative proportion of oxides of nitrogen for MM

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
On-road mobile	Motor vehicles	31352.5	68.6	68.6
Industry	Gas Supply	2865.6	6.3	74.9
Off-road Mobile	Aircraft	1871.1	4.1	79
Industry	Glass and glass product manufacturing	1649.5	3.6	82.6
Industry	Oil and fat manufacturing	1175.2	2.6	85.2
Industry	Petroleum refining and petroleum fuel manufacturing	931.7	2	87.2
Industry	Oil and gas extraction	823.3	1.8	89
Domestic	Wood heaters	686.2	1.5	90.5
Industry	Other electricity generation	558.4	1.2	91.7
Industry	Waste treatment and disposal services	544.9	1.2	92.9
Industry	Other	3235.44	7.08	100

Table 4-18: Total estimated annual emissions, proportion and cumulative proportion of oxides of nitrogen for PPR

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
On-road mobile	Motor vehicle	38091.6	69.6	69.6
Industry	Gas Supply	2865.6	5.2	74.9
Off-road mobile	Aircraft	1872.1	3.4	78.3
Industry	Glass and glass product manufacturing	1649.5	3	81.3
Industry	Petroleum refining and petroleum fuel manufacturing	1561.5	2.9	84.2
Industry	Oil and fat manufacturing	1175.2	2.1	86.3
Domestic	Wood heater	890.7	1.6	88
Industry	Oil and gas extraction	823.3	1.5	89.5
Industry	Fossil fuel electricity generation	658.4	1.2	90.7
Industry	Other electricity generation	563	1	91.7
Industry	Other	4540.45	8.3	100

Table 4-19: Total estimated annual emissions, proportion and cumulative proportion of oxides of nitrogen for LV

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Industry	Fossil fuel electricity generation	78311.2	93	93
On-road mobile	Motor vehicle	2716.6	3.2	96.2
Industry	Oil and gas extraction	1951.5	2.3	98.6
Industry	Pulp, paper and paperboard manufacturing	849.1	1	99.6
Industry	Gas supply	87.7	0.1	99.7
Domestic	Wood heater	86.1	0.1	99.8
Industry	Milk and cream processing	78	0.1	99.9
Industry	Log sawmilling	47.5	0.1	99.9
Industry	Other construction material mining	29.5	0	100
Industry	Cement and lime manufacturing	5.5	0	100
Industry	Other	33.15	0.04	100

Table 4-20: Total estimated annual emissions, proportion and cumulative proportion of oxides of nitrogen for VIC

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Industry	Fossil fuel electricity Generation	79279.89	48.0	48.0
On-road mobile	Motor vehicles	62840.8	38.0	86.0
Industry	Oil and gas extraction	5126.89	3.1	89.1
Industry	Gas supply	2999.75	1.8	90.9
Off-road mobile	Aircraft	1889.05	1.1	92.1
Industry	Glass and glass product manufacturing	1649.53	1.0	93.1
Industry	Petroleum refining and petroleum fuel manufacturing	1561.46	0.9	94.0
Off-road mobile	Rail	1498.75	0.9	94.9
Domestic	Wood heaters	1431.24	0.9	95.8
Industry	Oil and fat manufacturing	1185.39	0.7	96.5
Industry	Other	5798.12	3.51	100

4.4.3 Particulate matter ≤ 2.5 μm

Table 4-21: Total estimated annual emissions, proportion and cumulative proportion of $PM_{2.5}$ for MM

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Domestic	Wood heaters	1977.7	50.9	50.9
On-road mobile	Motor vehicles	1181.7	30.4	81.4
Off-road mobile	Aircraft	253.1	6.5	87.9
Commercial	Charcoal	135	3.5	91.4
Industry	Waste treatment and disposal services	38.9	1	92.4
Industry	Other construction material mining	32.9	0.8	93.2
Industry	Petroleum refining and petroleum fuel manufacturing	31.2	0.8	94
Industry	Fossil fuel electricity generation	22.1	0.6	94.6
Industry	Synthetic resin and synthetic rubber manufacturing	21.9	0.6	95.1
Industry	Gas supply	17	0.4	95.6
Industry	Other	171.74	4.42	100

Table 4-22: Total estimated annual emissions, proportion and cumulative proportion of $PM_{2.5}$ for PPR

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Domestic	Wood heater	2342.5	50.0	50.0
On-road mobile	Motor vehicle	1364.5	29.1	79.9
Off-road mobile	Aircraft	262.7	5.6	84.7
Industry	Petroleum refining and petroleum fuel manufacturing	220.1	4.7	89.4
Commercial	Charcoal	144.0	2.7	92.5
Industry	Waste treatment and disposal services	39.7	0.8	93.3
Industry	Other construction material mining	32.9	0.7	94.0
Industry	Fossil fuel electricity generation	25.6	0.5	94.6
Industry	Synthetic resin and synthetic rubber manufacturing	21.9	0.5	95.0
Industry	Port and water transport terminal operations	19.9	0.4	95.5
Industry	Other	213.22	4.5	100

Table 4-23: Total estimated annual emissions, proportion and cumulative proportion of $PM_{2.5}$ for LV

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Industry	Fossil fuel electricity generation	2781.2	87.8	87.8
Domestic	Wood heater	173.3	5.5	93.3
On-road mobile	Motor vehicle	83.0	2.6	95.9
Industry	Pulp, paper and paperboard manufacturing	63.6	2	97.9
Industry	Oil and gas extraction	42.2	1.3	99.2
Industry	Log sawmilling	6.9	0.2	99.5
Off-road mobile	Aircraft	4.8	0.2	99.6
Industry	Gas supply	4.2	0.1	99.7
Industry	Milk and cream processing	4.1	0.1	99.8
Industry	Other construction material mining	2.2	0.1	99.9
Industry	Other	2.1	0.1	100

Table 4-24: Total estimated annual emissions, proportion and cumulative proportion of $PM_{2.5}$ for VIC

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Domestic	Wood heaters	4029.89	37.9	37.9
Industry	Fossil fuel electricity generation	2826.27	26.6	64.5
On-road mobile	Motor vehicles	2368.61	22.3	86.7
Off-road mobile	Aircraft	403.1	3.8	90.5
Industry	Petroleum refining and petroleum fuel manufacturing	220.12	2.1	92.6
Commercial	Charcoal	157.47	1.5	94.1
Industry	Oil and gas extraction	97.12	0.9	95
Industry	Pulp, paper and paperboard manufacturing	69.99	0.7	95.6
Industry	Waste treatment and disposal services	40.98	0.4	96
Off-road mobile	Rail	40.93	0.4	96.4
Industry	Other	382.59	3.6	100

4.4.4 Particulate matter ≤ 10 μm

Table 4-25: Total estimated annual emissions, proportion and cumulative proportion of PM_{10} for MM

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
On-road mobile	Motor vehicles	16625.6	71.6	71.6
Domestic	Wood heater	3296.1	14.2	85.7
Industry	Other Construction Material Mining	1303	5.6	91.4
Industry	Clay Brick Manufacturing	487.4	2.1	93.4
Off-road mobile	Aircraft	426.3	1.8	95.3
Industry	Gravel and sand quarrying	266.1	1.1	96.4
Industry	Cement and lime manufacturing	89.6	0.4	96.8
Industry	Iron and steel casting	85.9	0.4	97.2
Industry	Petroleum refining and petroleum fuel manufacturing	78.2	0.3	97.5
Industry	Prepared animal and bird feed manufacturing	73	0.3	97.8
Industry	Other	503.2	2.2	100

Table 4-26: Total estimated annual emissions, proportion and cumulative proportion of PM_{10} for PPR

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
On-road mobile	Motor vehicle	19196.1	70.9	71.9
Domestic	Wood heater	3904.2	14.4	85.3
Industry	Other Construction Material Mining	1303	4.8	90.1
Industry	Clay Brick Manufacturing	487.4	1.7	91.9
Industry	Gravel and Sand Quarrying	466.1	1.8	93.7
Industry	Other Non-Metallic Mineral Mining and Quarrying	288	1.1	94.7
off-road mobile	Aircraft	282	1.0	95.8
Industry	Petroleum refining and petroleum fuel manufacturing	274.9	1.0	96.8
Industry	Cement and lime manufacturing	129.4	0.5	97.2
Industry	Iron and steel casting	85.9	0.3	97.6
Industry	Other	660.2	2.4	100

Table 4-27: Total estimated annual emissions, proportion and cumulative proportion of PM_{10} for LV

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Industry	Fossil fuel electricity generation	11425.7	86.0	86.0
On-road mobile	Motor vehicle	1167.2	8.8	94.8
Domestic	Wood heater	288.9	2.2	97.0
Industry	Pulp, paper and paperboard manufacturing	132.3	1	98.0
Industry	Milk and cream processing	117.9	0.9	98.9
Industry	Cement and lime manufacturing	52.1	0.4	99.3
Industry	Oil and gas extraction	44.4	0.3	99.6
Industry	Other construction material mining	32.5	0.2	99.8
Industry	Log sawmilling	7.4	0.1	99.9
Off-road mobile	Aircraft	6.7	0.1	99.9
Industry	Other	9.33	0.1	100

Table 4-28: Total estimated annual emissions, proportion and cumulative proportion of PM_{10} for VIC

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
On-road mobile	Motor vehicles	33323.24	51.8	51.8
Industry	Fossil fuel electricity generation	11502.71	17.9	69.7
Industry	Mineral sand mining	5870.3	10.4	80.1
Domestic	Wood heater	6716.5	9.1	89.3
Industry	Other construction material mining	1404.7	2.2	91.4
Industry	Gold ore mining	1032.76	1.6	93.1
Industry	Gravel and sand quarrying	597.19	0.9	94.0
Industry	Clay brick manufacturing	529.8	0.8	94.8
Industry	Other non-metallic mineral mining and quarrying	473.96	0.7	95.5
Off-road mobile	Aircraft	423.27	0.7	96.2
Industry	Other	2444.9	3.8	100

4.4.5 Sulfur dioxide

Table 4-29: Total estimated annual emissions, proportion and cumulative proportion of sulfur dioxide for MM

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Industry	Petroleum refining and petroleum fuel manufacturing	2793.9	63.4	63.4
Industry	Glass and glass product manufacturing	442.2	10	73.4
Industry	Oil and gas extraction	260.7	5.9	79.3
Industry	Clay brick manufacturing	211	4.8	84.1
Industry	Copper, silver, lead and zinc smelting and refining	188.8	4.3	88.4
On-road mobile	Motor vehicles	145	3.3	91.7
Off-road mobile	Aircraft	128.3	2.9	94.6
Domestic	Wood heaters	108.7	2.5	97.1
Industry	Other electricity generation	89.1	2	99.1
Industry	Water passenger transport	85	1.9	100
Industry	Other	0	0	100

Table 4-30: Total estimated annual emissions, proportion and cumulative proportion of sulfur dioxide for PPR

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Industry	Fossil fuel electricity generation	5910.8	49.2	49.2
Industry	Petroleum refining and petroleum fuel manufacturing	4149.2	34.5	83.7
Industry	Glass and glass product manufacturing	442.2	3.7	87.4
Industry	Oil and gas extraction	260.7	2.2	89.6
Industry	Port and water transport terminal operations	233.1	1.9	91.5
Industry	Clay brick manufacturing	211	1.8	93.3
Industry	Copper, silver, lead and zinc smelting and refining	188.8	1.6	94.8
On-road mobile	Motor vehicle	176.2	1.5	96.3
Domestic	Wood heater	142.1	1.2	97.5
Off-road mobile	Aircraft	128.3	1.1	98.5
Industry	Other	175.09	1.46	100

Table 4-31: Total estimated annual emissions, proportion and cumulative proportion of sulfur dioxide for LV

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Industry	Fossil fuel electricity generation	122934.1	98.5	98.5
Industry	Pulp, paper and paperboard manufacturing	1000	0.8	99.3
Industry	Oil and gas extraction	865.4	0.7	100
Domestic	Wood heater	14.2	0	100
On-road mobile	Motor vehicle	12.6	0	100
Industry	Log sawmilling	4.8	0	100
Industry	Gas supply	0.4	0	100
Industry	Milk and cream processing	0.4	0	100
Industry	Cement and lime manufacturing	0.3	0	100
Industry	Waste treatment and disposal services	0.1	0	100
Industry	Other	0.3	0	100

Table 4-32: Total estimated annual emissions, proportion and cumulative proportion of sulfur dioxide for VIC

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Industry	Fossil fuel electricity generation	128846.72	89.6	89.6
Industry	Aluminum smelting	6608.48	4.6	94.2
Industry	Petroleum refining and petroleum fuel manufacturing	4149.19	2.9	97.1
Industry	Oil and gas extraction	1137.66	0.8	97.9
Industry	Pulp, paper and paperboard manufacturing	1000.94	0.7	98.6
Industry	Glass and glass product manufacturing	442.22	0.3	98.9
On-road mobile	Motor vehicles	290.7	0.2	99.1
Industry	Port and water transport terminal operations	233.14	0.2	99.3
Domestic	Wood heater	231.32	0.2	99.4
Industry	Clay brick manufacturing	217.99	0.2	99.6
Industry	Other	575.37	0.4	100

4.4.6 Total VOC

Table 4-33: Total estimated annual emissions, proportion and cumulative proportion of VOC for MM

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Commercial	Domestic solvents	24227	32.3	32.3
Commercial	Architect coating	13718.2	18.3	50.6
Domestic	Wood heaters	10710.5	14.3	64.9
On-road mobile	Motor vehicles	9646.9	12.9	77.8
Commercial	Service stations	6177.5	8.2	86
Industry	Printing	1677	2.2	88.3
Commercial	Gas leak	1352.2	1.8	90.1
Commercial	Panel beaters	1154.3	1.5	91.6
Industry	Oil and gas extraction	808.5	1.1	92.7
Commercial	Cutback bitumen	644.9	0.9	93.5
Industry	Other	4843.16	6.46	100

Table 4-34: Total estimated annual emissions, proportion and cumulative proportion of VOC for PPR

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Commercial	Domestic solvents	26758.2	31.1	31.1
Commercial	Architect coating	15518.2	18	49.1
Domestic	Wood heater	13690.2	15.9	65
On-road mobile	Motor vehicle	11720.5	13.6	78.6
Commercial	Service stations	6686.9	7.8	86.4
Industry	Printing	1677	1.9	88.3
Commercial	Gas leak	1492.8	1.7	90.1
Commercial	Panel beaters	1243	1.4	91.5
Industry	Petroleum refining and petroleum fuel manufacturing	1001.6	1.2	92.7
Industry	Oil and gas extraction	808.5	0.9	93.6
Industry	Other	5501.39	6.39	100

Table 4-35: Total estimated annual emissions, proportion and cumulative proportion of VOC for LV

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Industry	Oil and gas extraction	2109.9	30.1	30.1
Domestic	Wood heater	1225.3	17.5	47.6
Industry	Fossil fuel electricity generation	913.3	13	60.7
On-road mobile	Motor vehicle	835.9	11.9	72.6
Commercial	Domestic solvents	831	11.9	84.5
Commercial	Architect coating	624	8.9	93.4
Commercial	Service stations	231.6	3.3	96.7
Commercial	Cutback bitumen	55.9	0.8	97.5
Commercial	Gas leak	42.6	0.6	98.1
Industry	Pulp, paper and paperboard manufacturing	41.2	0.6	98.7
Industry	Other	92.71	1.32	100

Table 4-36: Total estimated annual emissions, proportion and cumulative proportion of VOC for VIC

Category	Activity	Emissions (tonnes/year)	Proportion (%)	Cumulative proportion (%)
Commercial	Domestic solvents	31689.46	27.1	27.1
Domestic	Wood heaters	21367.44	18.3	45.4
Commercial	Architect coating	19371.52	16.6	62
On-road mobile	Motor vehicles	19335.63	16.5	78.5
Commercial	Service stations	8273.27	7.1	85.6
Industry	Oil and gas extraction	3542.78	3	88.6
Commercial	Gas leak	1706.35	1.5	90.1
Industry	Printing	1677.19	1.4	91.5
Commercial	Panel beaters	1464.8	1.3	92.8
Commercial	Cutback bitumen	1292.65	1.1	93.9
Industry	Other	7139.05	6.11	100

5 Spatial distribution of pollutants

Spatial maps of total emissions have been produced for the whole state of Victoria. Presented as maps of total emissions per 1 km by 1 km grid in kilograms, the spatial distributions of pollutants show emissions clustered around main population centres, transport lines and coastal areas.

5.1 Spatial distribution of carbon monoxide

Carbon monoxide emissions in 2016 are clustered around population centres and lines of transport (**Figure 5-1**).

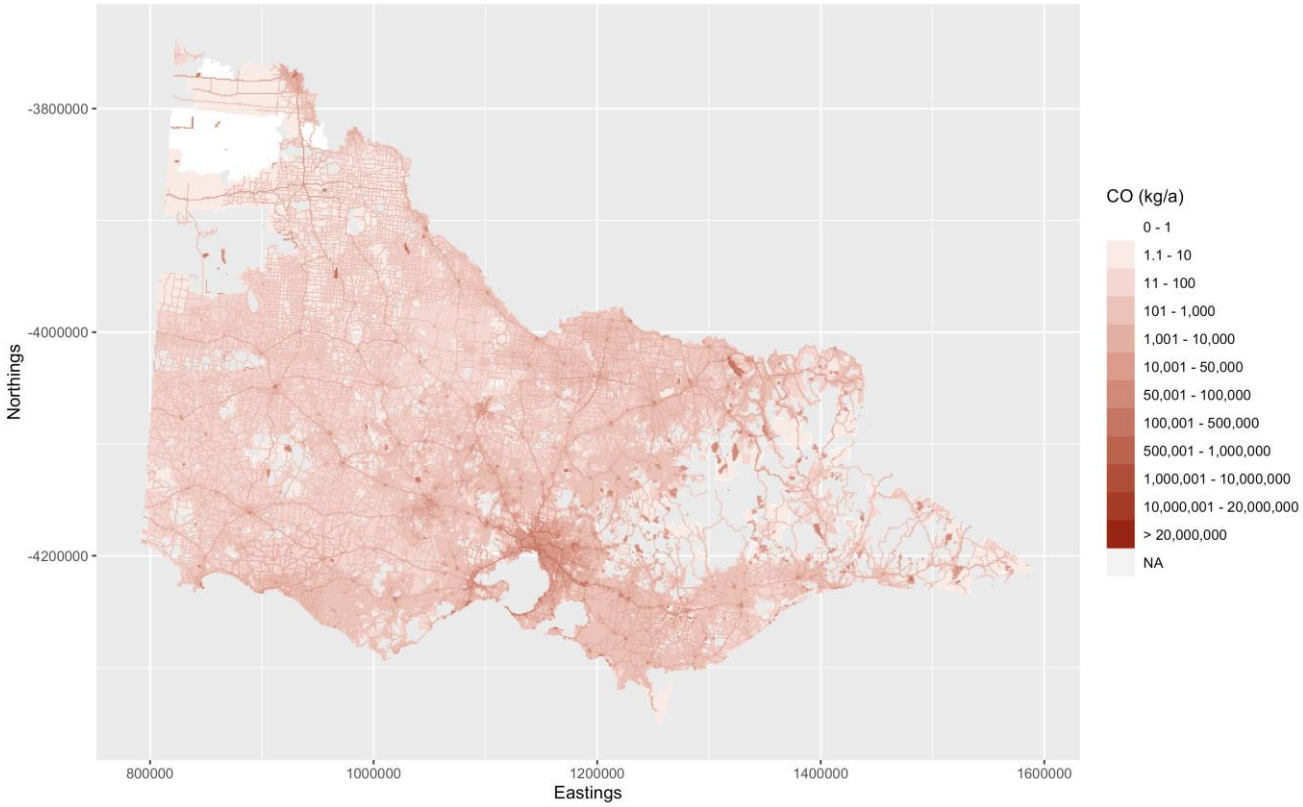

Figure 5-1: Total emissions per 1 km by 1 km grid in kg of CO for 2016.

5.2 Spatial distribution of oxides of nitrogen

Oxides of nitrogen emissions in 2016 are clustered around population centres and lines of transport (**Figure 5-2**).

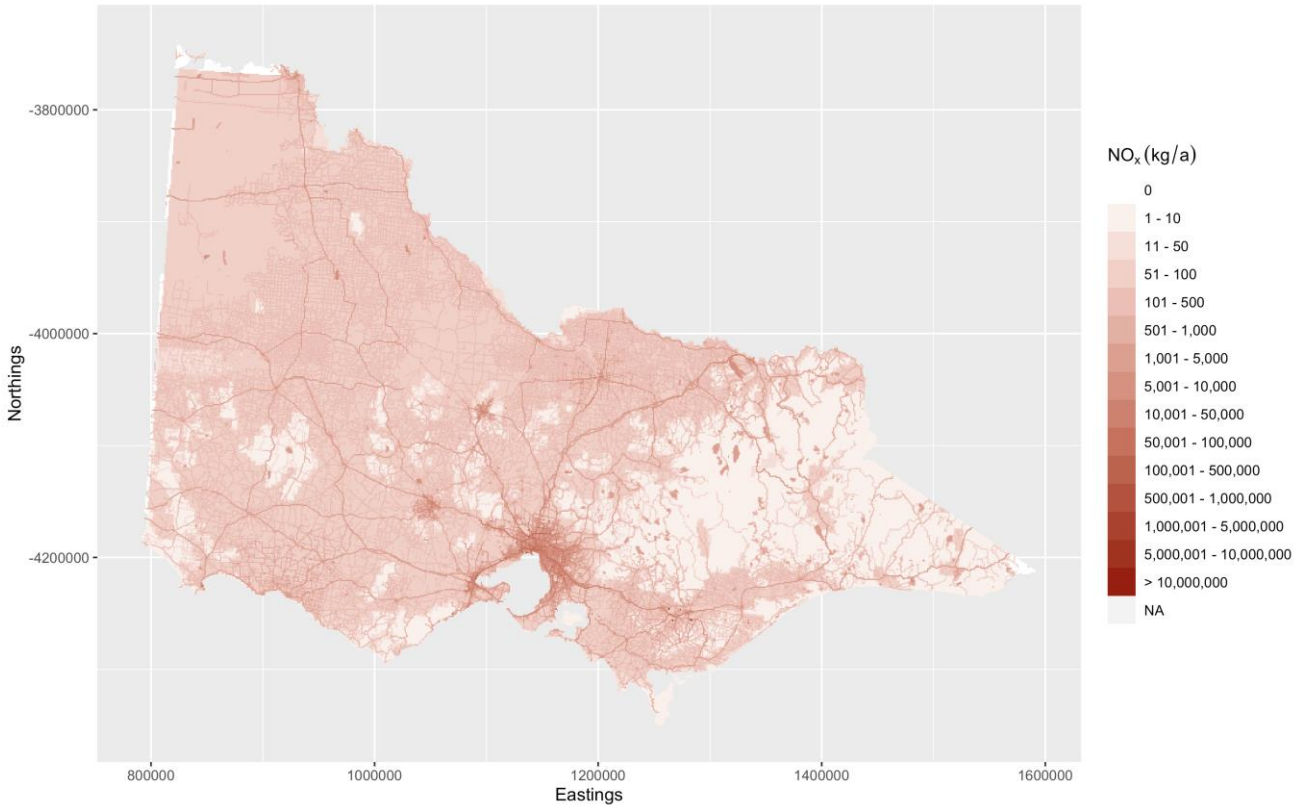

Figure 5-2: Total emissions per 1 km by 1 km grid in kg of NOx for 2016.

5.3 Spatial distribution of PM_{10}

PM_{10} emissions in 2016 are clustered around population centres, lines of transport, coastal areas and north-western areas where there are natural dust sources (**Figure 5-3**).

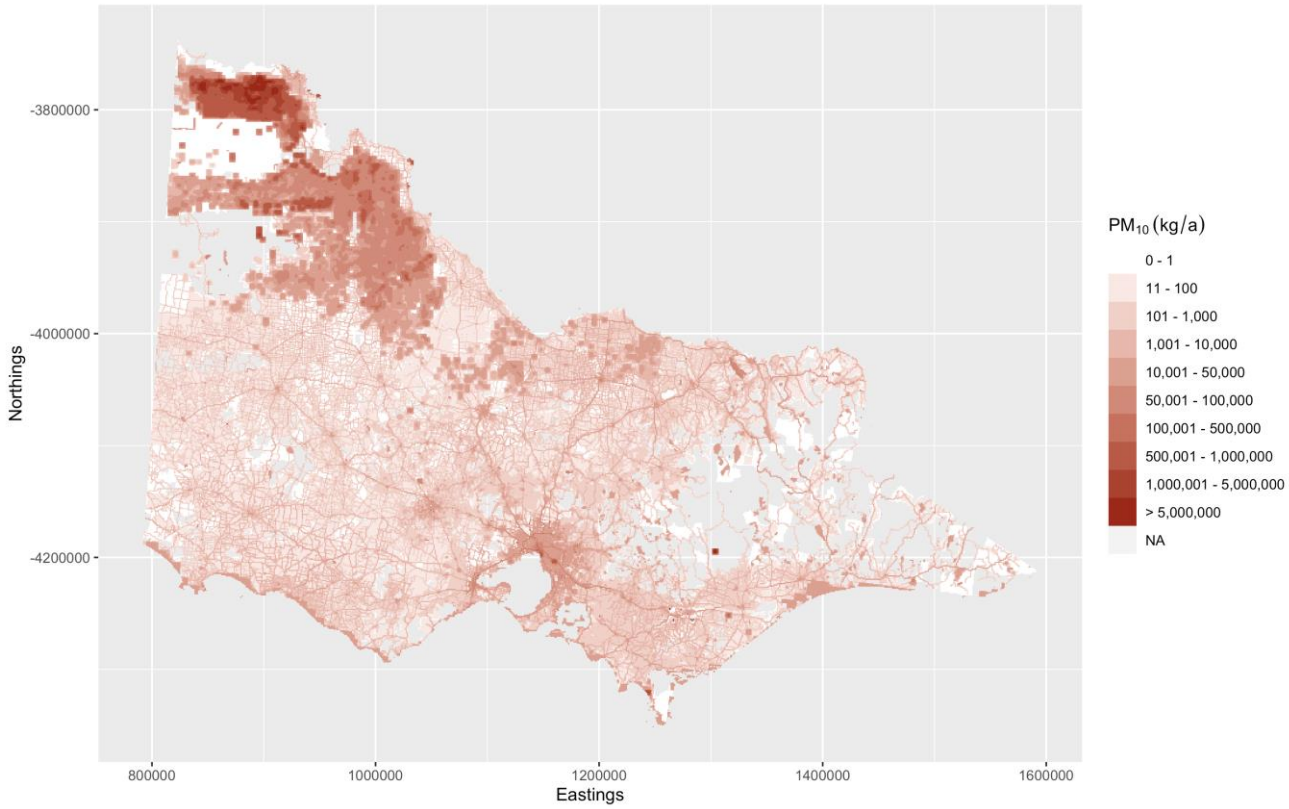

Figure 5-3: Total emissions per 1 km by 1 km grid in kg of PM_{10} for 2016.

5.4 Spatial distribution of $PM_{2.5}$

$PM_{2.5}$ emissions in 2016 are clustered around population centres, lines of transport, coastal areas and areas where bushfires and planned burns occurred in 2016 (**Figure 5-4**).

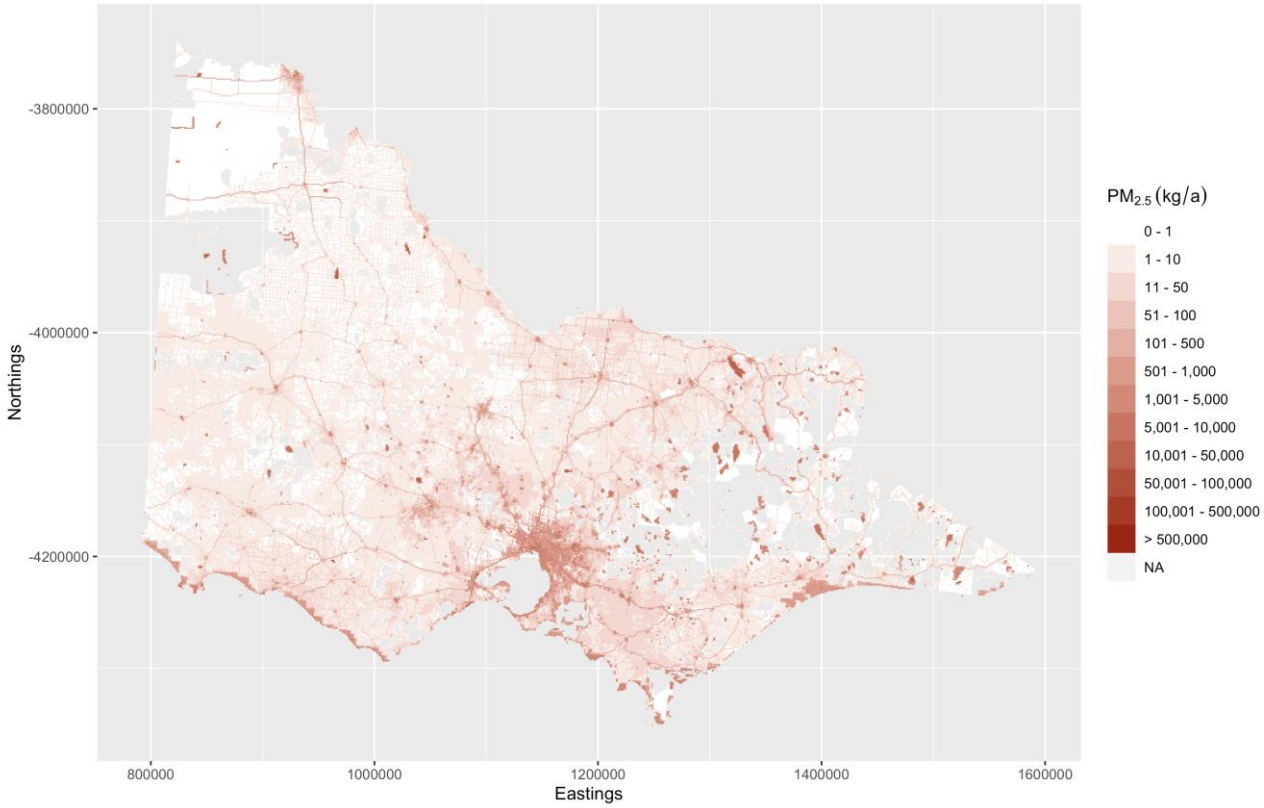

Figure 5-4: Total emissions per 1 km by 1 km grid in kg of $PM_{2.5}$ for 2016.

As wood heaters are a significant source of $PM_{2.5}$ emissions from some LGAs, a spatial distribution map (**Figure 5-5**) shows the emissions to be clustered around various parts of the state but especially in the upper lying areas such as the Yarra Ranges.

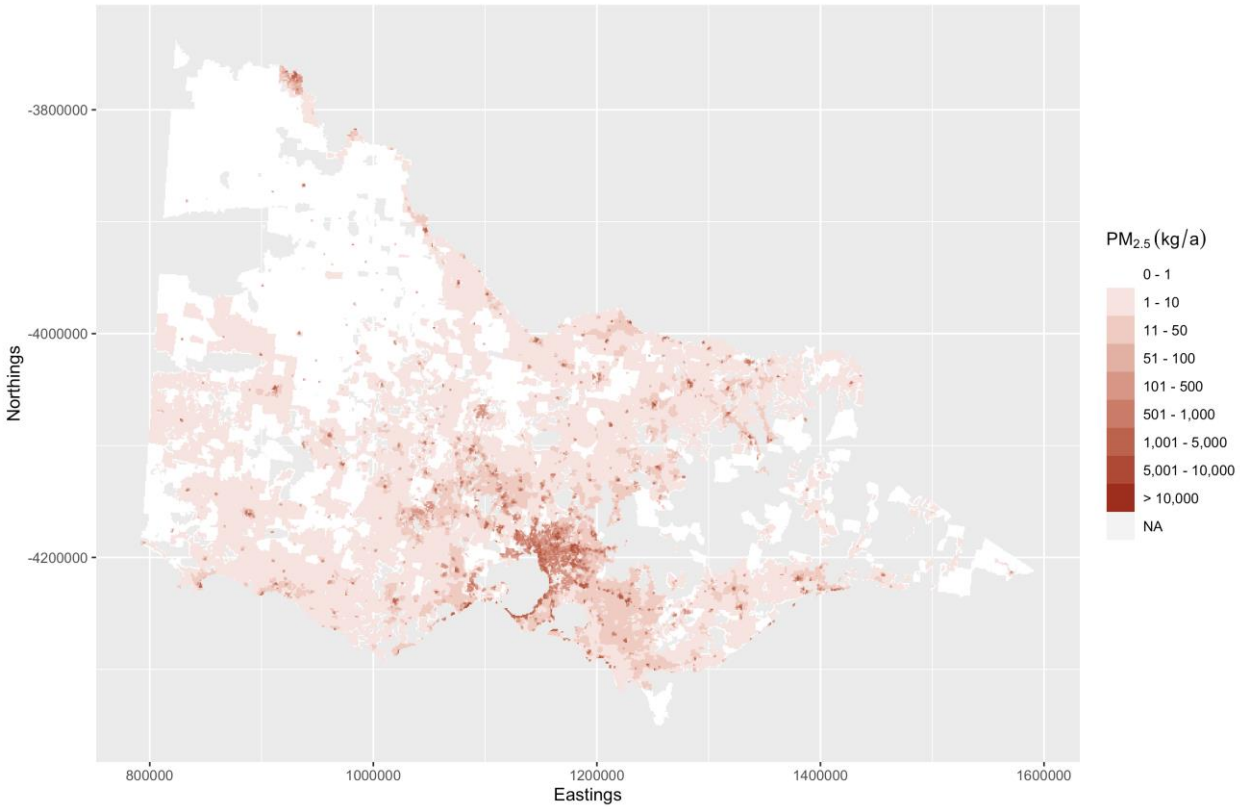

Figure 5-5: $PM_{2.5}$ emissions from wood heaters per 1 km by 1 km grid in kg for 2016

5.5 Spatial distribution of sulfur dioxide

Sulfur dioxide emissions are clustered around population centres, industrial point source locations, lines of transport and areas where planned burns and bushfires occurred in 2016. (**Figure 5.6**).

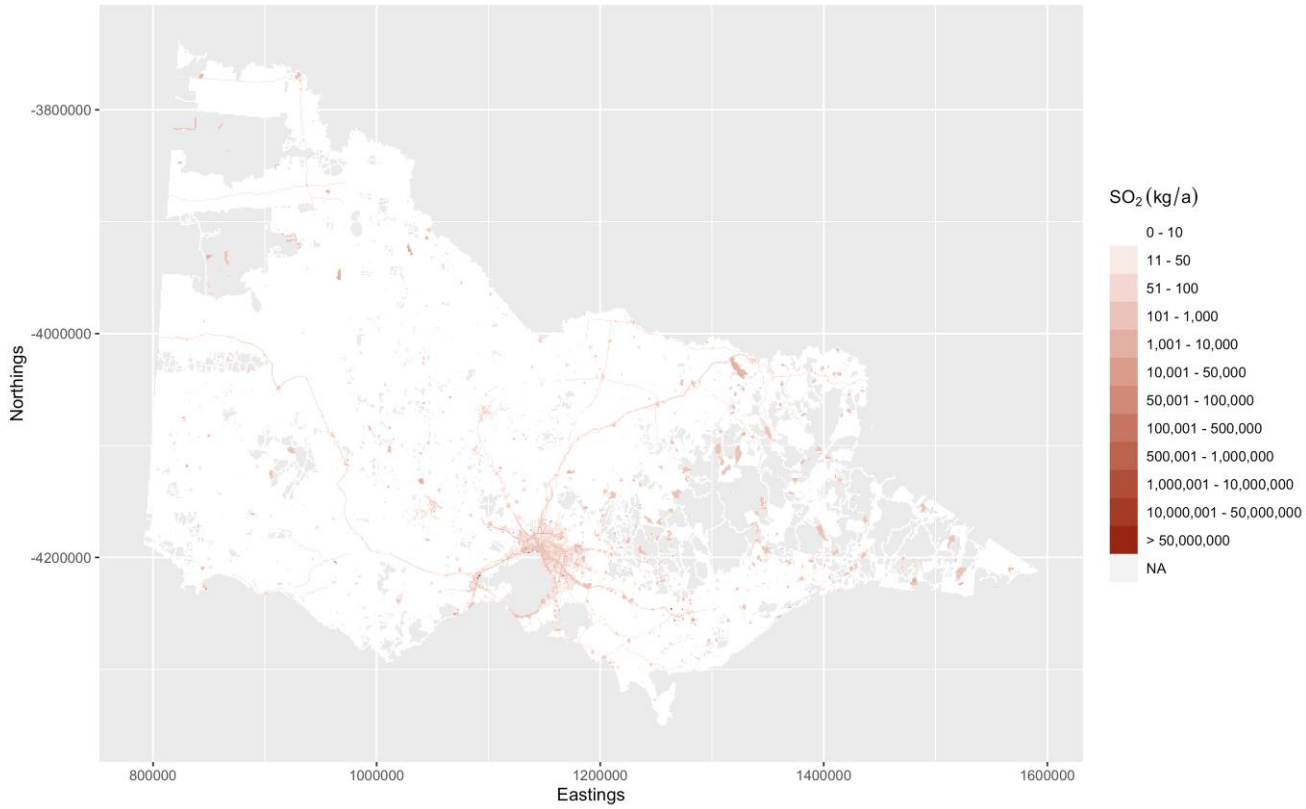

Figure 5-6: Total emissions per 1 km by 1 km grid in kg of SO_2 for 2016.

5.6 Spatial distribution of VOC

VOC emissions in 2016 are clustered around areas of native vegetation and population centres (**Figure 5-7**).

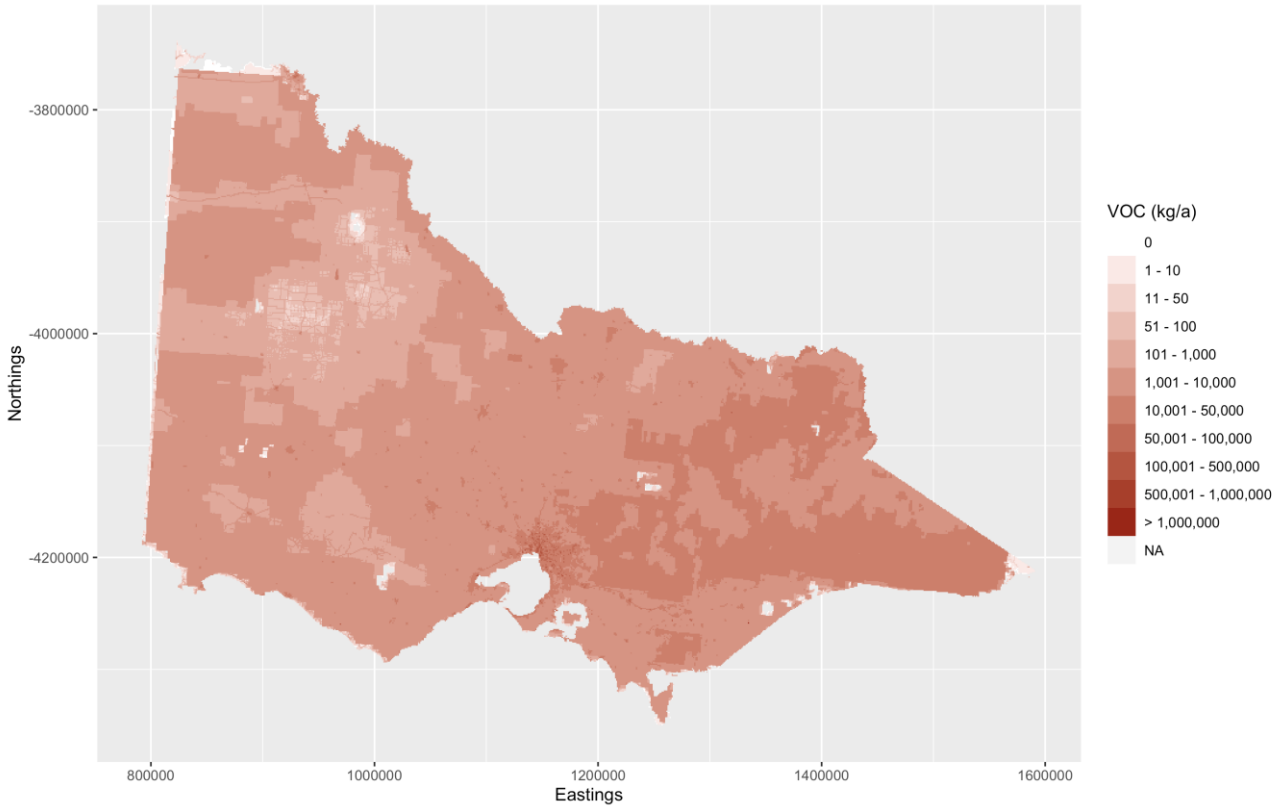

Figure 5-7: Total emissions per 1 km by 1 km grid in kg of VOC for 2016.

6 Comparison with other emission inventories

The previous APEI inventory prepared in 2006 was based on using the ABS census data for 2006. An attempt was made to compare the 2016 Victorian APEI to past emissions estimations in 2006. However, an informative comparison could not be made. The comparison between Victorian emissions inventories showed that differences in emissions between years were predominantly the result of differences in methods used, rather than differences in emissions.

6.1 Comparison with emissions inventories from other states

It is instructive to compare the 2016 Victorian APEI with APEIs from other states in Australia. However, it is noted that there is only one other state, NSW, that reports air pollution emission inventory estimates. The other states generally tend to link to the National Pollution Inventory (NPI).

For the comparison with NSW emissions inventory, we note three issues:

- the emissions are for two different calendar years (2016 for Victoria APEI compared to 2013 for NSW APEI)
- the emissions are for different regions (Victoria APEI considers emissions from Metropolitan Melbourne, Port Phillip Region, Latrobe Valley and the whole state whereas NSW considers emissions only from Sydney, Newcastle, Wollongong and the Greater Metropolitan Region (GMR)
- there are no state-wide emissions for NSW (largest area considered is the GMR).

Thus, there is no state-wide NSW APEI to compare with state-wide Victoria APEI. The GMR cannot be directly compared to the PPR as the latter doesn't include the industrial emissions of the Latrobe Valley unlike the GMR that includes the regions with the major industrial emissions. The regional comparison of the criteria pollutant between MM and Sydney (SYD) inventory regions is more appropriate and the comparison of the highest source of emissions for the criteria pollutants are summarised below:

- The highest contributing sources of $PM_{2.5}$ emissions in both cities are domestic-commercial emission sources (wood heaters), 50.9% for MM, compared to 50.4% for SYD.
- The highest PM_{10} emission sources differ, highest in MM is motor vehicles at 72% compared to SYD where the highest source is domestic-commercial (wood heaters) at 33.8%.
- Motor vehicle emissions contribute the highest emissions for carbon monoxide at 58.9% for MM compared to 43.4% for SYD and for oxides of nitrogen at 68.6% for MM compared to 55.4% for SYD.
- The highest sulfur dioxide sources are industrial emissions being petroleum refining and fuel manufacturing at 63.4% for MM compared to off-road ships at 65.1% for SYD.

7 Conclusions

The following conclusions for criteria pollutants can be drawn from the 2016 APEI:

(1) Regional (MM, PPR and LV) and state-wide (VIC) anthropogenic emissions of carbon monoxide, oxides of nitrogen, and sulfur dioxide are significantly higher than natural emissions. Anthropogenic sources of $PM_{2.5}$ and PM_{10} are also higher than natural sources in MM, PPR and LV.
(2) For VIC, natural emissions of $PM_{2.5}$ and PM_{10} are higher than anthropogenic sources due to bushfires and dust sources, respectively.
(3) Motor vehicle, wood heater and fossil fuel electricity power generation are the main sources of anthropogenic emissions in Victoria.
(4) Highest anthropogenic $PM_{2.5}$ emission sources are domestic wood heaters in MM (50.9%), PPR (50.0%) VIC (37.9%); fossil fuel electricity generation is highest source in LV (87.8%).
(5) On-road motor vehicle emissions is the highest anthropogenic PM_{10} source in MM (71.6%), PPR (70.9%, VIC (51.8%); fossil fuel electricity generation is highest source in LV (86.0%).
(6) Highest anthropogenic sources of oxides of nitrogen are on-road motor vehicle emissions for MM (68.6%), PPR (69%), VIC (48%) and fossil fuel electricity generation is highest source for LV (93%).
(7) On-road motor vehicle emissions is the highest anthropogenic carbon monoxide source in MM (58.9%) PPR (58.1%), VIC (51.2%), fossil fuel electricity generation is highest source in LV (55.0%).
(8) Fossil fuel electricity generation is highest source of sulfur dioxide, for PPR (49.2%), LV (98.5%), VIC (VIC (89.6%), petroleum Refining and Petroleum Fuel Manufacturing for MM (63.4%).

A major limitation of Victorian APEI is aligning with ABS census year which restricts updates to every five years and ensuring that nationally consistent methods are applied. Future emission inventories need to be compiled yearly or bi-yearly using a nationally consistent methods in order to give greater insight into the efficacy of intervention actions. More frequent and nationally consistent inventory data can be integrated into air pollution dispersion modelling to develop better and more targeted programs for the reduction of anthropogenic emissions in states and nationally.

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