Government of **Western Australia**
Department of **Water and Environmental Regulation**

Perth Air Emissions Study 2011–2012

Technical report 2: Domestic Emissions



Report

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Temporal and spatially allocated emission estimates produced for this study can be made available on request. Please contact **npi@dwer.wa.gov.au** with queries and requests for information.

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Summary

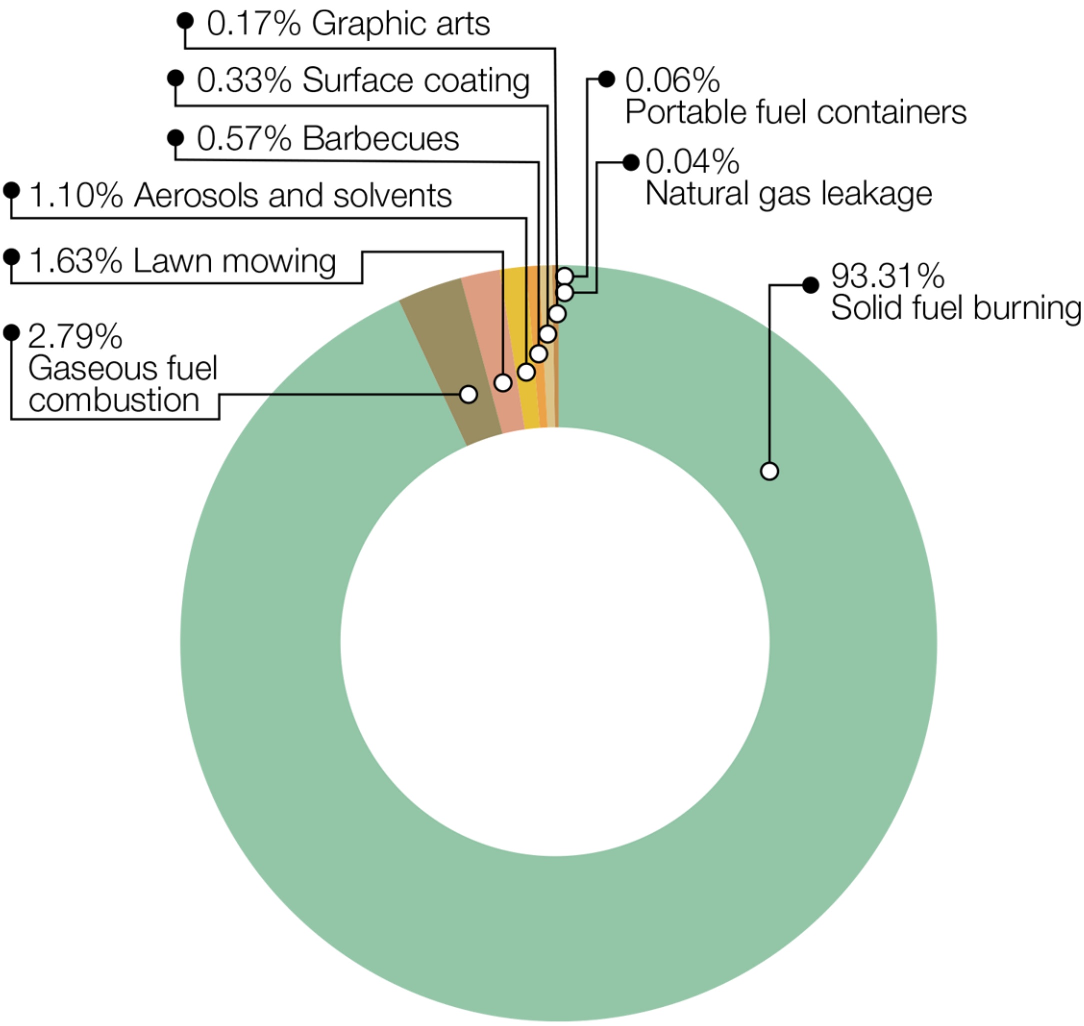
The Department of Water and Environmental Regulation (DWER) has completed an air emissions inventory of Perth for the 2011–12 financial year. The study area was generally consistent with the Australian Bureau of Statistics (ABS) Census Dataset: Greater Capital City Statistical Area – Greater Perth. The inventory estimated emissions for a variety of natural and anthropogenic emission sources.

This report summarises the estimated emissions from domestic sources, including aerosols and solvents, barbecues, gaseous fuel combustion, graphic arts, lawn mowing and garden equipment, natural gas leakage, portable fuel containers, solid fuel burning and surface coating.

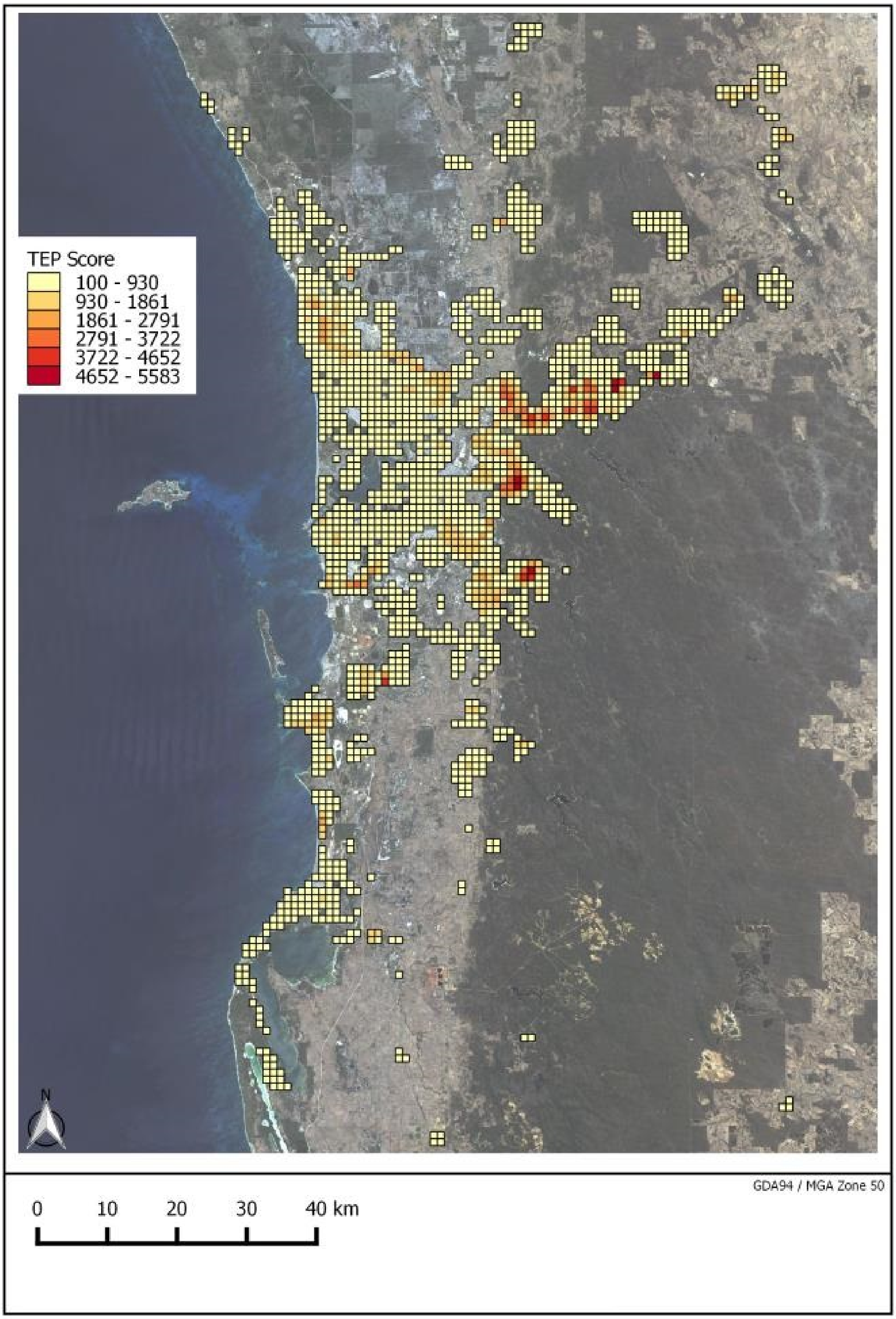
Emissions were estimated using the methodology published in the *2008 Calendar Year Air Emissions Inventory for the Greater Metropolitan Region in New South Wales* (NSW EPA 2012). Methodologies were adapted to address the availability of local data and, in some cases, were superseded by more relevant or recently developed methods. Emissions were spatially allocated based on population and dwelling density and other relevant activities.

Based on a toxic equivalency potential (TEP) scoring system, emission estimates from domestic sources for 2011–12 showed that particulate matter ≤ 2.5 µm ($PM_{2.5}$) emissions were the most significant of pollutants listed in the National Environment Protection (Ambient Air Quality) Measure. Emission estimates of metals such as cadmium and mercury (speciated from particulate emissions) and polychlorinated dioxins and furans (TEQ) were comparatively small, but were found to be significant pollutants due to their high toxicity.

The summary figures show the relative contribution from domestic emission sources to the overall TEP score, and the spatial allocation of the TEP score. Solid fuel burning made the largest contribution and represented 93 per cent of the emission risk from domestic sources.



Summary figure – relative TEP contributions from domestic sources



Summary figure – relative TEP contributions from domestic sources

1 Introduction

The Department of Water and Environmental Regulation (DWER) has completed an air emissions inventory of Perth for 2011–12.

This technical report presents the emission estimate methods, calculated emissions, and spatial allocation of emissions of domestic emission sources.

This technical report focuses on emissions estimated as a result of domestic activities. It is one of six reports prepared for the Perth Air Emissions Study 2011–2012:

1. *Perth Air Emissions Study 2011–2012: Summary of emissions*
2. *Technical report 1: Biogenic and geogenic emissions*
3. ***Technical report 2: Domestic emissions***
4. *Technical report 3: Commercial and industrial emissions*
5. *Technical report 4: On-road vehicle emissions*
6. *Technical report 5: Off-road mobile emissions*

1.1 Inventory scope

This module is defined by the following study parameters:

Year

The data presented by this study represent emissions estimated for the 2011–12 financial year. This time period aligns with Australian Bureau of Statistics (ABS) census data and available datasets.

Where data are not available for 2011–12, data outside the study period have been used as being broadly representative of 2011–12.

Boundaries

This study includes Local Government Areas (LGAs) in the ABS *Census Dataset: Greater Capital City Statistical Area – Greater Perth* (ABS 2012). The grid covers an area of 100 kilometres west to east (Rottnest Island to Toodyay) and 160 kilometres north to south (Two Rocks to Waroona). The corner coordinates are presented in Table 1, and the study area is shown in Figure 1.

Table 1 – Study grid corner coordinates

	Easting* (m)	Northing* (m)
North-west	350000	6525000
North-east	450000	6525000
South-west	350000	6365000
South-east	450000	6365000

* Geocentric Datum of Australia 1994 (GDA94 MGA Zone 50).

Figure 1 – Perth Air Emissions Study 2011–2012 boundaries

Spatial allocation

The study used a one kilometre grid to spatially allocate emission estimates. This scale balances the resolution of fine data (roads, individual point sources etc.) and computationally demanding calculations.

Grid coordinates start at the upper left corner, as illustrated in Figure 2.

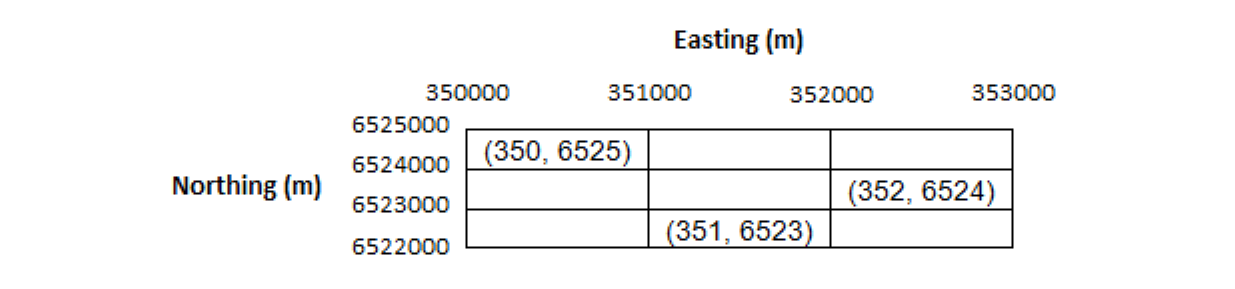


Figure 2 – Grid coordinate system

Emission substances

The substances of interest in this study module are those in the National Environment Protection (Ambient Air Quality) Measure. These include:

- carbon monoxide (CO);
- nitrogen dioxide (NO_2), as a subset of oxides of nitrogen (NO_X);
- particulate matter ≤ 2.5 µm ($PM_{2.5}$);
- particulate matter ≤ 10 µm (PM_{10}); and
- sulfur dioxide (SO_2).

Ozone (O_3), as a proxy for photochemical smog, is a secondary pollutant resulting from the chemical transformation of pollutants in the atmosphere over time, and was not directly considered in this study. Instead, emissions of volatile organic compounds (VOCs) were estimated because these, along with oxides of nitrogen, are considered to be precursors to smog formation.

Other emissions estimated are included in the list of substances of interest to the National Pollutant Inventory (NPI):

- ammonia;
- heavy metals, including lead, cadmium, copper, chromium, nickel, selenium and zinc; and
- organic compounds, including speciated volatiles, polycyclic aromatic hydrocarbons (B[a]Peq), and polychlorinated dioxins and furans (TEQ).

2 Study methodology

The domestic emissions inventory method has two discrete stages: the estimation of total domestic emissions, and the spatial allocation of those emissions. Activity and spatial data were sourced from government departments and industry organisations. In the absence of data specific to Western Australia, domestic survey data collected by NSW EPA in its 2008 inventory study (NSW EPA 2012a) were utilised.

The domestic emissions sources considered in this inventory include:

- aerosols and solvents (domestic and commercial);
- barbecues (domestic);
- gaseous fuel burning (domestic and unaccounted);
- graphic arts (domestic and commercial);
- lawn mowing (domestic and public open space);
- natural gas leakage;
- portable fuel containers (domestic and public open space);
- solid fuel combustion (domestic); and
- surface coatings (domestic, commercial and industrial).

2.1 Aerosols and solvents

Domestic aerosol and solvent use results in the release of VOCs. Emissions from the following group of products are accounted for in this study:

- adhesives and sealant products;
- coatings and related products;
- household cleaning products;
- miscellaneous products;
- motor vehicle aftermarket products;
- personal care products; and
- pesticide and herbicide products.

Methodology

Evaporative VOC emissions from aerosols and solvents have been estimated using per capita based emission factors combined with population in the study area. Emissions were calculated using the following equation from the Eastern Research Group (ERG 1996a).

$$E_{VOC,k} = P \times EF_{VOC,k}$$

Where:

$E_{VOC,k}$	=	Emissions of VOC form product group k	(kg/yr)
P	=	Population (capita)	(capita)
$EF_{VOC,k}$	=	Emission factor for VOC from product group k	(kg/capita/yr)
k	=	Product group	(–)

Emission factors for VOCs were sourced from ERG (1996a) and are presented in Table 2. Speciation factors where obtained from the Speciate Database Version 4.3 (Pechan 2011). Speciation profile numbers from each source have been provided in Table 2.

Table 2 – Aerosol and solvent product emission and speciation factors

Source	VOC emission factor (kg/capita/year)	SPECIATE speciation profile number[1]
Adhesives and sealant products	0.31	8523
Coatings and related products	0.72	8532
Household cleaning products	0.42	8511
Miscellaneous products	0.0334	8535
Motor vehicle aftermarket products	0.67	8520
Personal care products	1.72	8501
Pesticide and herbicide products	0.91	8526

Activity data

Total population for the study area was determined using the 2011 ABS census mesh block data (ABS 2011a). The population was 1,751,528.

Emission estimates

Emissions of domestic aerosol and solvents in the study area are summarised in Table 3.

Spatial allocation

Emissions from domestic aerosol and solvent use were spatially allocated according to the population density of each grid cell. Population density was determined using the 2011 ABS census mesh block data (ABS 2011a). The spatial allocation of VOC emissions is presented in Figure 3.

1 Speciate Database Version 4.3 https://www.epa.gov/air-emissions-modeling/speciate-version-45-through-32 (Pechan 2011)

Table 3 – Aerosol and solvent emission estimates

Pollutant	Product type emissions (kg)							
	Adhesives and sealant products	Coatings and related products	Household cleaning products	Miscellaneous products	Motor vehicle aftermarket products	Personal care products	Pesticide and herbicide products	Total
Acetic acid (ethanoic acid)						3,314	956	4,270
Acetone	63,908	266,344	74	2,252	10,679	42,177		385,434
Chloroform (trichloromethane)		3,531						3,531
Cyclohexane	760	126						886
Ethanol	4,887	21,439	118,291	9,401	3,990	1,837,402	155,723	2,151,133
2-Ethoxyethanol		631	74					705
Ethyl acetate	5,864	1,766	74		235	18,980		26,917
Ethylbenzene		2,648			117		956	3,722
Ethylene oxide							15,620	15,620
Formaldehyde (methyl aldehyde)		3,153					638	3,790
Glutaraldehyde							4,782	4,782
n-Hexane	71,238	9,458	589		3,403			84,688
Methanol	597	57,254	589	5,727	397,825		956	462,948
2-Methoxyethanol		2,396	74		117			2,587
Methyl ethyl ketone	34,479	25,474	147	6	3,638			63,744
Methyl isobutyl ketone	1,140	6,306	294		821			8,561
Tetrachloroethylene	597	504	6,253	842	22,297		159	30,653

Pollutant	Product type emissions (kg)							
	Adhesives and sealant products	Coatings and related products	Household cleaning products	Miscellaneous products	Motor vehicle aftermarket products	Personal care products	Pesticide and herbicide products	Total
Toluene (methylbenzene)	76,071	168,609	368		29,925	3,916		278,889
Total volatile organic compounds	542,974	1,261,100	735,642	58,501	1,173,524	3,012,629	1,593,891	8,378,260
Trichloroethylene	54	1,513			235			1,802
Xylenes (individual or mixed isomers)	8,850	89,160	1,177	140	15,373		109,978	224,679

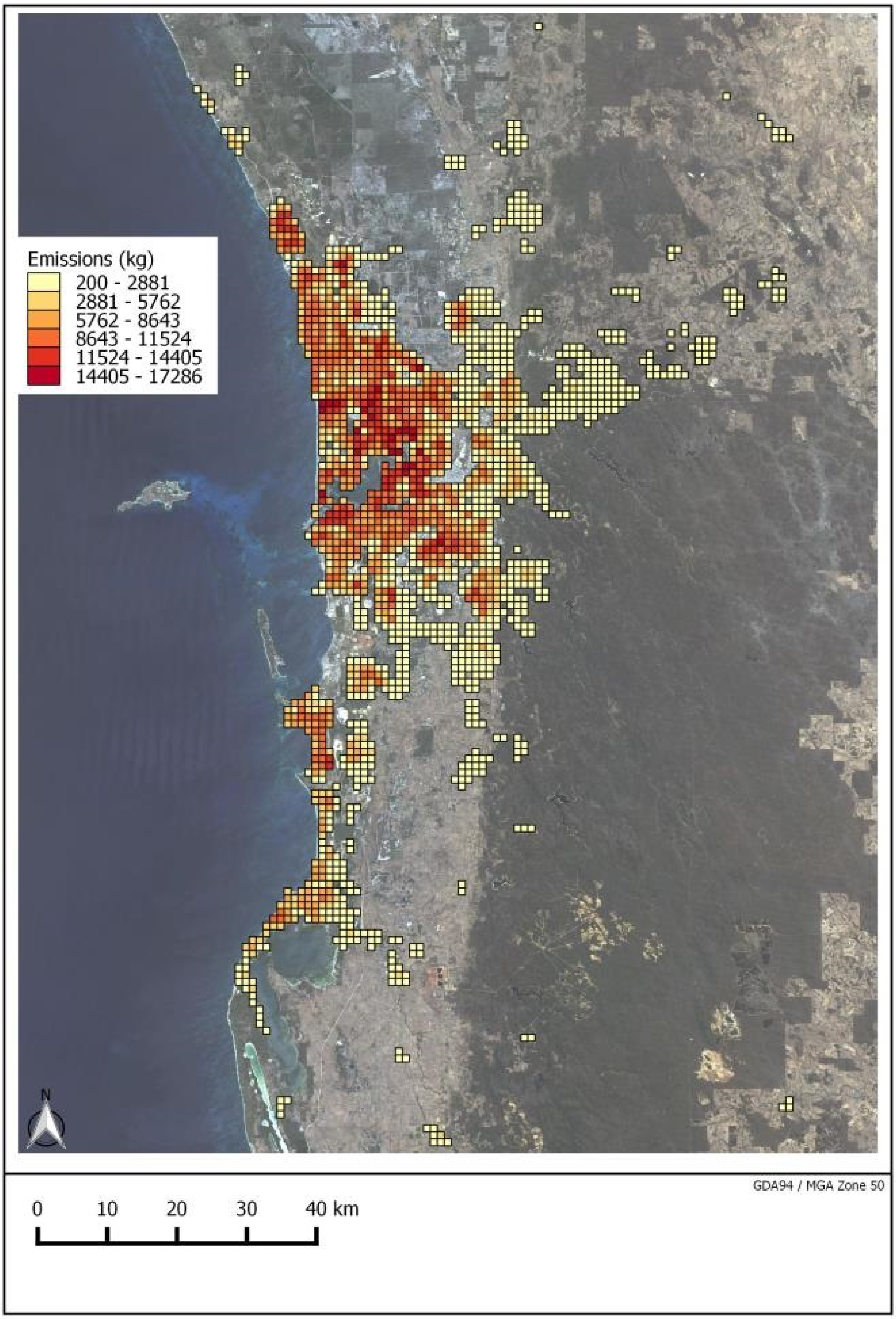


Figure 3 – Spatial allocation of aerosol and solvent VOC emissions

2.2 Barbecues

Emissions from combustion of natural gas, liquefied petroleum gas (LPG), butane, briquettes and wood in outdoor barbecues have been estimated in this study.

Methodology

Emissions of combustion products from barbecues have been estimated using fuel consumption based emission factors. Emissions were calculated using the following equation from Pechan (2006).

$$E_{i,j} = C_j \times EF_{i,j}$$

Where:

$E_{i,j}$	=	Emissions of substance i from fuel type j	(kg/yr)
C_j	=	Fuel consumption for fuel type j	
		Natural gas	(Mm^3/yr)
		LPG	(kL/yr)
		Butane	(kL/yr)
		Briquettes	(tonne/yr)
		Wood	(tonne/yr)
$EF_{i,j}$	=	Emission factor for substance i and fuel type j	
		Natural gas	(kg/Mm^3)
		LPG	(kg/kL)
		Butane	(kg/kL)
		Briquettes	(kg/tonne)
		Wood	(kg/tonne)
i	=	Substance	(–)
j	=	Fuel type	(–)

Emission factors used to estimate emissions from fuel combustion in barbecues are documented in Table 4. Emission and speciation factors were sourced from references summarised in Table 46 in Appendix B.

Table 4 – Barbecues emission factors

Substance	Emission factors			
	Natural gas (Mm^3/year)	LPG & butane (kL/year)	Briquettes (tonne/year)	Wood (tonne/year)
Ammonia (total)	320.34	0.213	1	0.9
Carbon monoxide	640.68	0.9	137.5	126.3
Oxides of nitrogen	1505.59	1.56	4.55	1.3
Particulate matter ≤ 2.5 µm	121.73	0.08	1.92	16.65

Substance	Emission factors			
	Natural gas (Mm^3/year)	LPG & butane (kL/year)	Briquettes (tonne/year)	Wood (tonne/year)
Particulate matter ≤ 10 µm	121.73	0.08	3.12	17.3
Polychlorinated dioxins and furans (TEQ)	4.98×10^{-8}	3.32×10^{-11}	1.75×10^{-9}	4.1×10^{-9}
Polycyclic aromatic hydrocarbons (B[a]P)	5.15×10^{-5}	4.20×10^{-8}	4.63×10^{-9}	3.62×10^{-3}
Sulfur dioxide	9.61	0.013	4.65	0.2
Total volatile organic compounds	88.09	0.06	5	114.5

Activity data

Barbecue fuel consumption was estimated using domestic survey data collected by NSW EPA in its 2008 inventory study (NSW EPA 2012a). It was assumed that barbecue use in the Sydney greater metropolitan region was similar to that of Perth.

Barbecue fuel consumption for wood, LPG and natural gas was estimated by multiplying the percentage of residential fuel consumption from NSW EPA (2012a) by total residential fuel consumption for the study area presented in Table 5 and Table 6 respectively.

Table 5 – Percentage use of residential fuel consumption in Sydney GMR[2]

Fuel type	Barbecues (%)	Other residential (%)
Wood	0.2	99.8
LPG	49.9	50.1
Natural gas	1.3	98.7

Table 6 – Total residential fuel consumption in study area

Study area	Wood (tonne/year)[3]	LPG (kL/year)[4]	Natural gas (Mm^3/year)[5]
Perth	104,161	20,172	228

Fuel consumption for briquettes and butane was calculated by multiplying the fuel consumption per dwelling type from NSW EPA (2012a) in Table 7 by the number of dwellings in the study area in Table 8. Dwelling type data were sourced from the 2011

2 Table ES-9 NSW EPA (2012a)

3 Method for determining residential wood consumption provided in Section 2.8

4 Total residential consumption is the sum of indoor residential and barbecue LPG consumption. Method for determining indoor residential LPG consumption provided in Section 2.3.

5 Provided by ATCO Gas (ATCO 2016)

ABS census mesh block data (ABS 2011a).

Table 7 – Fuel consumption per dwelling in NSW

Dwelling type	Wood (tonne/year)	Briquettes (tonne/year)	Natural gas (Mm^3/year)	LPG (kL/year)	Butane (kL/year)
Flat, unit or apartment	3.5×10^{-4}	6.0×10^{-4}	1.7×10^{-6}	0.01	9.6×10^{-6}
Semi detached	7.7×10^{-4}	1.3×10^{-3}	3.7×10^{-6}	0.03	1.9×10^{-5}
Separate house	7.8×10^{-4}	1.4×10^{-3}	4.0×10^{-6}	0.03	3.2×10^{-5}

Table 8 – Number of dwelling types in study area

Study area	Flat, unit or apartment	Semi detached	Separate house
Perth	74,988	90,082	565,682

Total barbecue fuel consumption for each fuel type is presented in Table 9. Total amount of fuel consumed by dwelling type was calculated by scaling fuel consumption per dwelling type from NSW EPA (2012a) in Table 7 relative to total fuel consumption in the study area.

Table 9 – Barbecues fuel consumption

Dwelling type	Natural gas (Mm^3/year)	LPG (kL/year)	Butane (kL/year)	Briquettes (tonne/year)	Wood (tonne/year)
Flat, unit or apartment	0.14	486	0.72	45	10
Semi detached	0.36	1,307	1.69	121	27
Separate house	2.43	8,293	12.61	770	170
Total	2.93	10,086	15.02	936	207

Emission estimates

Emission estimates from fuel combustion in barbecues are summarised in Table 10.

Table 10 – Barbecues emissions by fuel type

Substance	Emissions (kg/year)				
	Natural gas	LPG & butane	Briquettes	Wood	Total
Acetaldehyde	0.001	0.001	0.27	2,702	2,702
Acetone				1,188	1,188
Acrolein			0.14	99	99
Ammonia (total)	939	2,152	936	186	4,212
Antimony and compounds			0.01	0.001	0.01

Substance	Emissions (kg/year)				
	Natural gas	LPG & butane	Briquettes	Wood	Total
Arsenic and compounds			0.19	0.03	0.22
Benzene	0.10	0.22	1	608	609
Beryllium and compounds			0.01		0.01
1,3-Butadiene (vinyl ethylene)				185	185
Cadmium and compounds			0.02	1	1
Carbon disulfide			0.06		0.06
Carbon monoxide	1,877	9,091	128,696	26,096	165,760
Chloroform (trichloromethane)			0.03		0.03
Chromium (total)			0.16	0.11	0.27
Cobalt and compounds			0.05	0.06	0.11
Copper and compounds				1	1
Cumene (1-methylethylbenzene)			0.002		0.002
Cyanide (inorganic) compounds			1		1
Ethylbenzene			0.06	35	36
Formaldehyde (methyl aldehyde)	4	8	0.11	1,848	1,859
n-Hexane			0.03		0.03
Lead and compounds	0.02	0.05	0.20	2	2
Manganese and compounds			0.23	0.30	1
Mercury and compounds			0.04	0.04	0.08
Methyl ethyl ketone			0.16	341	341
Methyl methacrylate			0.01		0.01
Nickel and compounds			0.13	1	1
Oxides of nitrogen	4,412	15,758	4,259	269	24,697
Particulate matter ≤ 2.5 µm	357	808	1,797	3,440	6,402
Particulate matter ≤ 10 µm	357	808	2,920	3,574	7,660
Phenol			0.01		0.01

Substance	Emissions (kg/year)				
	Natural gas	LPG & butane	Briquettes	Wood	Total
Polychlorinated dioxins and furans (TEQ)	1.46×10^{-07}	3.35×10^{-07}	1.64×10^{-06}	8.47×10^{-07}	2.97×10^{-06}
Polycyclic aromatic hydrocarbons (B[a]P)eq	1.51×10^{-04}	4.24×10^{-04}	4.34×10^{-06}	1	1
Selenium and compounds			1	0.01	1
Styrene (ethenylbenzene)			0.01		0.01
Sulfur dioxide	28	131	4,352	41	4,553
Tetrachloroethylene			0.02		0.02
Toluene (methylbenzene)	0.16	0.36	0.11	251	251
Total volatile organic compounds	258	606	4,680	23,658	29,202
Xylenes (individual or mixed isomers)			0.07	123	123
Zinc and compounds			0.03	3	3

Spatial allocation

Emissions from fuel combustion in barbecues were allocated based on the dwelling types and density of each grid cell. Dwelling type data were sourced from the 2011 ABS census mesh block data (ABS 2011a). The spatial allocation of sulfur dioxide emissions is presented in Figure 4.

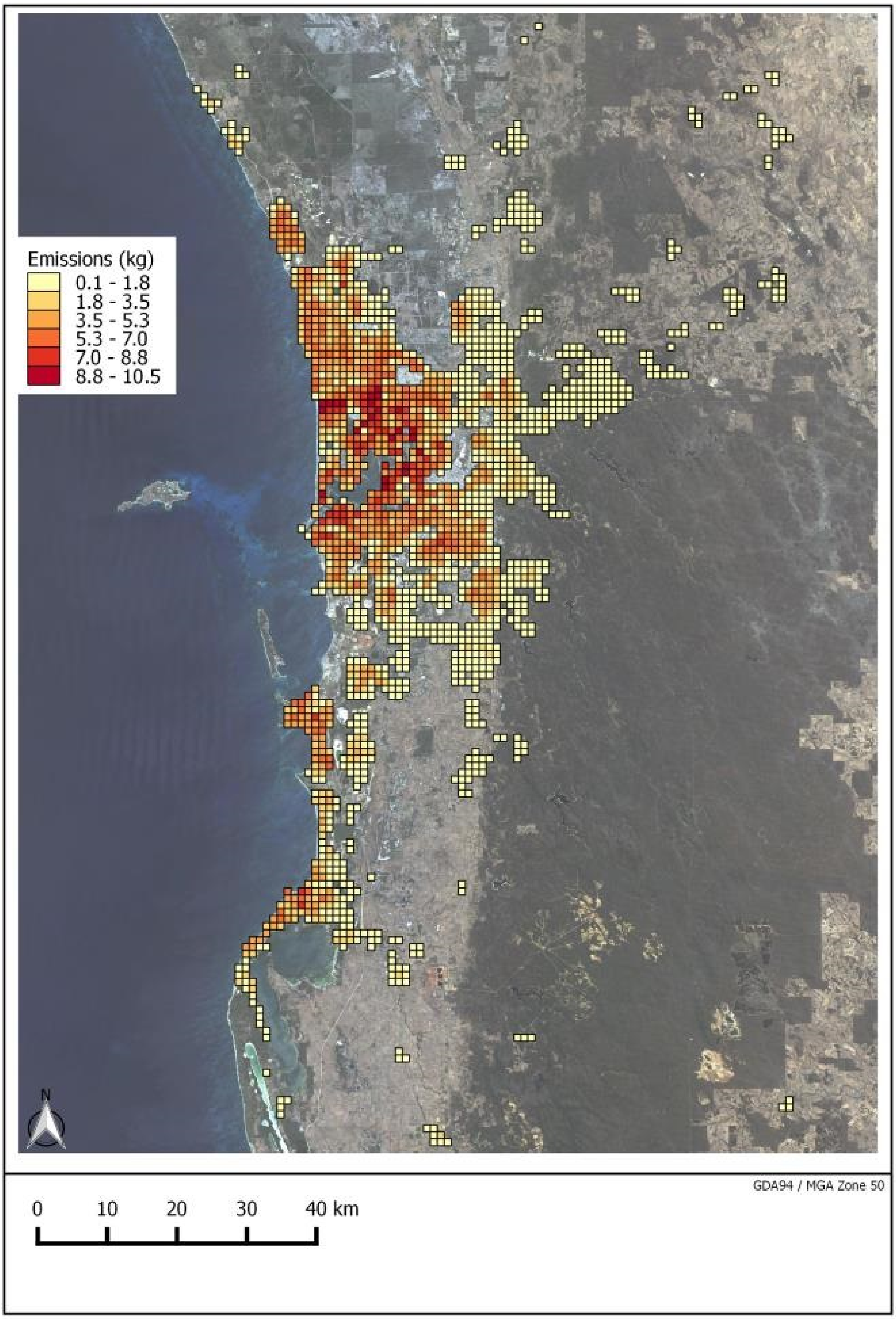


Figure 4 – Spatial allocation of barbecue SO_2 emissions

2.3 Gaseous fuel combustion

Emissions of combustion products from gaseous-fuel-fired residential appliances and unaccounted commercial business equipment have been estimated using fuel-consumption-based emission factors. Emissions were calculated using the following equation from Pechan (2006).

$$E_{i,j,k} = C_{j,k} \times EF_{i,j}$$

Where:

$E_{i,jk}$	=	Emissions of substance i from fuel type j and source type k	(kg/yr)
C_j	=	Fuel consumption for fuel type j	
		Natural gas	(Mm^3/yr)
		LPG	(kL/yr)
$EF_{i,j}$	=	Emission factor for substance i and fuel type j	
		Natural gas	(kg/Mm^3)
		LPG	(kg/kL)
i	=	Substance	(–)
j	=	Fuel type	(–)
k	=	Source type (either residential or unaccounted)	(–)

Emission factors used to estimate natural gas and LPG combustion emissions from residential and unaccounted commercial business equipment are documented in Table 11. Emission and speciation factors were sourced from the references summarised in Table 47 in Appendix B.

Table 11 – Gaseous fuel combustion emission factors

Substance	Emission factors	
	Natural gas (kg/Mm^3)	LPG (kg/kL)
Acetaldehyde	2.12×10^{-4}	1.39×10^{-7}
Ammonia (total)	320.34	0.213
Benzene	0.0336	2.2×10^{-5}
Carbon monoxide	640.68	0.9
Formaldehyde (methyl aldehyde)	1.2	7.84×10^{-4}
Lead and compounds	0.008	5.23×10^{-6}
Oxides of nitrogen	1505.59	1.56
Particulate matter ≤ 10 µm	121.73	0.08
Particulate matter ≤ 2.5 µm	121.73	0.08
Polychlorinated dioxins and furans (TEQ)	4.98×10^{-8}	3.32×10^{-11}
Polycyclic aromatic hydrocarbons (B[a]P)eq	6.30×10^{-5}	4.20×10^{-8}
Sulfur dioxide	9.61	0.013

Substance	Emission factors	
	Natural gas (kg/Mm^3)	LPG (kg/kL)
Toluene (methylbenzene)	0.0544	3.55×10^{-5}
Total volatile organic compounds	88.09	0.06

Activity data

Indoor residential LPG fuel consumption was estimated by multiplying dwelling LPG consumption (ABS 2012b) by the proportion of dwellings using LPG indoors (ABS 2011a, ABS 2011b). Parameters used for the calculation are listed in Table 12.

Table 12 – Inputs used to calculate indoor residential LPG consumption

Parameter	Value
LPG consumption per dwelling (litres/week) – ABS (2012b)	3
LPG consumption per dwelling (litres/year)	156
Number of dwellings in study area – ABS (2011a)	734,711
Proportion of dwellings using LPG indoors (%) – ABS (2011b)	8.8
Total indoor residential LPG consumption (kL)	10,086

Residential and non-residential natural gas consumption was provided by ATCO Gas and is presented in Table 13. Natural gas consumption for unaccounted commercial business equipment was estimated by subtracting commercial business natural gas consumption estimated in *Technical report 3: Commercial and industrial emissions* from non-residential consumption and is presented in Table 13.

It was assumed that natural gas consumed by facilities reporting to the NPI program was supplied directly by the natural gas pipelines and not through the ATCO Gas reticulation system. This assumption will result in an overestimation of unaccounted for commercial emissions.

Table 13 – Natural gas consumption by activity

Activity	2011–12 natural gas consumption (Mm^3/year)
Commercial businesses[6]	20.28
Non-residential[7]	325.71
Residential[7]	228.44
Unaccounted for commercial business equipment	305.44

Emission estimates

Emission estimates from gaseous fuel combustion are summarised in Table 14.

6 Natural gas consumption estimated in *Technical report 3 – Commercial and industrial emissions* from bread manufacturing, beer manufacturing, hospitals, laundry and dry-cleaning services, primary metal and metal product manufacturing and fabricated metal product manufacturing businesses.

7 Provided by ATCO Gas (ATCO 2016)

Table 14 – Gaseous fuel combustion emissions

Substance	Emissions (kg/year)			
	LPG combustion – residential	Natural gas combustion – residential	Natural gas combustion – unaccounted commercial business	Total gaseous fuel combustion
Acetaldehyde	0.001	0.05	0.06	0.11
Ammonia (total)	2,148	72,225	97,843	172,217
Benzene	0.22	7.58	10.26	18
Carbon monoxide	9,078	144,451	195,688	349,216
Formaldehyde (methyl aldehyde)	8	271	367	645
Lead and compounds	0.05	1.80	2.44	4.30
Oxides of nitrogen	15,734	339,458	459,863	815,056
Particulate matter ≤ 2.5 µm	807	27,446	37,181	65,434
Particulate matter ≤ 10 µm	807	27,446	37,181	65,434
Polychlorinated dioxins and furans (TEQ)	3.35×10^{-07}	1.12×10^{-05}	1.52×10^{-05}	2.68×10^{-05}
Polycyclic aromatic hydrocarbons (B[a]P)eq	4.24×10^{-04}	0.01	0.02	0.03
Sulfur dioxide	131	2,167	2,935	5,233
Toluene (methylbenzene)	0.36	12	17	29
Total volatile organic compounds	605	19,861	26,906	47,372

Spatial allocation

Emissions from indoor residential LPG fuel combustion were spatially allocated according to the dwelling density of each grid cell. Dwelling density was determined using the 2011 ABS census mesh block data (ABS 2011a).

Residential and unaccounted commercial business natural gas consumption emissions were spatially allocated according to the proportion of natural gas burnt in each grid cell. This was determined using natural gas consumption per postcode provided by ATCO Gas.

The spatial allocation of gaseous fuel combustion NO_X emissions is presented in Figure 5.

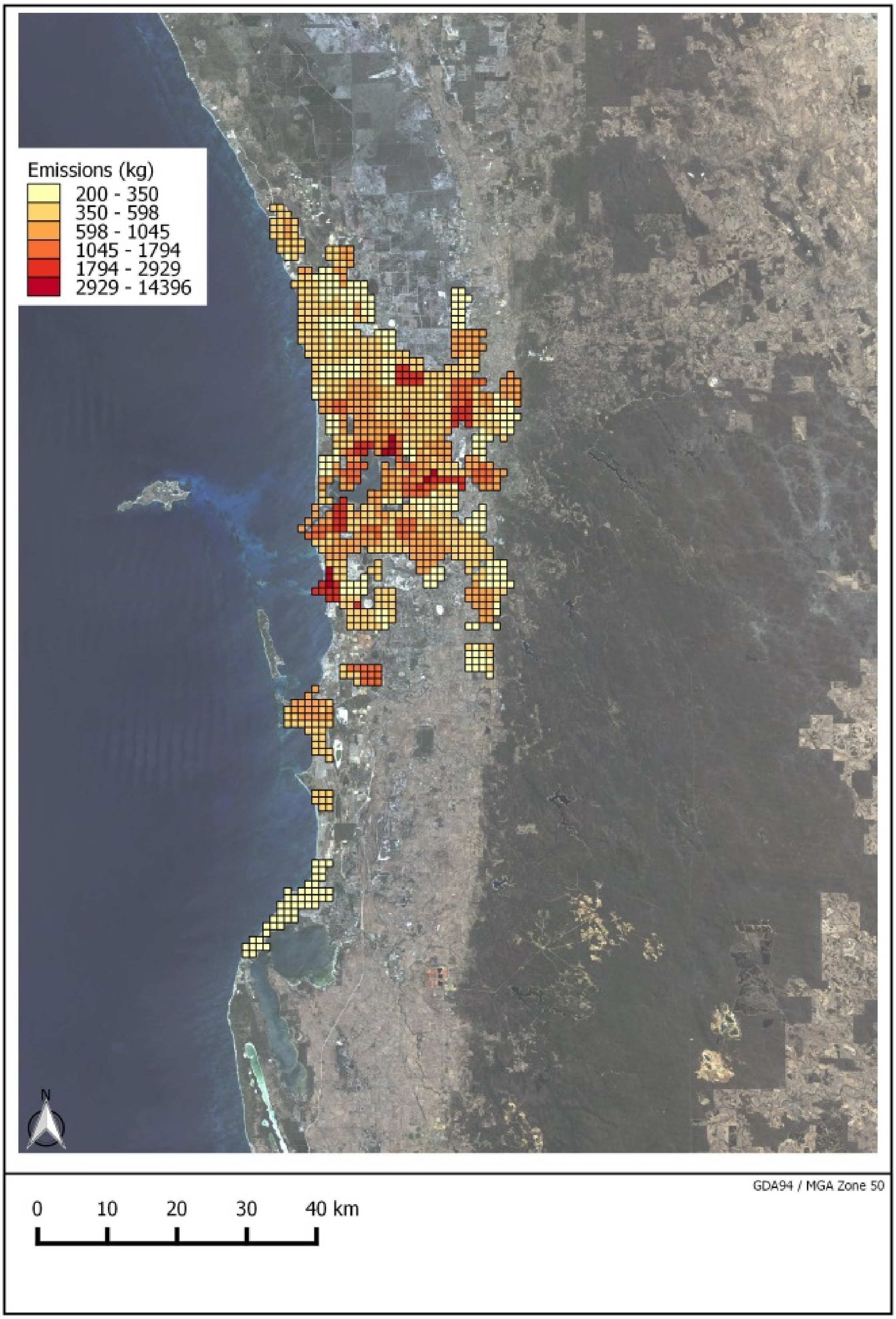


Figure 5 – Spatial allocation of gaseous fuel combustion NOx emissions

2.4 Graphic arts

Volatile organic compounds (VOC) emissions from domestic and unaccounted commercial activities involved in graphic arts have been estimated.

Methodology

Emissions for graphic arts have been estimated using a per capita emission factor combined with population in the study area. Emissions have been determined using the following equation from Pechan (2009a).

$$E_{VOC} = P \times EF_{VOC}$$

Where:

E_{VOC}	=	Emissions of VOC	(kg/yr)
P	=	Population	(capita)
EF_{VOC}	=	Emission factor for VOC	(kg/capita/yr)

The organic gas chemical profile ‘Printing evaporation loss – general’ (ORGPROF 517) from the Californian Air Resources Board (CARB) (2015) was used to speciate VOCs.

Activity data

Ink and solvent consumption for 2011–12 was estimated by scaling estimated ink consumption for Western Australia in 2008 (NSW EPA 2012a) to population. Parameters used for the calculation are listed in Table 15.

Table 15 – Inputs used to calculate ink consumption

Parameter	Value
WA ink consumption 2008 (tonne/year) – Table 3-74, NSW EPA (2012a) derived from IBISWorld (2008)	3,666
WA population 2008 – ABS (2008)	2,204,040
WA population 2011–12 – ABS (2011a)	2,239,171
Study area population 2011–12 – ABS (2011a)	1,751,528
WA ink consumption 2011–12 (tonne/year)	3,724
Study area ink consumption 2011–12 (tonne/year)	2,913

Total VOC emissions from ink solvent consumption was estimated using an emission factor of 0.66 kilograms VOC per kilogram ink (NSW EPA 2012a). This emission factor was derived by NSW EPA (2012a) from the *Graphic Arts, EIIP Technical Report Series Volume III* (ERG 1996b) and presented in Table 16.

Table 16 – Graphic arts component VOC emission factors

Printing process	Ink solvent use (%)	Component emission factor (kg VOC/kg ink)			
		Ink	Fountain solution	Cleaning solution	Total
Rotogravure	22	0.7		0.03	0.73
Flexography	16	0.6		0.04	0.64
Heatset	8.75	0.32	0.9	0.03	1.25
Non-heatset web	8.75	0.02	0.53	0.03	0.58
Non-heatset sheet	8.75	0.02	1.25	1.1	2.37
Newspaper	8.75	0.02	0.07	0.07	0.16
Letterpress	8	0.24			0.24
Screen	9.5				
Planographic	9.5				
Grand total	100	0.30	0.24	0.12	0.66

Graphic arts VOC emissions by activity are presented in Table 17. VOC emissions from domestic and unaccounted commercial activities involved were estimated by subtracting VOC emissions reported by NPI facilities and estimated from commercial activities in *Technical report 3: Commercial and industrial emissions* from total VOC emissions.

Table 17 – Graphic arts VOC emissions by activity

Activity	VOC (kg/year)
NPI facilities	630
Commercial	89,758
Domestic and unaccounted commercial	1,843,191
Total	1,933,579

Emission estimates

Emission estimates from unaccounted commercial businesses involved in graphic arts are summarised in Table 18.

Table 18 – Graphic arts emissions

Substance	Emissions (kg/year)
Ethylbenzene	3,871
Toluene (methylbenzene)	5,530
Total volatile organic compounds	1,843,191
Xylenes (individual or mixed isomers)	53,268

Spatial allocation

Emissions from domestic and unaccounted commercial activities in graphic arts were spatially allocated according to the population density of each grid cell. Population density was determined using the 2011 ABS census mesh block data (ABS 2011a).

The VOC emission factor of 1.05 kg/capita/year presented in Table 18 was derived by dividing the VOC emission for unaccounted commercial businesses by the population of the study area. This is used for spatial allocation.

Table 19 – Graphic arts emission factor for unaccounted commercial businesses

Emission source	VOC emission factor (kg/capita/year)
Evaporative emissions from unaccounted commercial businesses	1.05

The spatial allocation of VOC emissions is presented in Figure 6.

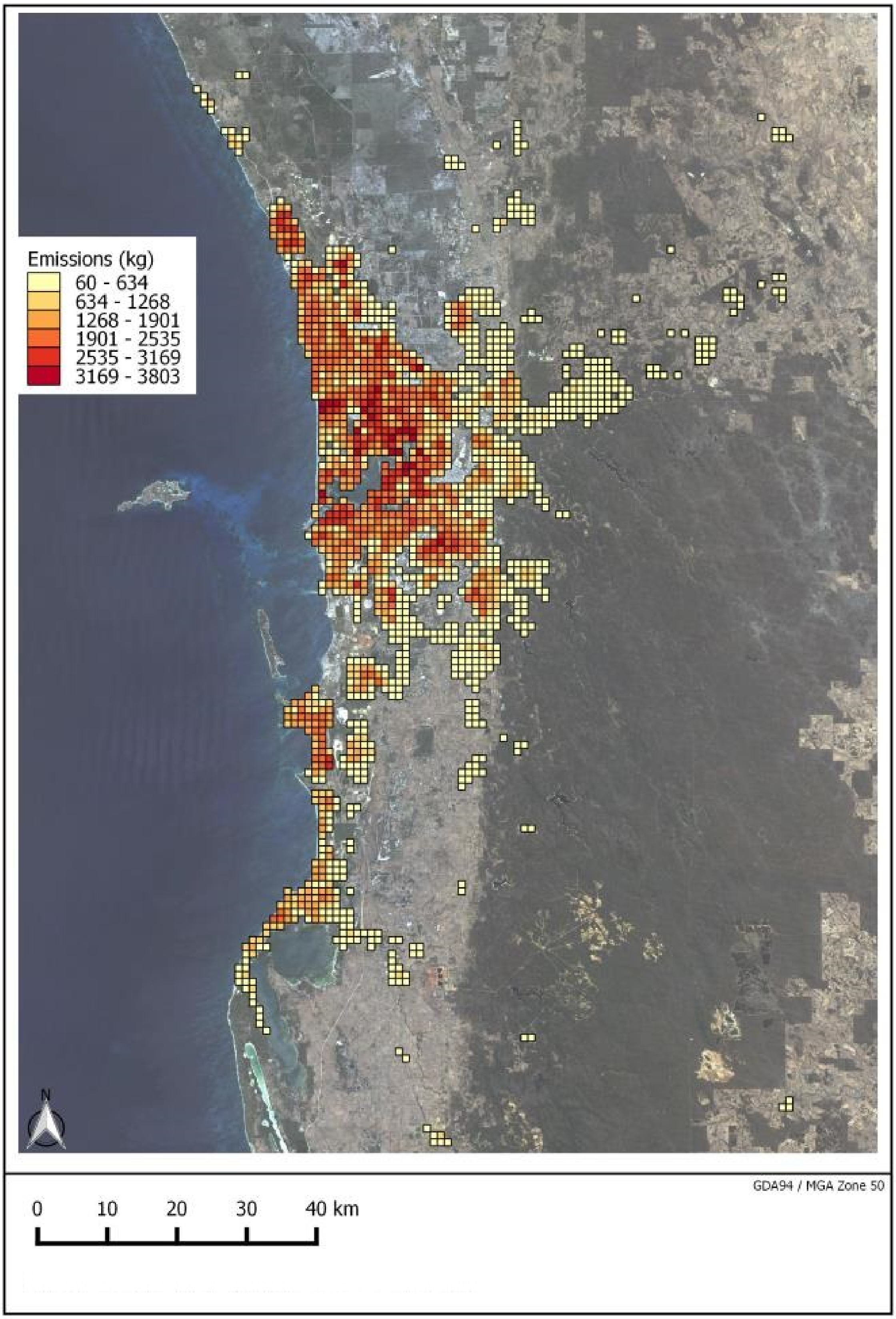


Figure 6 – Spatial allocation of graphic arts VOC emissions

2.5 Lawn mowing and garden equipment

Exhaust and evaporative emissions from lawn mowing and garden equipment have been estimated for two activities:

- domestic use (2-stroke and 4-stroke petrol engines); and
- public open space use (2-stroke, 4-stroke petrol engines and diesel engines).

Exhaust emissions are generated from fuel combustion. Evaporative emissions occur through the crankcase, and are caused by refuelling, permeation and temperature changes. Examples of equipment accounted for include lawn mowers, chain saws, leaf blowers, trimmers, edgers, shredders and pressure washers.

Methodology

Exhaust emissions from lawn mowing and garden equipment were estimated using the following equation.

$$\boldsymbol{E_{i,j} = C_j \times EF_{i,j}}$$

Where:

$E_{i,j}$	=	Emissions of substance i from fuel type j	(kg/yr)
C_j	=	Fuel consumption for fuel type j	(kL/yr)
$EF_{i,j}$	=	Emission factor for substance i and fuel type j	(kg/kL)
i	=	Substance	(–)
j	=	Fuel type	(–)

Evaporative emissions from lawn mowing and garden equipment were estimated using the following equation.

$$\boldsymbol{E_{VOC} = C_j \times EF_{VOC}}$$

Where:

E_{VOC}	=	Emissions of VOC	(kg/yr)
C_j	=	Fuel consumption for fuel type j	(kL/yr)
EF_{VOC}	=	Emission factor for VOC	(kg/kL)
j	=	Fuel type	(–)

Emission factors used to estimate exhaust and evaporative emissions from lawn mowing and garden equipment are documented in Table 20 and Table 21 respectively. Emission and speciation factors were sourced from the references summarised in Table 48 in Appendix B.

Table 20 – Exhaust emission factors for lawn mowing and garden equipment

Substance	Domestic (kg/kL)		Public open space (kg/kL)		
	2-stroke petrol	4-stroke petrol	2-stroke petrol	4-stroke petrol	Diesel exhaust
Ammonia (total)	0.03	0.03	0.03	0.03	0.02
Carbon monoxide	786.97	742.55	847.95	1132.04	26.73
Oxides of nitrogen	1.98	3.92	1.85	4.53	43.51
Particulate matter ≤ 2.5 µm	10.65	0.63	10.85	0.89	5.21
Particulate matter ≤ 10 µm	11.58	0.68	11.79	0.96	5.37
Polychlorinated dioxins and furans (TEQ)	3.29×10^{-12}	3.29×10^{-12}	3.29×10^{-12}	3.29×10^{-12}	4.57×10^{-9}
Polycyclic aromatic hydrocarbons (B[a]Peq)	8.44×10^{-4}	2.98×10^{-4}	8.59×10^{-4}	4.20×10^{-4}	8.78×10^{-6}
Sulfur dioxide	0.11	0.18	0.10	0.18	0.08
Total volatile organic compounds	339.17	64.50	374.76	65.78	8.21

Table 21 – Evaporative emission factors for lawn mowing and garden equipment

Substance	Domestic (kg/kL)		Public open space (kg/kL)		
	2-stroke petrol	4-stroke petrol	2-stroke petrol	4-stroke petrol	Diesel
Total volatile organic compounds	71.47	57.51	23.91	14.38	0.16

Activity data

Lawn mowing and garden equipment fuel consumption was estimated using domestic survey data collected by NSW EPA in its 2008 inventory study (NSW EPA 2012a). It was assumed lawn mowing and garden equipment use in the NSW EPA inventory area were similar to the Perth study area.

Survey data from NSW EPA (2012a) were scaled using a population ratio to determine the amount of fuel use for lawn mowing and garden equipment for NSW. Lawn mowing and garden equipment fuel consumption was then calculated by applying the per cent fuel consumption in lawn mowing and gardening equipment for NSW by the automotive fuel consumption sold to retailers in Perth. The parameters used in the calculation are presented in Table 22.

Domestic and public open space petrol consumption was apportioned by 2-stroke and 4-stroke engine type using the ratios from NSW EPA (2012a). Fuel use by engine type is presented in Table 23.

Table 22 – Parameters used to calculate fuel consumption for domestic lawn mowing and garden equipment use

Source	Fuel type	Lawn mowing and garden equipment fuel consumption (kL/yr)		Fuel sold in NSW (kL)[8]	Total fuel used in lawn mowing and garden equipment in NSW (%)	Fuel sold in WA (kL)	Fuel sold in study area (kL)[9]	Fuel consumption in study area (kL)
		NSW GMR	NSW[10]					
Domestic	Petrol	46,19011	61,546	6,032,164	1.02	1,743,997	1,366,540	13,943
Public open space	Petrol	19,22612	25,681		0.42			5,803
	Diesel	3,33612	4,445	2,964,389	0.15	937,185	733,087	1,099

Table 23 – Fuel consumption by engine type

Source	Engine type	NSW GMR (kL)	NSW GMR (%)	Study area (kL)
Domestic[11]	2-stroke petrol	15,665	34	4,729
	4-stroke petrol	30,525	66	9,214
Public open space[12]	2-stroke petrol	10,014	52	3,023
	4-stroke petrol	9,212	48	2,781

8 BREE (2012a)

9 Scaled based on population ratio of study area: WA (1,751,528: 2,239,171) sourced from ABS (2012a)

10 Scaled based on population ratio of GMR: NSW (5,284,560: 6,943,461) sourced from NSW EPA (2012a) and ABS (2008)

11 Table 3-98 NSW EPA (2012a)

12 Table 3-129 NSW EPA (2012a)

Emission estimates

Emission estimates from domestic and public open space use of lawn mowers and garden equipment are summarised in Table 24 and Table 25 respectively.

Table 24 – Emissions from domestic lawn mowing and garden equipment

Substance	Emissions (kg/year)				
	2-stroke petrol exhaust	4-stroke petrol exhaust	2-stroke petrol evaporative	2-stroke petrol evaporative	Total
Acetaldehyde	2,669	2,437			5,106
Acrolein	481	416			897
Ammonia (total)	137	267			404
Benzene	40,348	31,181	2,636	4,133	78,298
1,3-Butadiene (vinyl ethylene)	3,441	5,659			9,100
Carbon monoxide	3,721,236	6,841,951			10,563,187
Chromium (total)	1.32×10^{-04}	2.56×10^{-04}			3.88×10^{-04}
Cyclohexane			169	265	434
Ethylbenzene	38,424	11,782	338	530	51,073
Formaldehyde (methyl aldehyde)	4,070	10,192			14,263
n-Hexane	22,697	5,897	743	1,166	30,503
Manganese and compounds	4.45×10^{-05}	8.67×10^{-05}			1.31×10^{-04}
Nickel and compounds	9.68×10^{-05}	1.89×10^{-04}			2.85×10^{-04}
Oxides of nitrogen	9,363	36,119			45,482
Particulate matter ≤ 2.5 µm	50,359	5,805			56,164
Particulate matter ≤ 10 µm	54,757	6,266			61,022
Polychlorinated dioxins and furans (TEQ)	1.56×10^{-08}	3.03×10^{-08}			4.59×10^{-08}
Polycyclic aromatic hydrocarbons (B[a]Peq)	3.99	2.74			6.73

Substance	Emissions (kg/year)				
	2-stroke petrol exhaust	4-stroke petrol exhaust	2-stroke petrol evaporative	2-stroke petrol evaporative	Total
Styrene (ethenylbenzene)	2,077	451			2,528
Sulfur dioxide	515	1,677			2,192
Toluene (methylbenzene)	156,845	42,697	6,421	10,068	216,031
Total volatile organic compounds	1,603,786	594,311	337,950	529,905	3,065,952
Xylenes (individual or mixed isomers)	172,391	40,294			217,458

Table 25 – Emissions for public open space lawn mowing and garden equipment

Substance	Emissions (kg/year)						
	2-stroke petrol exhaust	4-stroke petrol exhaust	Diesel exhaust	2-stroke petrol evaporative	2-stroke petrol evaporative	Diesel evaporative	Total
Acetaldehyde	1,885	750	479				3,114
Acrolein	340	128	27.3				495
Ammonia (total)	87.7	80.6	24.2				192
Benzene	28,499	9,597	184	564	312		39,155
1,3-Butadiene (vinyl ethylene)	2,431	1,742	16.8				4,189
Carbon monoxide	2,563,164	3,147,852	29,383				5,740,399
Chromium (total)	8.41×10^{-05}	7.74×10^{-05}					1.61×10^{-04}
Cumene (1-methylethylbenzene)						8.86	8.86
Cyclohexane				36.1	20.0		56.1
Ethylbenzene	27,140	3,626	28.0	72.3	40.0	1.04	30,907
Formaldehyde (methyl	2,875	3,137	1,066				7,078

Substance	Emissions (kg/year)						
	2-stroke petrol exhaust	4-stroke petrol exhaust	Diesel exhaust	2-stroke petrol evaporative	2-stroke petrol evaporative	Diesel evaporative	Total
aldehyde)							
n-Hexane	16,032	1,815	14.4	159	88		18,108
Manganese and compounds	2.84×10^{-05}	2.62×10^{-05}					5.46×10^{-05}
Nickel and compounds	6.19×10^{-05}	5.69×10^{-05}		392	217	16	1.19×10^{-04}
Oxides of nitrogen	5,592	12,597	47,828				66,017
Particulate matter ≤ 2.5 µm	32,797	2,475	5,727				40,999
Particulate matter ≤ 10 µm	35,639	2,669	5,903				44,211
Polychlorinated dioxins and furans (TEQ)	9.94×10^{-09}	9.15×10^{-09}	5.02×10^{-06}				5.04×10^{-06}
Polycyclic aromatic hydrocarbons (B[a]Peq)	2.60	1.17	0.01				3.78
Styrene (ethenylbenzene)	1,467	139	135				1,741
Sulfur dioxide	299	503	90.1				893
Toluene (methylbenzene)	110,786	13,141	135	1,373	760	4.87	126,200
Total volatile organic compounds	1,132,816	182,914	9,025	72,275	39,986	176	1,437,192
Xylenes (individual or mixed isomers)	121,766	12,401	95.5	398	220	15.9	134,897

Spatial allocation

Domestic lawn mowing and garden equipment emissions were spatially allocated based on the density of separate and semi-detached dwellings in each grid cell. Dwelling density was determined using the 2011 ABS census mesh block data (ABS 2011a).

Public open space lawn mowing and garden equipment emissions were spatially allocated based on population density of each grid cell where population was greater or equal to 50 people. Population density was determined using the 2011 ABS census mesh block data (ABS 2011a).

The spatial allocation of carbon monoxide emissions for lawn mowing emissions is presented in Figure 7.

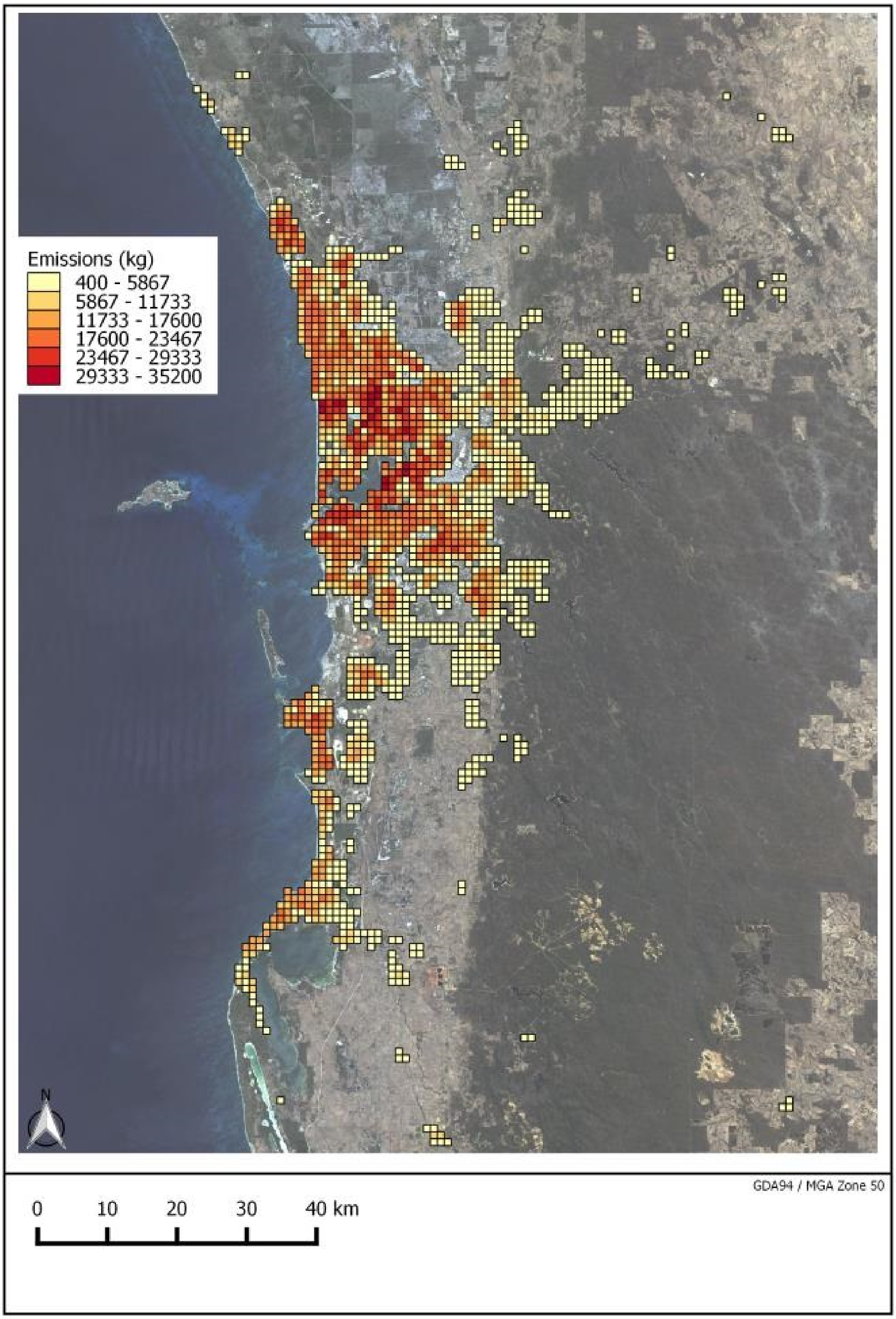


Figure 7 – Spatial allocation of lawn mowing CO emissions

2.6 Natural gas leakage

Methodology

Emissions of natural gas from the reticulation system have been estimated using the natural gas leakage rate and composition, combined with the amount of ‘unaccounted for’ gas (UAFG). Emissions have been determined using the following equation from the Department of the Environment and Energy (DoEE 2016).

$$E_i = F \times UAFG \times 0.55 \times C_i$$

Where:

$E_{i,}$	=	Emissions of substance i	(kg/yr)
F	=	Flow rate of natural gas through reticulation network	(Mm^3/yr)
UAFG	=	Fraction of ‘unaccounted for’ gas	(Mm^3/ Mm^3)
0.55	=	Fraction of UAFG allocated as leakage	(Mm^3/ Mm^3)
C_i	=	Composition of natural gas for substance i	(kg/Mm^3)
i	=	Substance	(–)

The composition of natural gas published by the Australian Pipeline Association (APIA 2011) is provided in Table 26.

Table 26 – Natural gas composition

Substance	% Volume
Methane	90
Ethane	4
Propane	1.7
Butane	0.4
Pentane	0.11
Hexane	0.08
Heptane	0.01
Carbon dioxide	2.7
Nitrogen	1
Hydrogen sulfide[13]	0.000757
Total volatile organic compounds	6.3

Activity data

Flow rate of natural gas through the reticulation network and UAFG were provided by ATCO Gas for 2011–12. Inputs used to calculate natural gas leakage are presented in Table 27.

13 Table 3-168 NSW (2012)

Table 27 – Inputs used to calculate natural gas leakage

Parameter	Value
Flow rate of natural gas (Mm^3/yr)[14]	554.14
UAFG (%)	2.89
UAFG (Mm^3/yr)	16.01
Natural gas leakage (Mm^3/yr)	8.81
Natural gas leakage (kg/yr)[15]	6,650,082

Emission estimates

Emission estimates from natural gas leakage are summarised in Table 28.

Table 28 – Natural gas leakage emissions

Substance	Emissions (kg/year)
Hydrogen sulfide	50
Total volatile organic compounds	418,955

Spatial allocation

Natural gas leakage emissions were spatially allocated according to the proportion of natural gas consumed in each grid cell. This was determined from natural gas consumption per postcode provided by ATCO Gas. The spatial allocation of VOC emissions for natural gas leakage emissions is presented in Figure 8.

14 Provided by ATCO Gas

15 Natural gas density is 0.755 kg/m^3 (DoEE 1999)

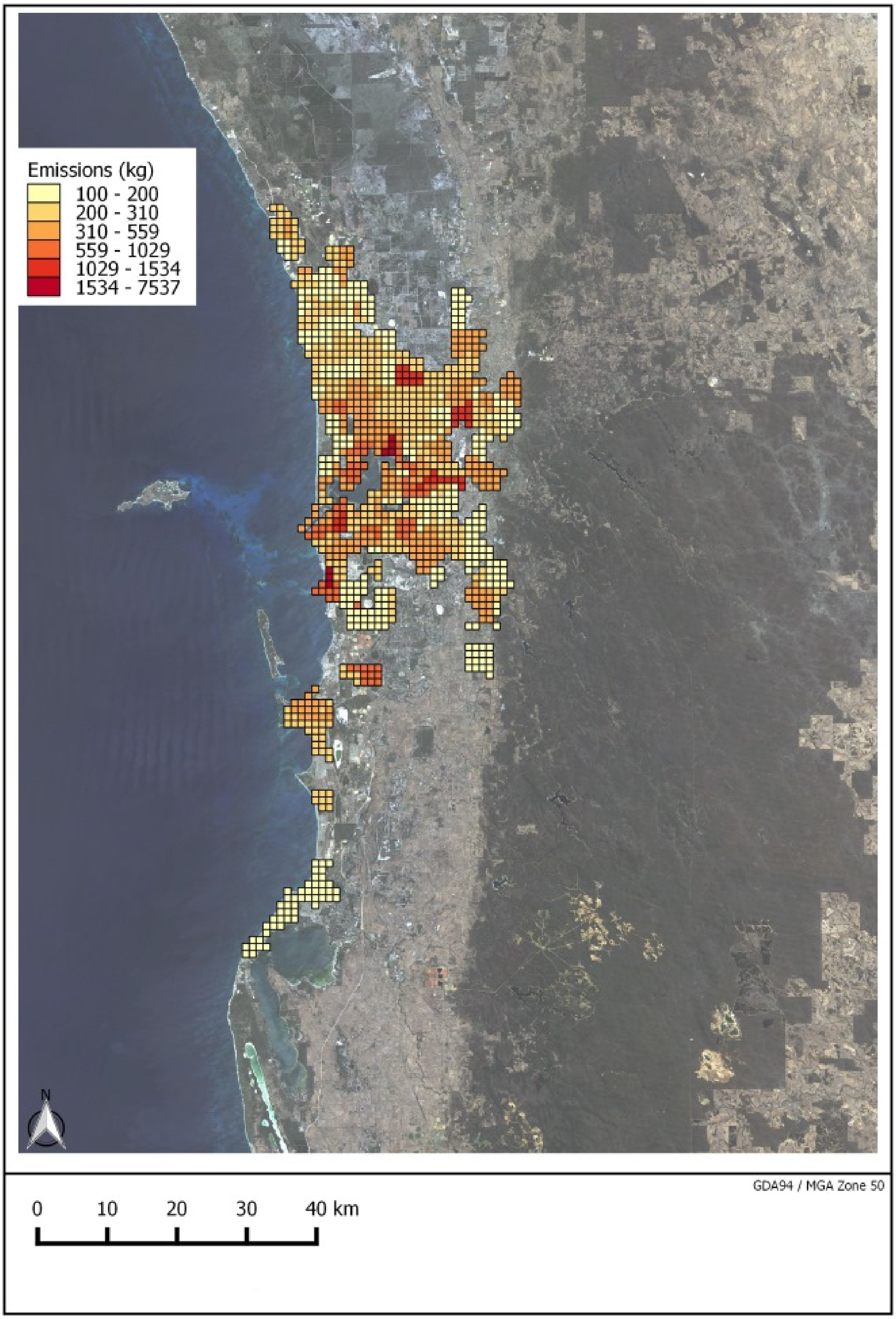


Figure 8 – Spatial allocation of natural gas leakage VOC emissions

2.7 Portable fuel containers

VOC emissions from domestic and public open space use of portable metal and plastic fuel containers have been estimated. Emissions from vapour displacement and spillage during refuelling and from transport, as well as those from diurnal sources (temperature changes) and permeation during storage, have been determined. Emissions of diesel have been assumed to be zero as it has a higher boiling point than petrol.

Methodology

The number of domestic use portable fuel containers was calculated using the following equation from CARB (1999).

$$\boldsymbol{N = \frac{C \times 1000}{14.9 \times 3.7862}}$$

Where:

N	=	Number of portable fuel containers	(–)
C	=	Consumption of petrol from lawn mowing and garden equipment	(kL/yr)
14.9	=	Petrol throughput for each portable container	(US gal/portable fuel container/yr)
1000	=	Conversion factor	(L/kL)
3.7862	=	Conversion factor	(L/US gal)

The number of public open space portable fuel containers was calculated using the following equation from CARB (1999).

$$\boldsymbol{N = \frac{C \times 1000}{1206.9 \times 3.7862}}$$

Where:

N	=	Number of portable fuel containers	(–)
C	=	Consumption of petrol from lawn mowing and garden equipment	(kL/yr)
1206.9	=	Petrol throughput for each portable container	(US gal/portable fuel container/yr)
1000	=	Conversion factor	(L/kL)
3.7862	=	Conversion factor	(L/US gal)

Vapour displacement emissions of VOCs from refuelling of portable fuel containers were estimated using the following equation (USEPA 2009). Inputs considered include the volume of petrol consumed, the ambient temperature and Reid vapour pressure (RVP) of petrol.

$$E_{VOC} = e^{(-1.2798 - 0.0049 \times (T_d - T_a) + 0.0203 \times T_d + 0.1315 \times RVP)} \times \frac{PD}{3.7862}$$

Where:

E_{VOC}	=	Vapour displacement emissions of VOC during refuelling	(kg/yr)
T_d	=	Temperature of petrol dispensed (T_d = 62 + 0.6 x (T_a -62))	(°F)
T_a	=	Temperature of ambient air	(°F)
RVP	=	Reid vapour pressure of petrol	(psia)
PD16	=	Volume of petrol dispensed	(kL/yr)
3.7862	=	Conversion factor	(L/US gal)

Emissions from spillage may occur during refuelling and transport. The following equation has been used to estimate emissions from spillage during refuelling (USEPA 2007).

$$E_{VOC} = 0.3128 \times \frac{PD}{3.7862}$$

Where:

E_{VOC}	=	Petrol spillage emissions of VOC during refuelling	(kg/yr)
0.3128	=	Petrol spillage VOC emission factor during refuelling	(g/US gal)
PD[16]	=	Volume of petrol dispensed	(kL/yr)
3.7862	=	Conversion factor	(L/US gal)

The following equation was used to estimate emissions from spillage during transport (CARB 1999).

$$E_{VOC,c,u} = EF_{VOC,c} \times PC_{c,u} \times \frac{PD}{3.7862}$$

Where:

$E_{VOC,c,u}$	=	Petrol spillage emissions of VOC during transport for portable fuel container condition c and use u	(kg/yr)
$EF_{VOC,c}$	=	Petrol spillage VOC emission factor for	(g/US gal)

16 Assumed to be equal to amount of petrol consumed (kL)

		portable fuel container condition c (9.829 for closed;13.889 for open)	
$PC_{c,u}$	=	Portion of portable containers transported in condition c and use u	(%)
PD3	=	Volume of petrol dispensed	(kL/yr)
c	=	Portable fuel container condition (closed or open)	(–)
u	=	Portable fuel container use (domestic or public open space)	(–)
3.7862	=	Conversion factor	(L/US gal)

Emissions from portable fuel containers in storage are influenced by temperature changes during the day. The rate of evaporation increases as fuel temperature in the portable fuel container rises – referred to as a diurnal emission. Emissions for closed portable fuel containers were estimated using the following equation (CARB 1999).

$$E_{VOC,c,t,u} = EF_{VOC,c,t} \times \frac{PSP}{100} \times \frac{PF}{100} \times \frac{PC_{c.t,u}}{100} \times V_u \times N \times \frac{365}{1000}$$

Where:

$E_{VOC,c,t,u}$	=	Diurnal emissions of VOC during storage for portable fuel container condition c, type tand use u	(kg/yr)
$EF_{VOC,c,t}$	=	Diurnal VOC emission factor for portable fuel container condition c and type t (1.38 for closed plastic; 0.44 for closed metal)	(g/US gal/day)
PSP	=	Portion of portable containers stored with petrol (70%)	(%)
PF	=	Petrol fill rate of portable containers (49%)	(%)
$PC_{c,t,u}$	=	Proportion of portable fuel containers stored in condition c, type t and use u	(%)
V_u	=	Volume of portable fuel containers for use u	(US gal)
N	=	Number of portable containers	(number)
c	=	Portable fuel container condition (closed)	(–)
t	=	Portable fuel container type (metal or plastic)	(–)
u	=	Portable fuel container use (domestic or public open space)	(–)
365	=	Conversion factor	(day/yr)
1000	=	Conversion factor	(g/kg)

Diurnal emissions for open portable fuel containers were estimated using the following equation (CARB 1999).

$$E_{VOC,c,t,u} = EF_{VOC,c,t} \times \frac{PSP}{100} \times \frac{PC_{c,t,u}}{100} \times N \times \frac{365}{1000}$$

Where:

$E_{VOC,c,t,u}$	=	Diurnal emissions of VOC during storage for portable fuel container condition c, type t and use u	(kg/yr)
$EF_{VOC,c,t}$	=	Diurnal VOC emission factor for portable fuel container condition c and type t (21.8 for open plastic and metal)	(g/US gal/day)
PSP	=	Portion of portable containers stored with petrol (70%)	(%)
$PC_{c,t,u}$	=	Proportion of portable fuel containers stored in condition c, type t and use u	(%)
N	=	Number of portable containers	(number)
c	=	Portable fuel container condition (open)	(–)
t	=	Portable fuel container type (metal or plastic)	(–)
u	=	Portable fuel container use (domestic or public open space)	(–)
365	=	Conversion factor	(day/yr)
1000	=	Conversion factor	(g/kg)

Diurnal emissions of VOC from portable fuel containers in storage have been adjusted using monthly ambient temperature and RVP of petrol using the following equation (EEA 2010).

$$E_{VOC,c,t,l} = E_{VOC,c,t} \times (RVP\ x\ 10^{(AT_{s,l}+B)}) / \sum_{l=1}^{n} (RVP_l \times (RVP\ x\ 10^{(AT_{s,l}+B)})$$

Where:

$E_{VOC,c,t,l}$	=	Diurnal emissions of VOC during storage for portable fuel container condition c, type t and time interval l	(kg/time interval)
$E_{VOC,c,t}$	=	Diurnal emissions of VOC during storage for portable fuel container condition c and type t	(kg/yr)
RVP_l	=	RVP of petrol for time interval l	(kPa)
A	=	0.000007047 x RVP_k + 0.0132	(kPa)
$T_{s,l}$	=	Portable fuel container storage temperature for time interval l ($T_{s,l} = T_{a,l}$ +5)	(°C)
$T_{a,l}$	=	Temperature of ambient air for time interval l	(°C)
B	=	0.0002311 x RVP_k - 0.5236	(kPa)
c	=	Portable fuel container condition (closed or open)	(–)

t	=	Portable fuel container type (metal or plastic)	(–)
l	=	Time interval (12 for month)	(number)
n	=	12 for l = month	(number)

Permeation is a diffusion process where fuel molecules migrate through the walls of the portable fuel container. Plastic portable fuel containers have higher permeation emissions rates than metal containers. Permeation emissions from closed portable fuel containers have been estimated using the following equation (CARB 1999).

$$\boldsymbol{E_{VOC,i,t,u} = EF_{VOC,i,t} \times \frac{PSP}{100} \times \frac{PF}{100} \times \frac{PC_{i,t,u}}{100} \times V_u \times N \times e^{(0.0327 \times (T_s - 85.53))} \times \frac{365}{1000}}$$

Where:

$E_{VOC,c,t,u}$	=	Diurnal emissions of VOC during storage for portable fuel container condition c, type t and use u	(kg/yr)
$EF_{VOC,c,t}$	=	Diurnal VOC emission factor for portable fuel container condition c and type t (1.57 for closed plastic; 0.06 for closed metal)	(g/US gal/day)
PSP	=	Portion of portable containers stored with petrol (70%)	(%)
PF	=	Petrol fill rate of portable containers (49%)	(%)
$PC_{c,t,u}$	=	Proportion of portable fuel containers stored in condition c, type t and use u	(%)
V_u	=	Volume of portable fuel containers for use u	(US gal)
N	=	Number of portable containers	(number)
T_s	=	Portable fuel container storage temperature ($T_s = T_a + 5$)	(°F)
T_a	=	Temperature of ambient air	(°F)
c	=	Portable fuel container condition (closed)	(–)
t	=	Portable fuel container type (metal or plastic)	(–)
u	=	Portable fuel container use (domestic or public open space)	(–)
365	=	Conversion factor	(day/yr)
1000	=	Conversion factor	(g/kg)

VOC emissions from portable fuel containers were speciated using petrol vapour phase speciation profiles in Table 49.

Activity data

Residential portable container survey data from CARB (1999), combined with petrol throughput, were used to determine the number of portable fuel containers and their emissions. The portable fuel container capacity, type and storage condition variables used to estimate emissions are provided in Table 29.

Lawn mowing and garden equipment petrol consumption was estimated using domestic survey data collected by NSW EPA in its 2008 inventory study (NSW EPA 2012a). The methodology used to estimate lawn mowing and garden equipment fuel consumption is provided in Section 2.5.

Table 29 – Portable fuel containers survey data and estimates

Parameter	Domestic portable containers		Public open space containers	
Fuel consumption (kL) (C)	13,943		5,803	
Estimated no. of portable fuel containers (N)	243,714		1,250	
Container storage capacity (V)	2.34 US gal		3.43 US gal	
Stored petrol volume (PF)	49%		49%	
Container type (t)	plastic – 76%	metal – 24%	plastic – 72%	metal – 28%
Plastic container storage condition (PC)	open – 23%	closed – 53%	open – 39%	closed – 33%
Metal container storage condition (PC)	open – 11%	closed – 13%	open – 10%	closed – 18%
All containers storage condition (PC)	open – 34%	closed – 66%	open – 49%	closed – 51%

Ambient air temperature data were generated using 'The Air Pollution Model' Version 4 (TAPM V4). The model was used to generate gridded meteorology data for the study area. More information on study area meteorology development is provided in Section 2.1 of *Technical report 1: Biogenic and geogenic emissions*. Ambient temperature used in estimates is the monthly average for the entire study area and is presented in Table 30.

Table 30 – Ambient air temperature (T_a)

Month	T_a (°F)	T_a (°C)
July	56.4	13.6
August	58.3	14.6
September	59.5	15.3
October	64.4	18.0
November	67.6	19.8
December	73.9	23.3
January	78.4	25.8
February	75.2	24.0
March	73.5	23.1
April	67.2	19.6
May	61.3	16.3
June	58.8	14.9

Petrol RVP data were based on local fuel terminal sampling provided by industry.

A diesel RVP value of 3.5 kPa was used for calculations because local fuel terminal data were not available (NSW EPA 2012b).

Emission estimates

Emission estimates from domestic and public open space portable fuel containers are summarised in Table 31 and Table 32 respectively.

Table 31 – Domestic portable fuel container emissions

Substance	Emissions (kg/yr)					
	Refuelling [17]	Spillage (refuelling)[17]	Spillage (transport)	Diurnal	Permeation	Total
Benzene	122	9	322	4,096	306	4,855
Cyclohexane	8	1	21	263	20	311
Ethylbenzene	16	1	41	525	39	622
n-Hexane	34	2	91	1,155	86	1,369
Toluene (methylbenzene)	296	22	784	9,978	746	11,826
Total volatile organic compounds	15,585	1,152	41280	525,149	39,266	622,432
Xylenes (individual or mixed isomers)	86	6	227	2,888	216	3,423

Table 32 – Public open space portable fuel container emissions

Substance	Emissions (kg/yr)					
	Refuelling[17]	Spillage (refuelling)[17]	Spillage (transport)	Diurnal	Permeation	Total
Benzene	51	4	141	29	1	226
Cyclohexane	3	0.2	9	2	0.1	15
Ethylbenzene	6	0.5	18	4	0.2	29
n-Hexane	14	1	40	8	0.4	64
Toluene (methylbenzene)	123	9	344	71	3	551
Total volatile organic compounds	6,486	479	18,114	3,757	174	29,011
Xylenes (individual or mixed isomers)	36	3	100	21	1	160

17 Refuelling emissions occurring at fuel retail stations have been excluded from spatial allocation

Spatial allocation

Domestic portable fuel container emissions were spatially allocated based on the density of separate and semi-detached dwellings in each grid cell. Dwelling density was determined using the 2011 ABS census mesh block data (ABS 2011a).

Public open space portable fuel container emissions were spatially allocated based on the population density of each grid cell where population was greater or equal to 50 people. Population density was determined using the 2011 ABS census mesh block data (ABS 2011a).

Refuelling emissions occur at fuel retailing facilities and have been accounted for in Section 2.7 of *Technical report 3: Commercial and industrial emissions*. These emissions have been excluded from spatial allocation. Adjusted total emissions for domestic and portable fuel container emissions are provided in Table 33.

Table 33 – Portable fuel container emissions for spatial allocation

Substance	Total domestic portable fuel container emissions (kg/yr)	Total public open space portable fuel container emissions (kg/yr)	Total (kg/yr)
Benzene	4,724	172	4,896
Cyclohexane	303	11.0	314
Ethylbenzene	606	22.0	628
n-Hexane	1,333	48.5	1,381
Toluene (methylbenzene)	11,508	419	11,927
Total volatile organic compounds	605,695	22,045	627,740
Xylenes (individual or mixed isomers)	3,331	121	3,452

The spatial allocation of VOC emissions from portable fuel container emissions is presented in Figure 9.

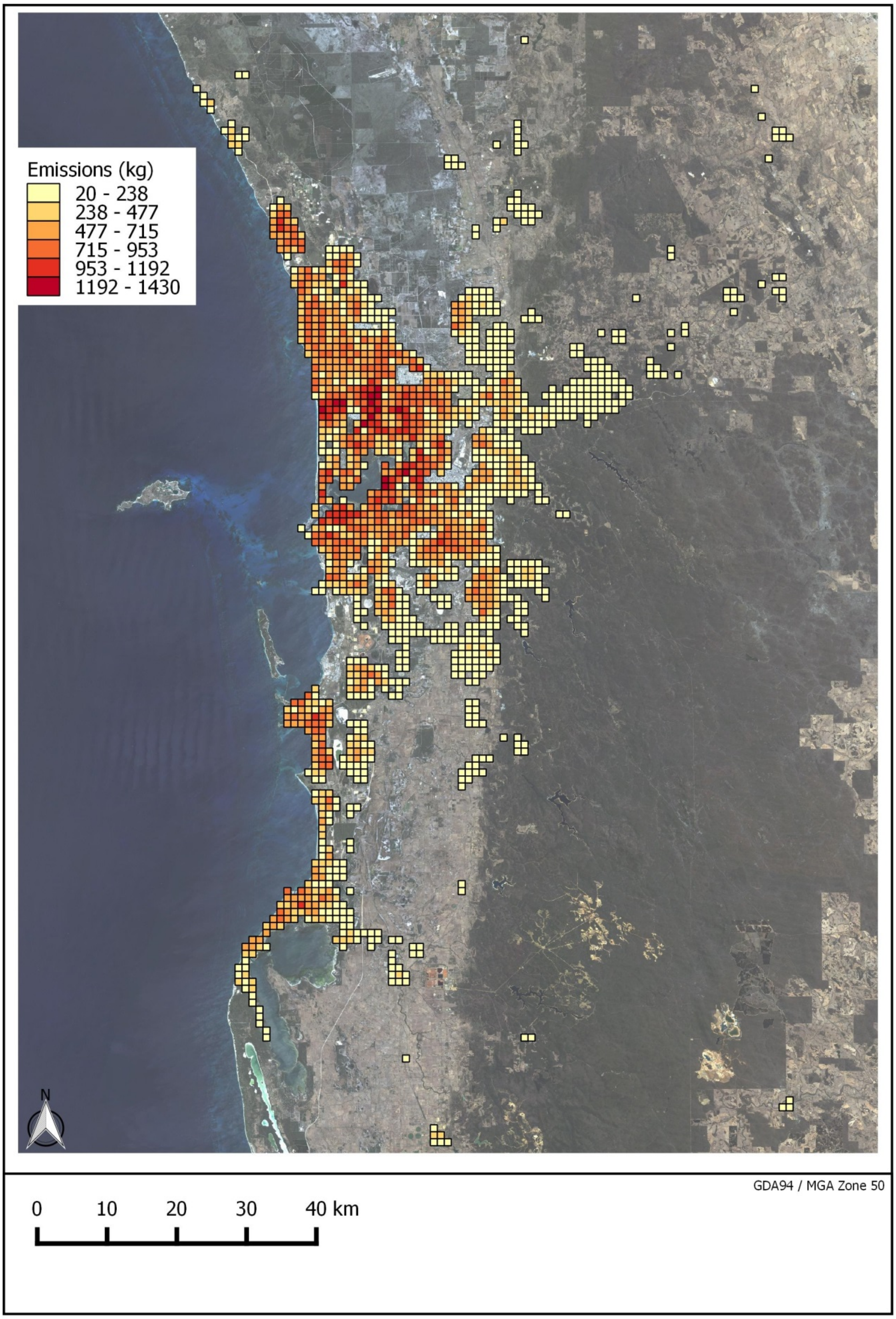


Figure 9 – Spatial allocation of portable fuel container VOC emissions

2.8 Solid fuel burning

Emissions from the combustion of wood were estimated from the following wood-fuel-fired residential space heater types:

- slow combustion heater with compliance plate;
- slow combustion heater without compliance plate;
- open fireplace; and
- potbelly stove.

Methodology

Emissions of combustion products from wood-fuel-fired residential space heaters were estimated using fuel-consumption-based emission factors. Emissions were calculated using the following equation (Pechan 2009b).

$$\boldsymbol{E_{i,j} = C_j \times EF_{i,j}}$$

Where:

$E_{i,j}$	=	Emissions of substance i from fuel type j	(kg/yr)
C_j	=	Wood fuel consumption for residential space heater type j	(tonne/yr)
$EF_{i,j}$	=	Emission factor for substance i and residential space heater type j	(kg/tonne)
i	=	Substance	(–)
j	=	Residential space heater type	(–)

Emission factors used to estimate wood combustion emissions from residential space heaters are documented in Table 34. Emission and speciation factors were sourced from the references summarised in Table 51 of Appendix B.

Table 34 – Residential space heater emission factors

Substance	Emission factors (kg/tonne)			
	Slow combustion heater (compliant)	Slow combustion heater (non-compliant)	Open fire	Pot belly
Ammonia (total)	0.45	0.85	0.9	0.85
Carbon monoxide	70.4	115.4	74.5	115.4
Oxides of nitrogen	1.14	1.4	1.3	1.4
Particulate matter ≤ 10 µm	9.8	15.3	11.8	15.3
Particulate matter ≤ 2.5 µm	9.43	14.73	11.36	14.73
Polychlorinated dioxins and furans (TEQ)	4.1×10^{-09}	4.1×10^{-09}	4.1×10^{-09}	4.1×10^{-09}

Substance	Emission factors (kg/tonne)			
	Slow combustion heater (compliant)	Slow combustion heater (non-compliant)	Open fire	Pot belly
Polycyclic aromatic hydrocarbons (B[a]Peq)	0.0028	0.001	0.0036	0.001
Sulfur dioxide	0.2	0.2	0.2	0.2
Total volatile organic compounds	6	26.5	9.45	26.5

Activity data

Data for annual residential wood consumption in Western Australia were obtained from the Bureau of Resources and Energy Economics (BREE 2012b) and used to derive wood consumption in the study area. Variables considered when scaling wood consumption included climate and wood heater ownership rates.

Differences in climate were accounted for by apportioning wood consumption based on the average annual heating degree days (HDD[18]) per free-standing dwelling (ABS 2011a). Average annual heating degree day shapefiles were obtained from the Bureau of Meteorology (BOM 2004). Average heating degree day zones are presented in Figure 10.

Residential space heater ownership in Western Australia is higher outside of Perth. Differences in rates of ownership were accounted for by further scaling wood consumption by the per cent of dwellings that use wood as the main source of heating (ABS 2011c). Inputs used to scale wood consumption are provided in Table 35.

Table 35 – Inputs used to scale wood consumption

Area	Wood consumption based on average HDD (tonnes)	Number of dwellings[19]	Wood burnt per dwelling (tonnes)	Dwellings using wood as main source of energy (%)	Scaled wood consumption (tonnes)
Study area	241,573	735,949	0.33	4.7	104,161
Balance of state	70,989	227,378	0.31	32	208,400
Western Australia	312,562	963,327	0.32	11.8	312,562

Residential space heater wood consumption was estimated by multiplying the estimated residential fuel consumption for the study area by the percentage of residential wood use by source from NSW EPA (2012a) presented in Table 36.

18 A heating degree day (HDD) is a measurement designed to measure the demand for energy needed to heat a building. The base temperature used was 18°C.

19 ABS census mesh block data (ABS 2011a)

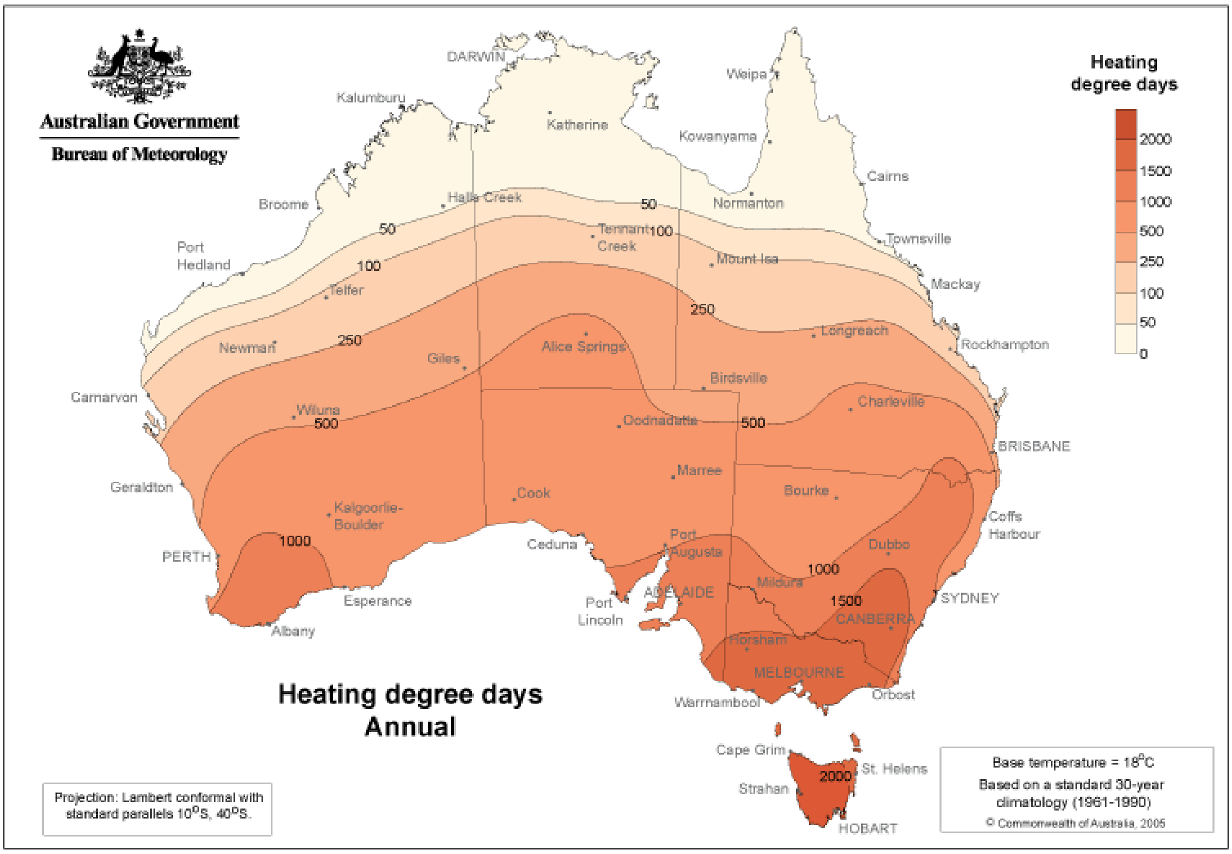


Figure 10 – Annual heating degree day zones

Table 36 – Wood consumption by activity

Activity	Consumption in Sydney GMR[20] (%)	Wood consumption (tonnes)
Barbecues	0.2	207
Residential space heaters	99.8	103,955

Wood consumption was apportioned to residential space heater types using percentage of heaters used most often (ABS 2011d) and is presented in Table 37.

Table 37 – Wood consumption by residential space heater type

Residential space heater type	Type of heater used most often (%)[21]	Wood consumption (tonnes)
Slow combustion heater	10.9	93,645
Slow combustion heater (compliant)	7.922	65,166
Slow combustion heater	3.3[22]	28,479

20 Sourced from NSW EPA (2012a)

21 Sourced from ABS (2011d)

22 Scaled based on ratio of compliant and non-compliant combustion heaters (100,653: 43,987) sourced from Table 3-219 in NSW EPA (2012a)

Residential space heater type	Type of heater used most often (%)[21]	Wood consumption (tonnes)
(non-compliant)		
Open fire	0.5	4,296
Pot belly	0.7	6,014

Emission estimates

Emission estimates from wood heaters are summarised in Table 38.

Table 38 – Solid fuel combustion emissions

Substance	Emissions (kg/yr)				
	Slow combustion heater (compliant)	Slow combustion heater (non-compliant)	Open fire	Pot belly	Total
Acetaldehyde	44,652	86,185	4,636	18,200	153,673
Acetone	19,628	37,885	2,038	8,000	67,552
Acrolein	1,642	3,170	170	669	5,652
Ammonia (total)	29,325	24,207	3,866	5,112	62,510
Antimony and compounds	0.11	0.073	0.0084	0.015	0.20
Arsenic and compounds	5.53	3.78	0.44	0.80	10.5
Benzene	10,049	19,395	1,043	4,096	34,583
1,3-Butadiene (vinyl ethylene)	3,050	5,887	317	1,243	10,496
Cadmium and compounds	122	83.2	9.68	17.6	232
Carbon monoxide	4,587,713	3,286,450	320,026	694,005	8,888,194
Chromium (total)	19.6	13.4	1.55	2.82	37.3
Cobalt and compounds	10.8	7.33	0.85	1.55	20.5
Copper and compounds	106	72.3	8.41	15.3	202
Ethylbenzene	586	1,132	60.9	239	2,018
Formaldehyde (methyl aldehyde)	30,537	58,941	3,170	12,447	105,095
Lead and compounds	60.4	41.2	4.79	8.70	115
Manganese and compounds	53.4	36.5	4.24	7.70	102
Mercury and compounds	7.66	5.23	0.61	1.10	14.6
Methyl ethyl ketone	5,630	10,867	585	2,295	19,377

Substance	Emissions (kg/yr)				
	Slow combustion heater (compliant)	Slow combustion heater (non-compliant)	Open fire	Pot belly	Total
Nickel and compounds	104	70.8	8.24	15.0	198
Oxides of nitrogen	74,290	39,870	5,584	8,419	128,164
Particulate matter ≤ 2.5 µm	614,519	419,492	48,799	88,585	1,171,395
Particulate matter ≤ 10 µm	638,631	435,725	50,689	92,013	1,217,057
Polychlorinated dioxins and furans (TEQ)	0.00027	0.00012	0.000018	0.000025	0.00043
Polycyclic aromatic hydrocarbons (B[a]Peq)	184	29.4	15.5	6.21	235
Selenium and compounds	0.96	0.65	0.076	0.14	1.83
Sulfur dioxide	13,033	5,696	859	1,203	20,791
Toluene (methylbenzene)	4,145	8,000	430	1,689	14,264
Total volatile organic compounds	390,998	754,687	40,594	159,369	1,345,648
Xylenes (individual or mixed isomers)	2,033	3,924	211	829	6,997
Zinc and compounds	499	341	39.6	71.9	951

Spatial allocation

Solid fuel combustion emissions were spatially allocated according to the proportion of dwellings with slow combustion heaters in each grid cell. Slow combustion heater population was determined for each suburb using the keyword search function for properties sold on the realestate.com.au[23] website. The proportion of slow combustion heaters in each suburb was then combined with dwelling density (ABS 2011a).

The spatial allocation of particulate matter ≤ 2.5 µm for solid fuel combustion emissions is presented in Figure 11.

The distribution of wood consumption in the study area is dependent on dwelling age and availability of alternative fuels. Wood consumption is generally higher in areas with older housing estates, areas not connected to the natural gas reticulation system and areas than can readily access free wood.

23 For each suburb, keyword searches were conducted using ‘combustion’ and ‘wood heater’ to identify the number of properties with slow combustion heaters. The search criterion for property type was limited to house, apartment and unit, townhouse and villa. The search was conducted on 21 and 22 October 2016.

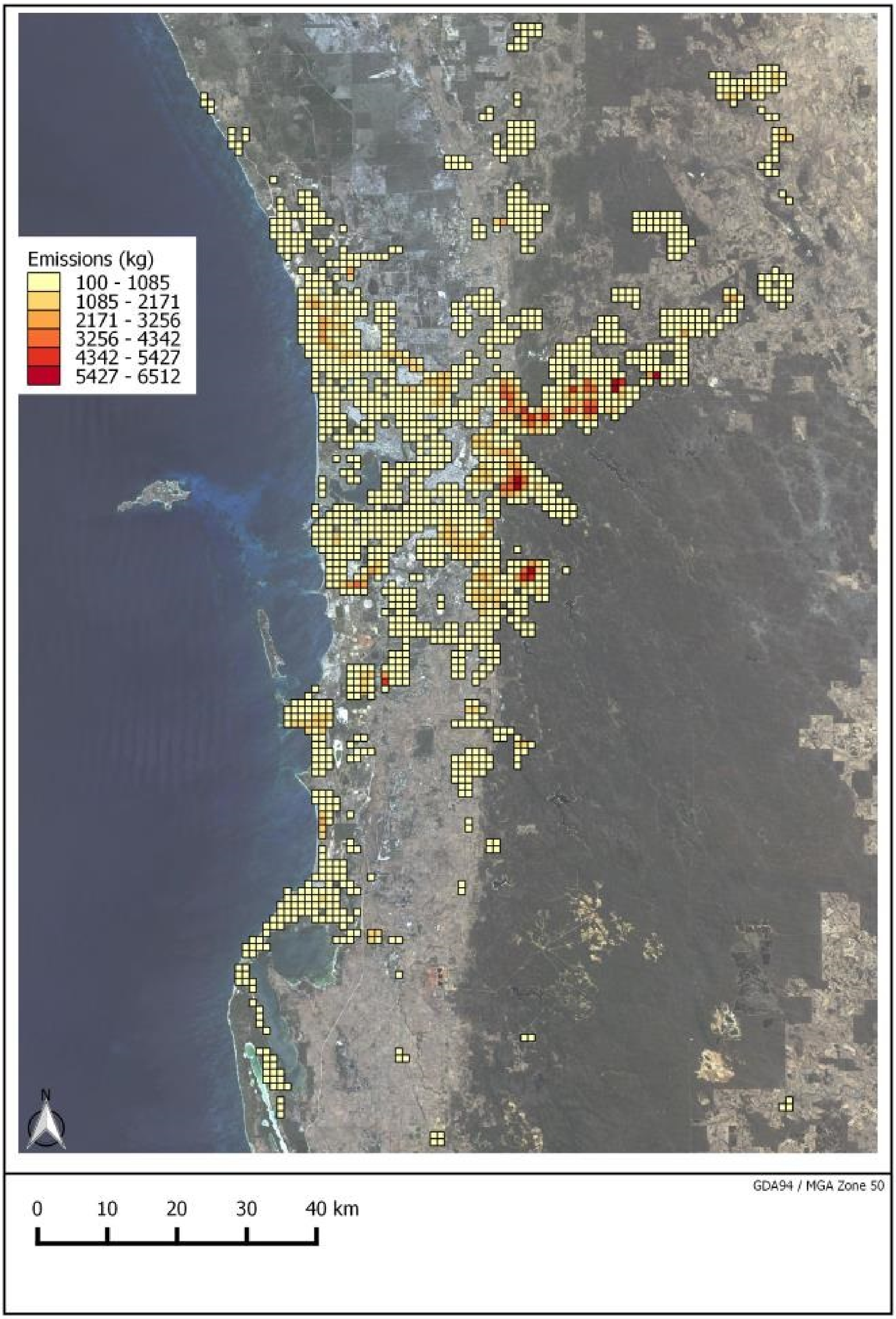


Figure 11 – Spatial allocation of solid fuel burning $PM_{2.5}$ emissions

2.9 Surface coating

VOC emissions from the application of architectural and decorative and industrial surface coatings and thinners have been included in the inventory, including the following group of products:

- architectural and decorative – water based;
- architectural and decorative – solvent based;
- architectural and decorative – water-based wood care;
- architectural and decorative – solvent-based wood care;
- architectural and decorative thinners;
- industrial surface coatings;
- industrial timber finishes; and
- industrial thinners.

Methodology

Evaporative VOC emissions from surface coatings and thinners have been estimated using consumption-based emission factors. Emissions have been estimated using the following equation (CARB 1997a, CARB 1997b, CARB 2003; EC 2000).

$$E_{VOC,i} = \frac{SC_i \times EF_{VOC,i}}{1000}$$

Where:

$E_{VOC,i}$	=	Emissions of VOC from surface coating and thinner type i	(kg/yr)
SC	=	Consumption of surface coating and thinner type i	(L/yr)
$EF_{VOC,i}$	=	Emission factor for VOC from surface coating and thinner type i	(g/L)
i	=	Surface coating and thinner type	(–)
1000	=	Conversion factor	(g/kg)

Emission factors used to estimate emissions from surface coatings and thinners are documented in Table 39. Emission factors were sourced from the references summarised in Table 51 in Appendix B.

Speciation factors were obtained from the Speciate Database Version 4.3 (Pechan 2011). Speciation profile numbers from each source have been provided in Table 39.

Table 39 – Surface coating and thinner emission and speciation factors

Surface coating category	Surface coating type	VOC emission factor (g/L)	Speciation profile number[24]
Architectural and decorative – water based	Paving paint	69.78	3140
	Roof paint	84.16	
	Fence paint	5.33	
	Speciality finishes	91.38	
	Texture coatings	34.48	
	Prepcoats	43.84	
	Ceiling paint/ flat topcoats	24.28	
	Door, window, trim topcoats	70.99	
	Waterbased – interior topcoat	30.6	
	Waterbased – exterior topcoat	45.7	
	Other	36.48	
Architectural and decorative – solvent based	Paving paint	498.28	3139
	Roof paint	406.77	
	Metal finishes	462.77	
	Prepcoats	461.79	
	Door, window, trim topcoats	392.85	
	Other	431.85	
Architectural and decorative – water-based wood care	Decking	42.99	2405
	Flooring	116.19	
	Interior stains	135.57	
	Exterior stains	96.75	
	Prepcoats	50	
	Interior clears	135.57	
	Exterior clears	85.16	
Architectural and decorative – solvent-based wood care	Decking	634.55	
	Flooring	561.79	
	Interior stains	447.51	
	Exterior stains	643.45	
	Prepcoats	485.18	
	Interior clears	450	

24 Speciate Database Version 4.3 https://www.epa.gov/air-emissions-modeling/speciate-version-45-through-32 (Pechan 2011)

Surface coating category	Surface coating type	VOC emission factor (g/L)	Speciation profile number[24]
	Exterior clears	424.5	
Architectural and decorative – thinners	Thinners	766.99	3141
Industrial surface coatings	Protective coatings	298.69	2418
	Marine coatings	376.02	2415
	Road and runway marking paint	83.12	2403
	Can and coil	452.4	2408
	Flat board coatings	384.69	2404
	Other	323.39	2418
Industrial timber finishes	Stains	771.94	2405
	Clears	611.37	
	Solid colours	516.31	
Industrial thinners	Thinners	766.99	3141

Activity data

Architectural and decorative surface coating consumption was derived from quarterly national sales reports provided by the Australia Paint Manufacturers Federation (APMF) (Informark 2011a–b, 2012a–g, 2013). A population ratio[25] was used to scale sales data from all of Australia to only the study area. Informark reports do not provide a breakdown between solvent and water-based products. Consumption of solvent and water-based products was determined using the sales percentages provided in Environ (2009) and documented in Table 40.

Architectural and decorative thinner consumption was estimated using consumption factors derived by NSW EPA (2012a) and provided in Table 41. It is assumed that only solvent-based surface coatings would require the use of thinners.

Industrial surface coating and thinner consumption was derived from state quarterly sales reports provided by the APMF (2012a–d, 2013a–b). A population ratio[26] was used to scale the sales data from all of Western Australia to the study area.

Surface coating and thinner consumption in the study area is provided in Table 42.

25 National sales data scaled based on population ratio of study area: Australian population (1,751,528: 21,507,170) sourced from ABS (2011a)

26 Scaled based on population ratio of study area: WA (1,751,528: 2,239,171) sourced from ABS (2012a)

Table 40 – Percentage water- and solvent-based architectural and decorative product sales

Product category	Surface coating type	% water borne	% solvent borne
Paints, enamels and clears	Paving paint	47	53
	Roof paint	76	24
	Fence paint	100	0
	Speciality finishes	100	0
	Texture coatings	100	0
	Metal finishes	0	100
	Prepcoats	82	18
	Ceiling paint/flat topcoats	100	0
	Door, window, trim topcoats	24	76
	Waterbased – interior topcoat	100	0
	Waterbased – exterior topcoat	100	0
	Other	93	7
Wood care	Decking	10	90
	Flooring	14	86
	Interior stains	17	83
	Exterior stains	50	50
	Prepcoats	80	20
	Interior clears	22	78
	Exterior clears	90	10

Table 41 – Architectural and decorative thinner consumption factors

Surface coating category	Thinner L/surface coating L
Architectural and decorative – solvent-based thinners	0.18
Architectural and decorative – solvent-based timber finishes thinners	0.35

Table 42 – Surface coating and thinner consumption in the study area

Surface coating category	Surface coating type	Consumption (L/yr)
Architectural and decorative – water based	Paving paint	67,030
	Roof paint	12,467
	Fence paint	88,379
	Speciality finishes	200,017
	Texture coatings	2,120,314
	Prepcoats	937,767
	Ceiling paint/flat topcoats	1,520,142
	Door, window, trim topcoats	127,677
	Water based – interior topcoat	2,979,091
	Water based – exterior topcoat	1,767,276
	Other	3,567
Architectural and decorative – solvent based	Paving paint	75,587
	Roof paint	3,937
	Metal finishes	158,501
	Prepcoats	205,851
	Door, window, trim topcoats	404,311
	Other	268
Architectural and decorative – water-based wood care	Decking	32,113
	Flooring	7,709
	Interior stains	4,359
	Exterior stains	16,280
	Prepcoats	31,001
	Interior clears	10,198
	Exterior clears	21,391
Architectural and decorative – solvent-based wood care	Decking	289,014
	Flooring	47,353
	Interior stains	21,281
	Exterior stains	16,280
	Prepcoats	7,750
	Interior clears	36,156
	Exterior clears	2,377
Architectural and decorative – thinners	Thinners	299,796
Industrial surface coatings	Protective coatings	2,055,970
	Marine coatings	417,678
	Road and runway marking paint	1,127,987
	Can and coil	159,582

Surface coating category	Surface coating type	Consumption (L/yr)
	Flat board coatings	25,039
	Other	542,633
Industrial timber finishes	Stains	2,894
	Clears	55,236
	Solid colours	97,601
Industrial thinners[27]	Thinners	780,552

Emission estimates

Emission estimates from surface coatings are summarised in Table 43.

Spatial allocation

Surface coating emissions were spatially allocated based on dwelling density of each grid cell. Dwelling density was determined using the 2011 ABS census mesh block data (ABS 2011a). The spatial allocation of total VOCs for surface coating emissions is presented in Figure 12.

27 Automotive thinner consumption estimated in Section 2.9 of *Technical report 3: Commercial and industrial emissions* has been subtracted from the total industrial thinner consumption.

Table 43 – Surface coating emissions

Substance	Emissions (kg/yr)								
	Architectural and decorative					Industrial			Total
	Water based	Solvent based	Water-based wood care	Solvent-based wood care	Thinners	Surface coatings	Timber finishes	Thinners	
Acetaldehyde	107								107
Acetone		2,456	102	2,786	8,002	46,098	959	20,834	81,238
Cyclohexane					368			958	1,326
Dibutyl phthalate	35.7								35.7
Dichloromethane		4,070							4,070
Ethanol	35.7	6,966	940	25,656	5,450	1,651	8,830	14,189	63,716
2-Ethoxyethanol			6.44	176		2,382	60.5		2,624
2-Ethoxyethanol acetate		36.7	9.20	251		3,466	86.4		3,849
Ethyl acetate		73.3	265	7,230		37,556	2,488		47,612
Ethylbenzene		1,283			989			2,574	4,846
Ethylene glycol (1,2-ethanediol)	56,220	36.7	6.44	176		4,478	60.5		60,977
Formaldehyde (methyl aldehyde)	35.7								35.7
n-Hexane	178								178
Methanol	10,095	367			851			2,215	13,528
Methyl ethyl ketone		9,166	509	13,907	23.0	38,469	4,786	59.9	66,921
Methyl isobutyl ketone		2,016	669	18,250	69.0	78,406	6,281	180	105,870
Methyl methacrylate	143								143
Styrene (ethenylbenzene)	856	183			46.0			120	1,205

Substance	Emissions (kg/yr)								
	Architectural and decorative					Industrial			Total
	Water based	Solvent based	Water-based wood care	Solvent-based wood care	Thinners	Surface coatings	Timber finishes	Thinners	
Tetrachloroethylene		36.7							36.7
Toluene (methylbenzene)	392	11,659	2,417	65,972	9,543	229,538	22,705	24,845	367,070
Total volatile organic compounds	356,723	366,624	9,196	251,034	229,940	1,122,220	86,395	598,676	3,020,809
Xylenes (individual or mixed isomers)	107	17,671	1,371	37,429		242,427	12,882	10,716	322,603

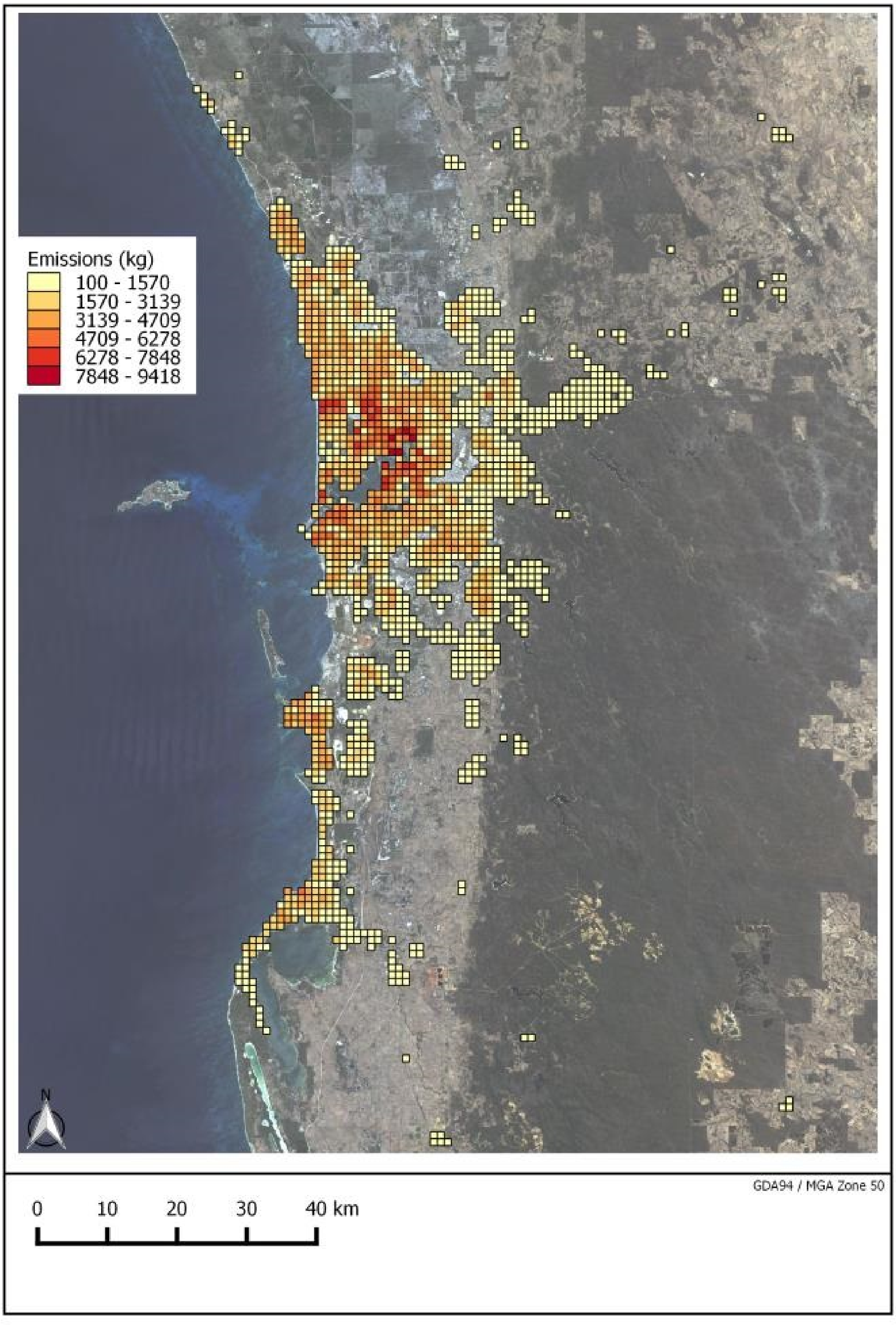


Figure 12 – Spatial allocation of surface coating VOC emissions

3 Total emission estimates

This section presents cumulative and comparative emission estimates for domestic activities.

To assess the relative risk for all emission estimates, toxic equivalency potential (TEP) scores were calculated. TEP is a technique increasingly being used by Australian and international environment agencies for comparing substances that have varying toxicities. TEP provides a screening-level evaluation of substances according to their effect on human health, and can be calculated in two ways. The ‘non-cancer risk’ score converts emissions to toluene-equivalents and is an assessment of the potential impact of toxins on general human health. The ‘cancer risk’ score converts emissions to benzene-equivalents and is an assessment of the potential impact of carcinogenic toxins (Scorecard 2015)[28].

This study assessed TEP using the non-cancer risk score to indicate the more general health risk. TEP is calculated by multiplying the emission estimates for substances by their corresponding non-cancer risk score. A list of NPI substances and their associated risk scores is included in Appendix A.

3.1 Total domestic emissions

Emissions estimated and TEP scores for all domestic sources are presented in Table 44. Total emissions from each source are presented in Table 45.

Table 44 – Domestic emission estimates: total

Substance	Emissions (tonnes/year)	Toxic equivalency potential (TEP) score
Key pollutants		
Particulate matter ≤ 2.5 µm	1,340	22,786
Total volatile organic compounds	20,214	20,214
Carbon monoxide	25,706	3,599
Oxides of nitrogen	1,079	2,375
Particulate matter ≤ 10µm	1,395	2,093
Sulfur dioxide	33.6	104
Other NPI-listed pollutants[29]		
Cadmium and compounds	0.23	443,008
Polychlorinated dioxins and furans (TEQ)	0.00000046	405,710
Mercury and compounds	0.015	73,431
Lead and compounds	0.12	70,454
Acrolein	7.14	11,429

28 Further information on how TEP is calculated can be found on the Scorecard website at: http://scorecard.goodguide.com/env-releases/def/tep_caltox.html

29 ‘Polycyclic aromatic hydrocarbons’ include a range of organic compounds of varying toxicities. It does not have an assigned TEP score. Ethanol, 2-ethoxyethanol acetate, acetic acid and glutaraldehyde also do not have a TEP score.

Substance	Emissions (tonnes/year)	Toxic equivalency potential (TEP) score
Copper and compounds	0.20	2,631
Formaldehyde (methyl aldehyde)	133	2,124
Tetrachloroethylene	30.7	1,995
Acetaldehyde	165	1,531
Benzene	158	1,276
Toluene (methylbenzene)	1,020	1,020
Ammonia (total)	240	910
Arsenic and compounds	0.011	905
Ethylene oxide	15.6	875
Cobalt and compounds	0.021	638
Nickel and compounds	0.20	635
Xylenes (individual or mixed isomers)	963	260
Zinc and compounds	0.95	181
Chromium (total)	0.038	116
Manganese and compounds	0.10	79.8
1,3-Butadiene (vinyl ethylene)	24.0	52.7
Chloroform (trichloromethane)	3.53	49.4
Methanol	476	42.9
Dichloromethane	4.07	28.5
Acetone	468	23.4
Ethylene glycol (1,2-ethanediol)	61.0	15.2
Ethylbenzene	97.1	13.6
Methyl ethyl ketone	150	7.52
Ethyl acetate	90.6	8.16
Selenium and compounds	0.0024	5.85
2-Methoxyethanol	2.59	5.17
2-Ethoxyethanol	3.33	4.33
n-Hexane	135	4.05
Methyl isobutyl ketone	114	3.43
Antimony and compounds	0.00021	1.72
Hydrogen sulfide	0.050	1.71
Trichloroethylene	1.80	1.14
Cyanide (inorganic) compounds	0.0012	0.68
Styrene (ethenylbenzene)	5.47	0.44
Dibutyl phthalate	0.036	0.39
Beryllium and compounds	0.0000097	0.24
Methyl methacrylate	0.14	0.076
Cyclohexane	3.02	0.060
Cumene (1-methylethylbenzene)	0.0089	0.0036

Substance	Emissions (tonnes/year)	Toxic equivalency potential (TEP) score
Carbon disulfide	0.000061	0.000073
Phenol	0.0000075	0.0000028
2-Ethoxyethanol acetate	3.85	N/A
Acetic acid (ethanoic acid)	4.27	N/A
Ethanol	2,199	N/A
Glutaraldehyde	4.78	N/A
Polycyclic aromatic hydrocarbons (B[a]Peq)	0.25	N/A

The relative contribution from individual domestic emission sources to the overall TEP is presented in Figure 13. The relative contributions of all domestic emission sources to key pollutants are summarised in Figure 14.

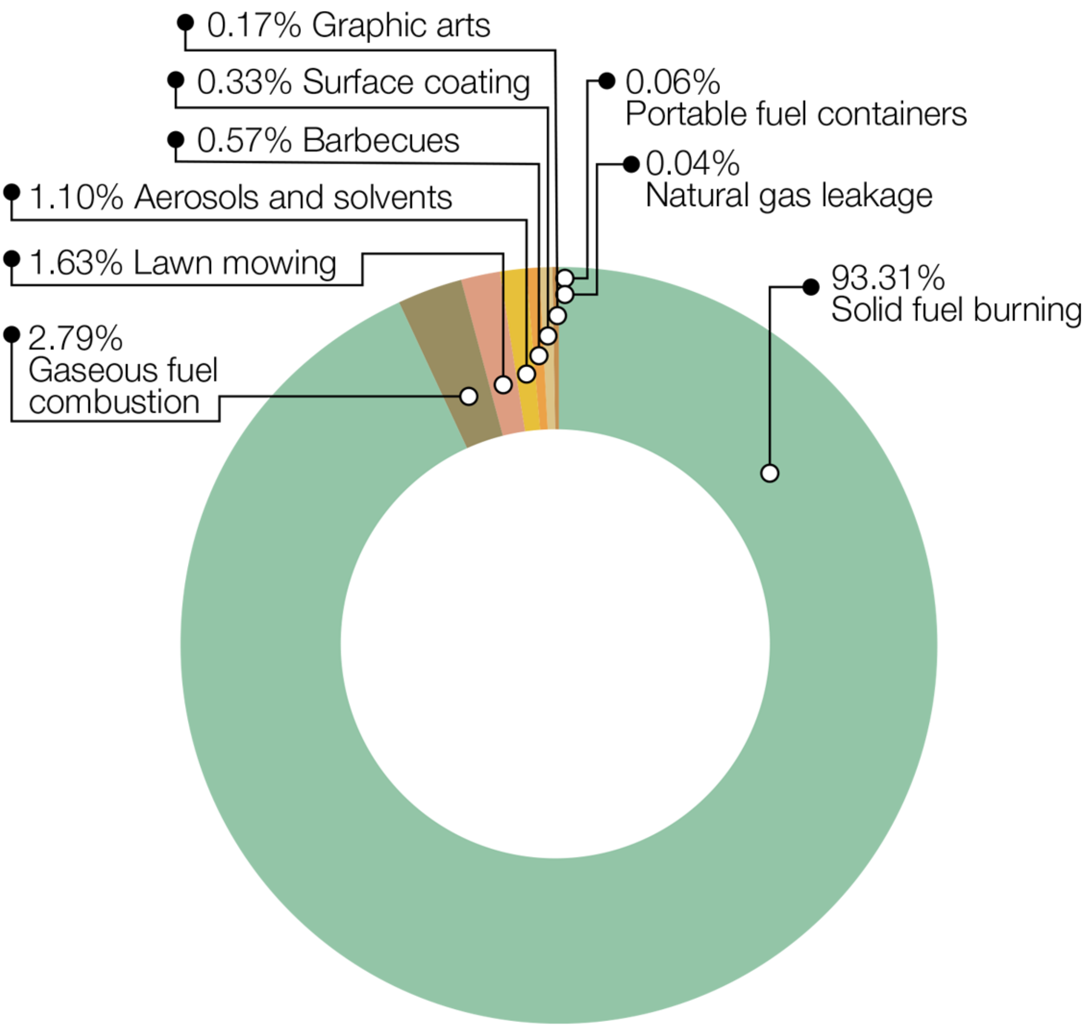


Figure 13 – Domestic TEP source contributions

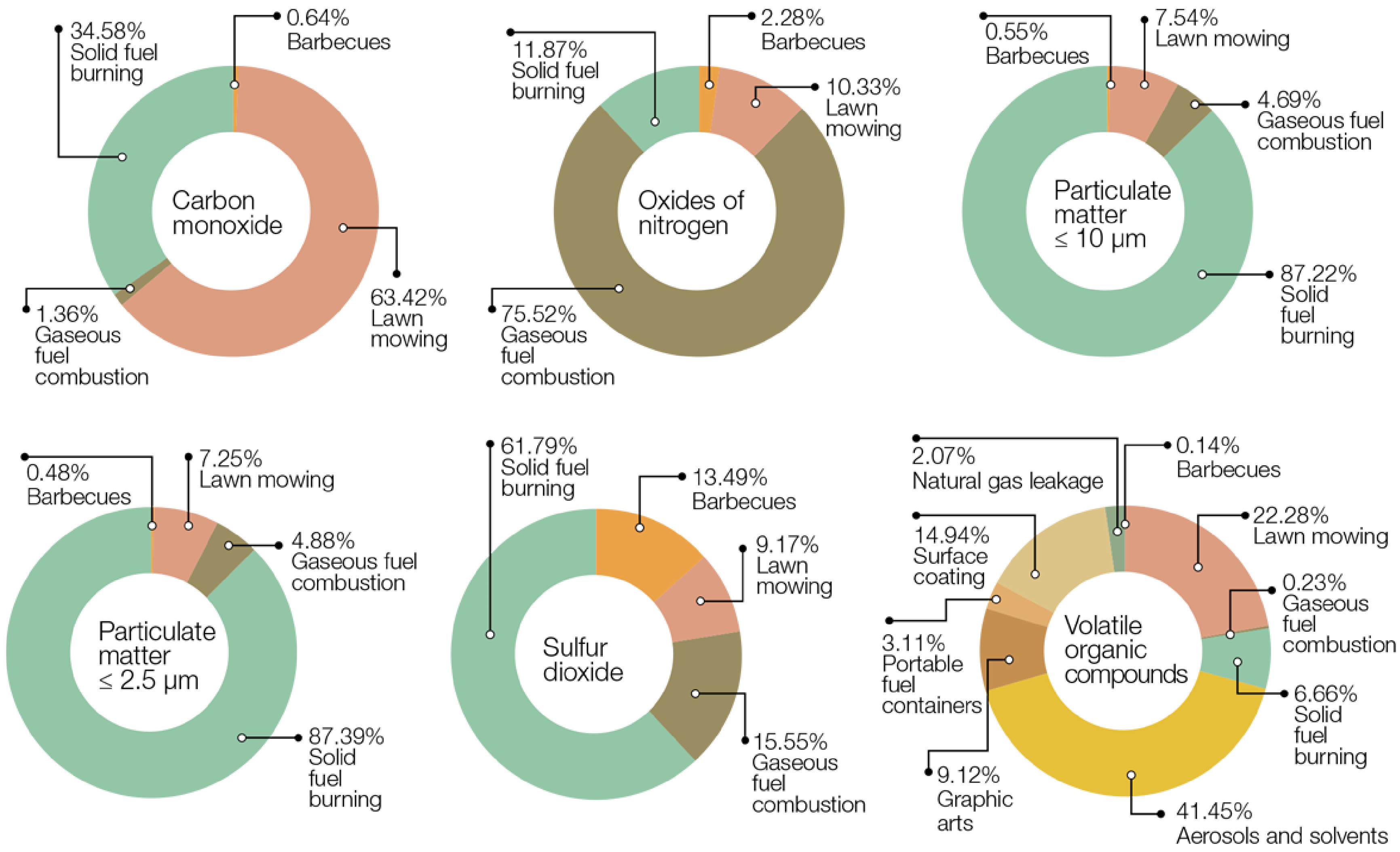


Figure 14 – Domestic emission estimates: source contributions by mass

Table 45 – Domestic emission estimates: source

Substance	Emissions (kg/yr)									
	Aerosols and solvents	Barbecues	Gaseous fuel combustion	Graphic arts	Lawn mowing	Natural gas leakage	Portable fuel containers	Solid fuel burning	Surface coating	Total
Key pollutants										
Carbon monoxide		165,197	349,255		16,303,586			8,888,194		25,706,232
Oxides of nitrogen		24,613	815,123		111,499			128,164		1,079,399
Particulate matter ≤ 2.5 µm		6,380	65,437		97,163			1,171,395		1,331,376
Particulate matter ≤ 10 µm		7,633	65,437		105,233			1,217,057		1,395,360
Sulfur dioxide		4,538	5,234		3,085			20,791		33,647
Total volatile organic compounds	8,378,260	29,103	47,375	1,843,191	4,503,144	418,955	627,740	1,345,648	3,020,809	20,214,225
Other NPI-listed pollutants										
Acetaldehyde		2,693	0.11		8,171			153,673	107	164,644
Acetic acid (ethanoic acid)	4,270									4,270
Acetone	385,434	1,184							81,238	467,856
Acrolein		99.2			1,384			5,652		7,135
Ammonia (total)		4,198	172,226		594			62,510		239,528
Antimony and compounds		0.0090						0.20		0.21
Arsenic and compounds		0.22						10.5		10.8
Benzene		607	18.1		116,829		4,896	34,583		156,933
Beryllium and compounds		0.010								0.010
1,3-Butadiene (vinyl ethylene)		184			13,222			10,496		23,902

Substance	Emissions (kg/yr)									
	Aerosols and solvents	Barbecues	Gaseous fuel combustion	Graphic arts	Lawn mowing	Natural gas leakage	Portable fuel containers	Solid fuel burning	Surface coating	Total
Cadmium and compounds		0.70						232		233
Carbon disulfide		0.061								0.061
Chloroform (trichloromethane)	3,531	0.0028								3,531
Chromium (total)		0.27			0.00039			37.3		37.6
Cobalt and compounds		0.11						20.5		20.6
Copper and compounds		0.59						202		202
Cumene (1-methylethylbenzene)		0.0025			8.73					8.73
Cyanide (inorganic) compounds		1.17								1.17
Cyclohexane	886				489		314		1,326	3,015
Dibutyl phthalate									35.7	35.7
Dichloromethane									4,070	4,070
Ethanol	2,151,133								47,612	2,198,745
2-Ethoxyethanol	704								2,624	3,328
2-Ethoxyethanol acetate									3,849	3,849
Ethyl acetate	26,917								63,716	90,634
Ethylbenzene	3,722	35.4		3,871	81,487		628	2,018	4,846	96,607
Ethylene glycol (1,2-ethanediol)									60,977	60,977
Ethylene oxide	15,620									15,620
Formaldehyde (methyl aldehyde)	3,790	1,853	645		21,229			105,095	35.7	132,648

Substance	Emissions (kg/yr)									
	Aerosols and solvents	Barbecues	Gaseous fuel combustion	Graphic arts	Lawn mowing	Natural gas leakage	Portable fuel containers	Solid fuel burning	Surface coating	Total
Glutaraldehyde	4,782									4,782
Hydrogen sulfide	84,688	0.031			49,083		1,381		178	135,330
Lead and compounds						50.3				50.3
Manganese and compounds		2.16	4.30					115		121
Mercury and compounds		0.53			0.00013			102		102
Methanol		0.081						14.6		14.7
2-Methoxyethanol	2,587									2,587
Methyl ethyl ketone	462,948								13,528	476,476
Methyl isobutyl ketone	63,744	340						19,377	66,921	150,382
Methyl methacrylate	8,561								105,870	114,432
n-Hexane		0.0093							143	143
Nickel and compounds		0.71			0.00029			198		198
Phenol		0.0075								0.0075
Polychlorinated dioxins and furans (TEQ)		0.0000030	0.000027		0.000000046			0.00043		0.00046
Polycyclic aromatic hydrocarbons (B[a]Peq)		0.75	0.034		10.9			235		247
Selenium and compounds		0.61						1.83		2.44
Styrene (ethenylbenzene)		0.012			4,241				1,205	5,447
Tetrachloroethylene	30,653	0.022							36.7	30,690

Substance	Emissions (kg/yr)									
	Aerosols and solvents	Barbecues	Gaseous fuel combustion	Graphic arts	Lawn mowing	Natural gas leakage	Portable fuel containers	Solid fuel burning	Surface coating	Total
Toluene (methylbenzene)	278,889	251	29.2	5,530	342,231		11,927	14,264	367,070	1,020,190
Trichloroethylene	1,802									1,802
Xylenes (individual or mixed isomers)	224,679	123		53,268	352,354		3,453	6,997	322,603	963,477
Zinc and compounds		2.82						951		954

The largest substance emitted by mass was carbon monoxide. Emissions of $PM_{2.5}$ and total VOC represented the greatest risk from the key pollutants. Emissions of heavy metals including cadmium and mercury and polychlorinated dioxins and furans (TEQ) were substantially smaller compared with key pollutant emissions, but represented a greater risk due to their high toxicity. The main source of these substances was wood combustion in slow combustion heaters and barbecues. Polychlorinated dioxins and furans (TEQ) was also emitted during LPG, petrol, diesel and natural gas combustion.

Lawn mowing and solid fuel burning were the main sources of carbon monoxide emissions. Exhaust emissions from 2-stroke and 4-stroke petrol engines (63 per cent) and wood combustion in slow combustion heaters (31 per cent) made up the bulk of these emissions.

The main source of NO_X emissions was gaseous fuel combustion. Residential and unaccounted commercial business natural gas consumption accounted for three-quarters of NO_X emissions. Wood combustion in slow combustion heaters contributed 11 per cent of NO_x emissions.

Solid fuel burning was the primary source of particulate (PM_{10} and $PM_{2.5}$). Solid fuel burning also dominated the domestic emissions risk profile, with other domestic sources contributing only eight per cent of total emission risk.

The main sources of SO_2 emissions were solid fuel burning and gaseous fuel burning. Slow combustion heaters accounted for 56 per cent of SO_2 emissions. Other large contributions included residential and unaccounted commercial business natural gas consumption (15 per cent) and briquette consumption in barbecues (13 per cent).

Aerosols and solvents and lawn mowing were the main sources of VOC emissions. Activities such as use of personal care products (15 per cent), exhaust emissions from 2-stroke petrol engines (14 per cent) and evaporative graphic arts emissions from unaccounted commercial businesses (9 per cent) were the largest single-source contributors.

3.2 Spatial allocation summary

Emissions

Spatial allocation of key pollutant emissions from all domestic sources is presented in Figure 15 through to Figure 20.

Particulate emissions, presented in Figure 15 and Figure 19, are consistent with the distribution of particles generated from solid fuel combustion (see Figure 11). The contribution of non-solid fuel combustion sources did not have a significant influence on the overall distribution of particulate emissions from domestic sources.

The VOC emissions presented in Figure 16 align with population and dwelling distribution. Areas with greater population and dwelling density in the inner regions of Perth's metropolitan area had higher emissions of VOCs.

The distribution of CO emissions presented in Figure 17 is influenced by lawn mowing and solid fuel burning. Higher emissions of CO occur in areas with greater density of separate and semi-detached dwellings and ownership of slow combustion heaters.

The NO_X emissions presented in Figure 18 align with the distribution of gaseous fuel burning (see Figure 5). High emissions of NO_X are a result of high natural gas combustion from unaccounted activities. These emissions may have been reported directly to the NPI program and could be an overestimation.

The distribution of SO_2 emissions presented in Figure 20 is influenced by solid fuel burning emissions. Higher emissions of SO_2 occur in areas with greater ownership of wood heaters and natural gas combustion from unaccounted businesses.

TEP score

The TEP of all domestic emission sources was calculated and spatially allocated to the study area. The cumulative TEP score for the study area is presented in Figure 21. The areas with higher TEP scores were associated with solid fuel combustion sources, reflecting the trace levels of heavy metals in these sources (heavy metals have significantly larger TEP scores compared with other emitted substances from domestic sources).

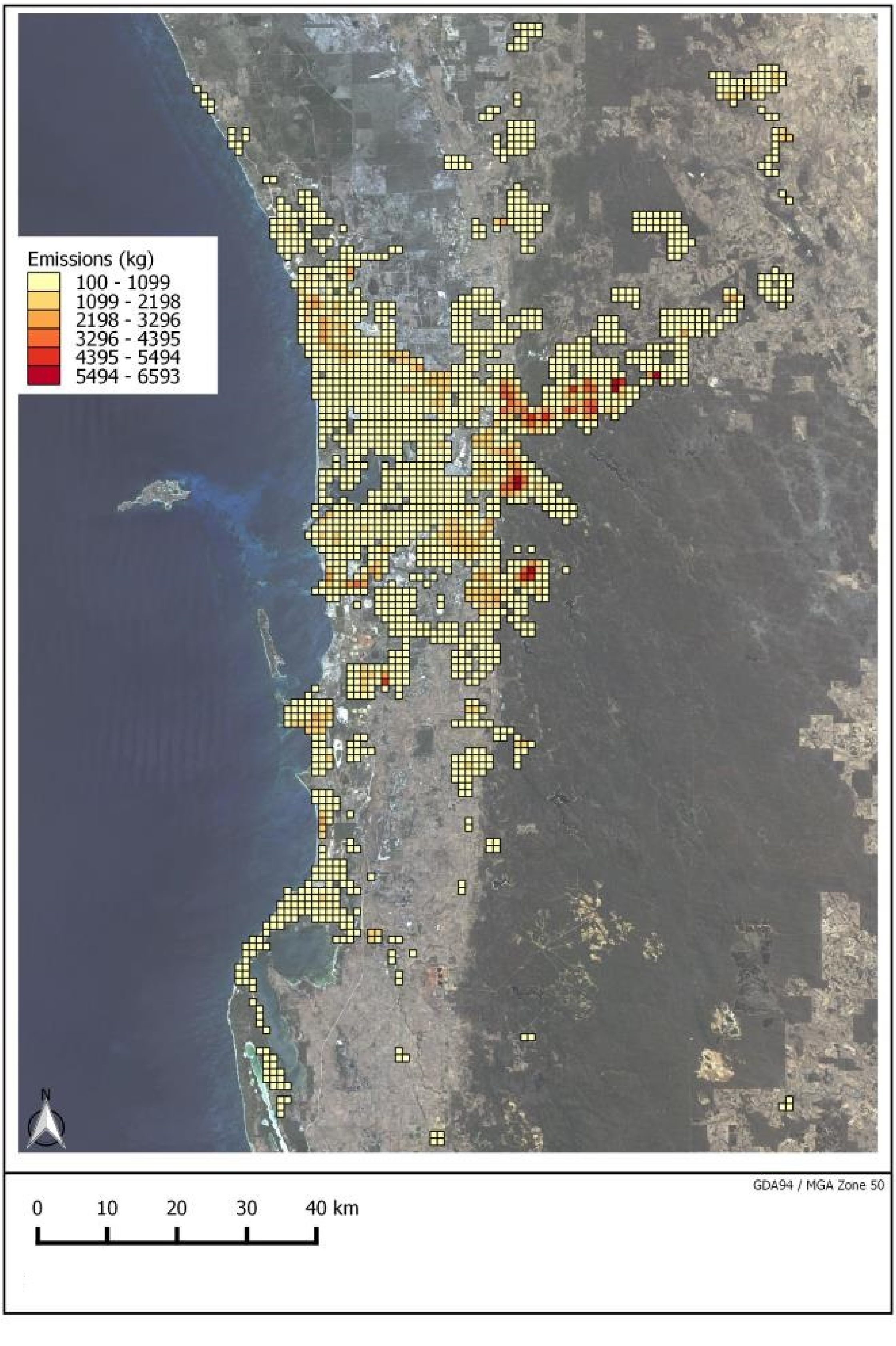


Figure 15 – Spatial allocation of domestic $PM_{2.5}$ emissions

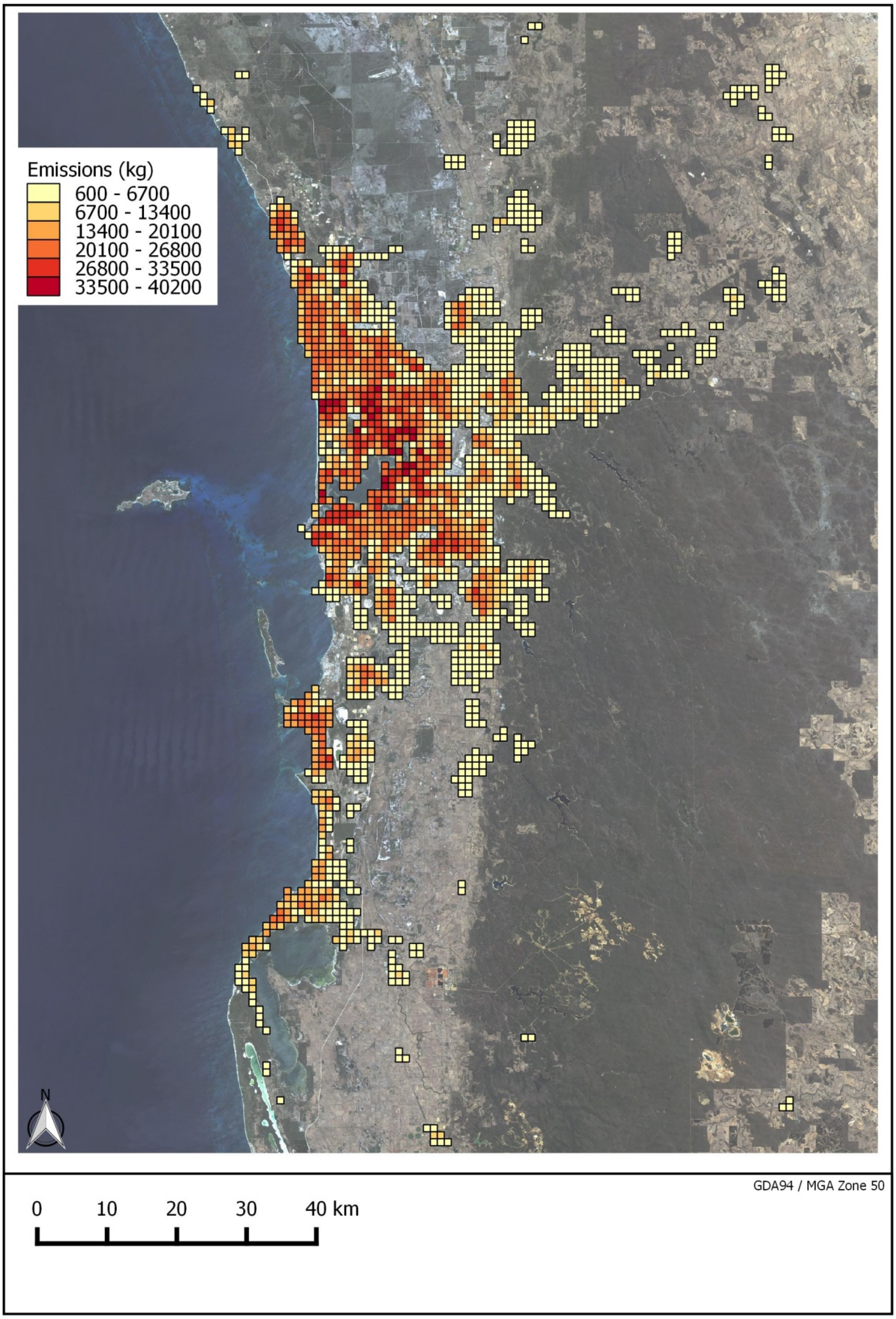


Figure 16 – Spatial allocation of domestic VOC emissions

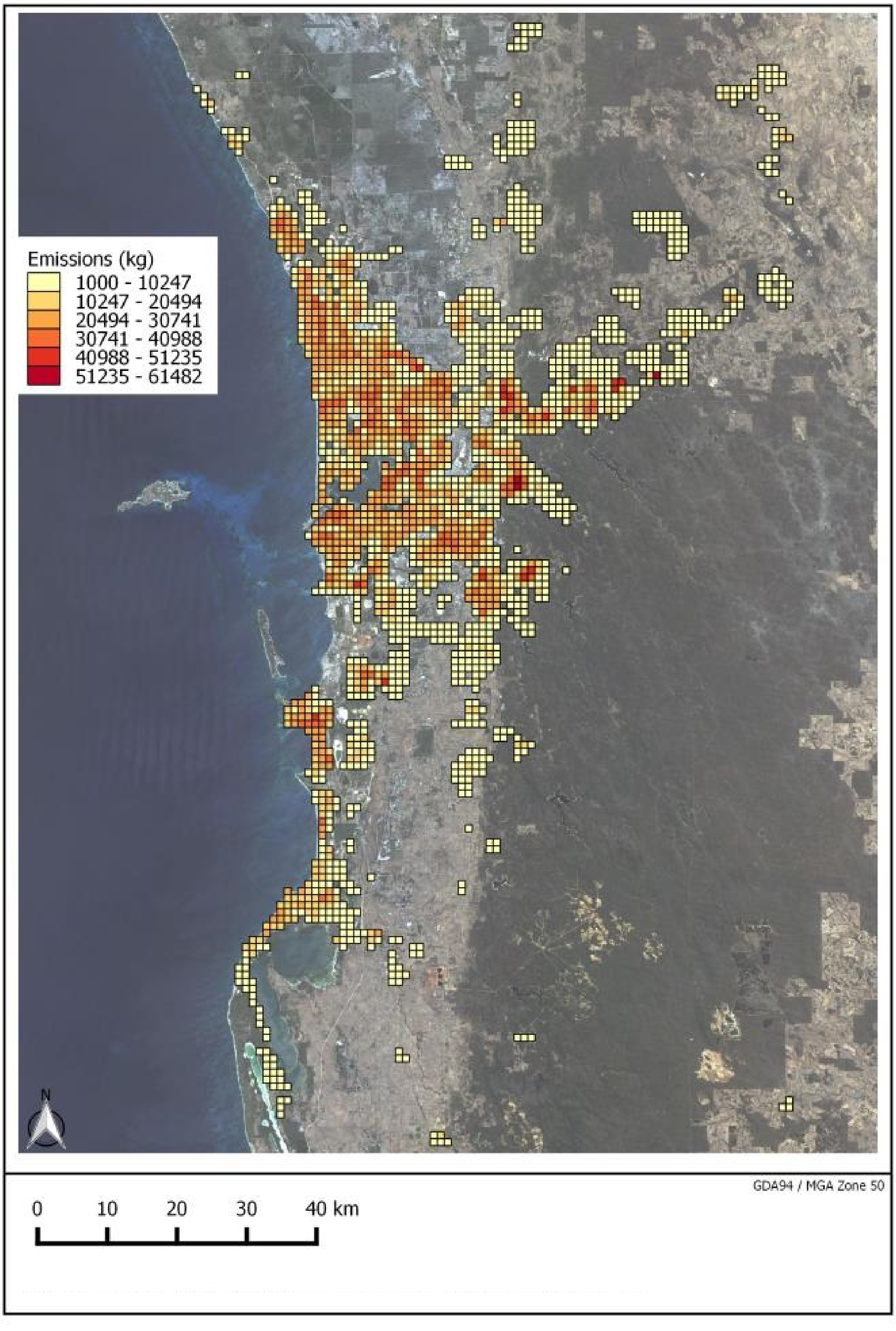


Figure 17 – Spatial allocation of domestic CO emissions

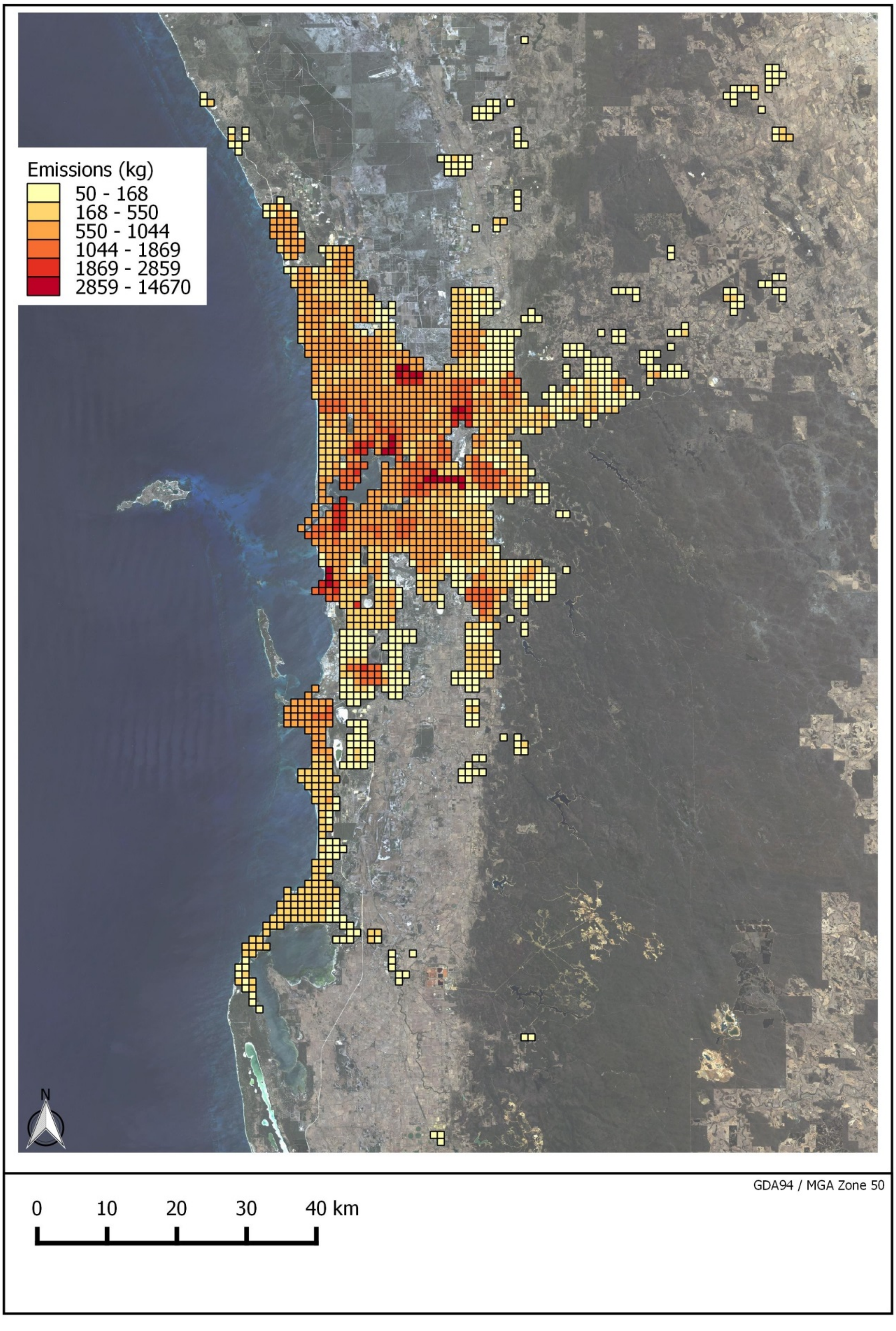


Figure 18 – Spatial allocation of domestic NOx emissions

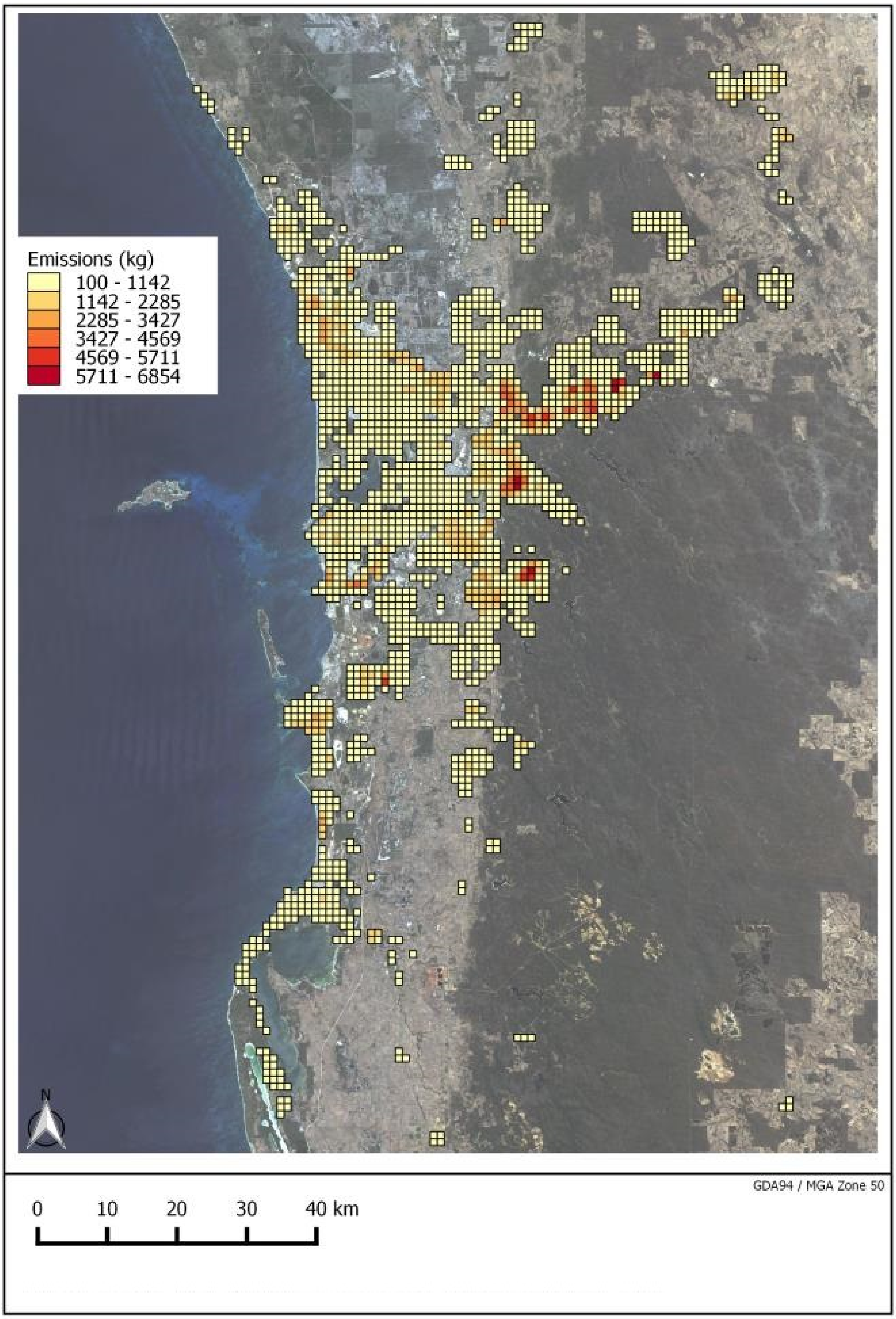


Figure 19 – Spatial allocation of domestic PM_{10} emissions

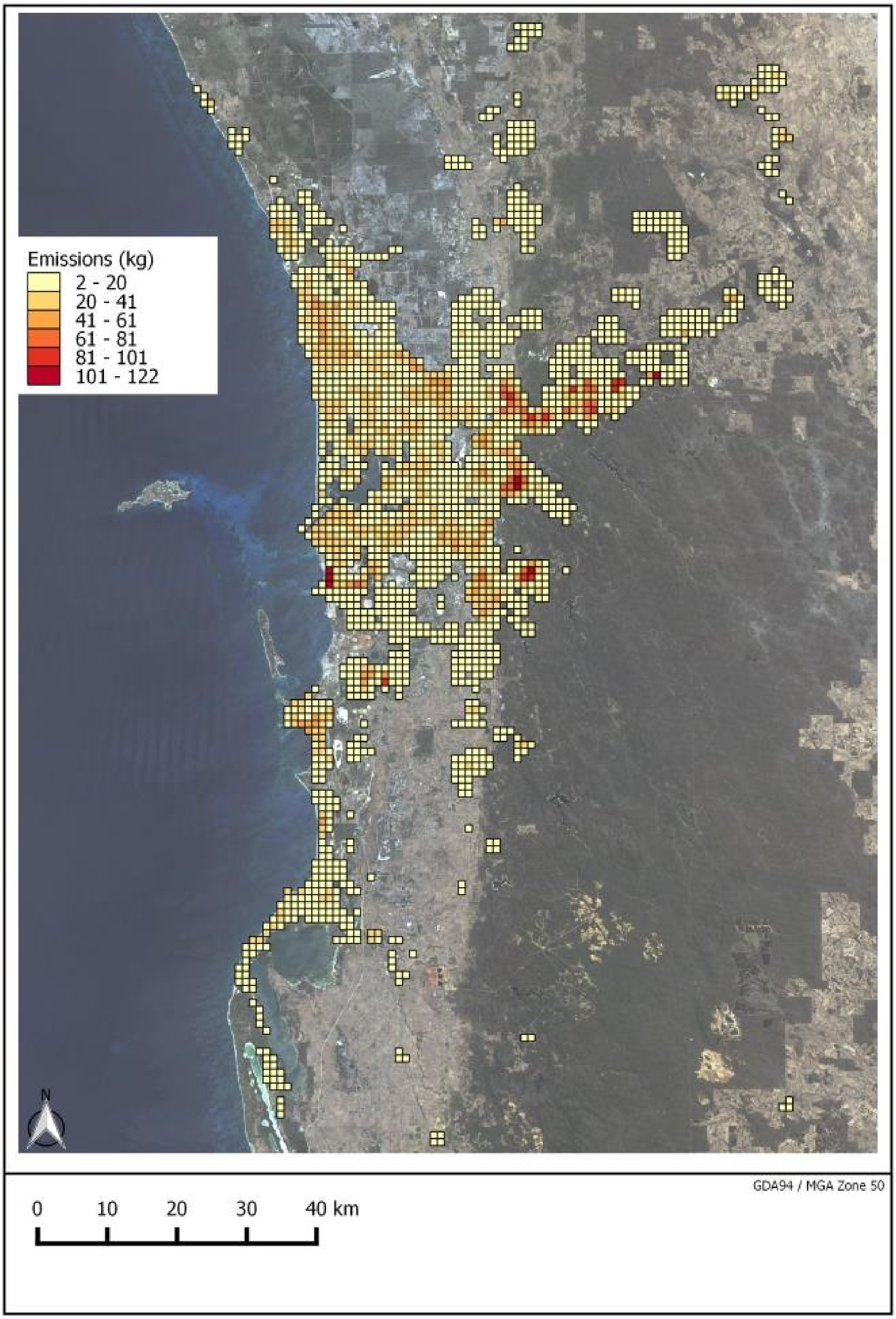


Figure 20 – Spatial allocation of domestic SO_2 emissions

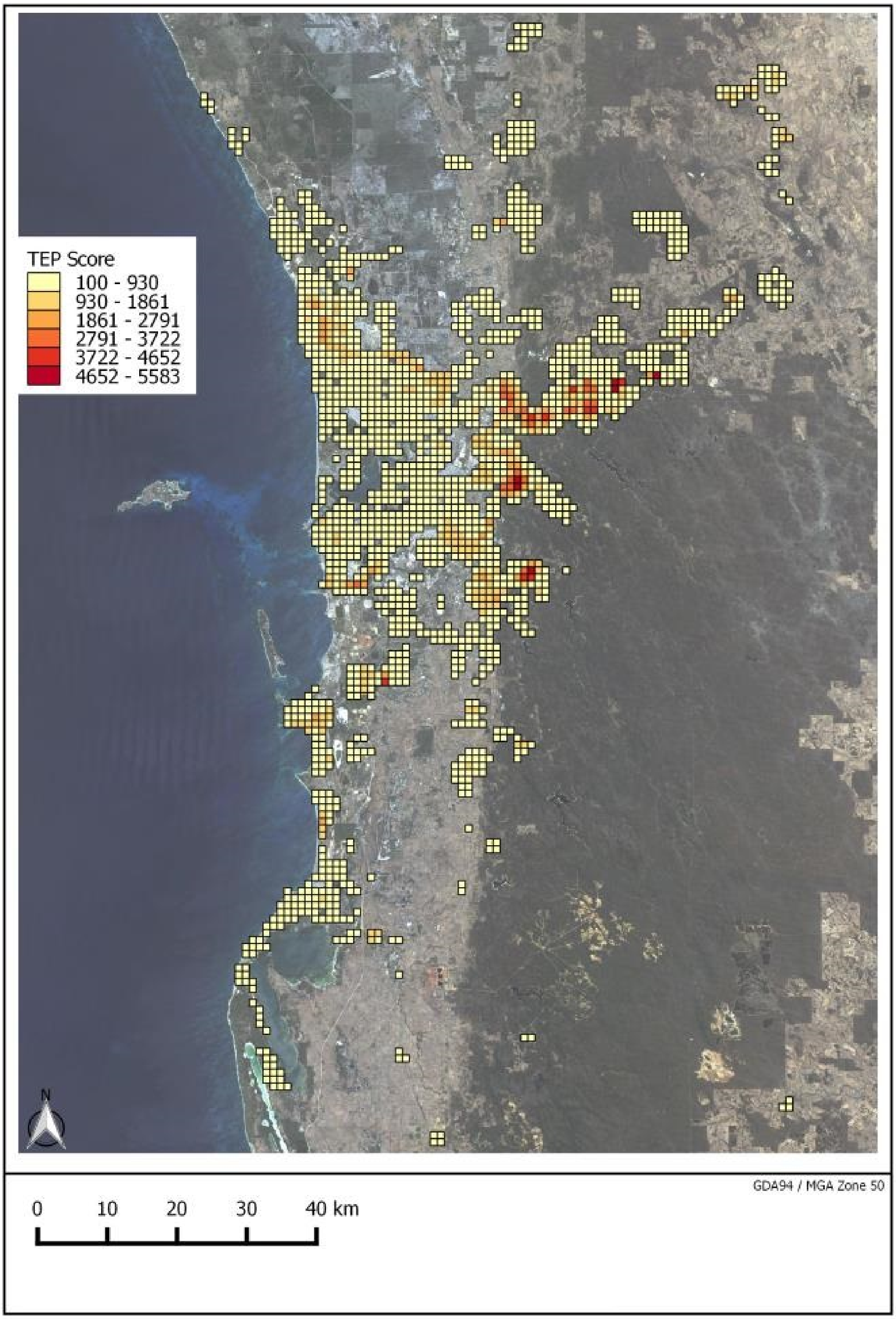


Figure 21 – Spatial allocation of domestic TEP score

4 Key considerations

This study has found that:

- Emissions of heavy metals including cadmium, mercury and lead, as well as of polychlorinated dioxins and furans (TEQ), were the most significant emissions risk from domestic sources due to their high toxicity. Heavy metal emissions are typically based on generic combustion speciation profiles and will have a higher degree of uncertainty than the more specific estimation methods used for key pollutants. The main source of emissions of these substances is solid fuel burning.
- $PM_{2.5}$ emissions were the most significant of the key pollutants, and were almost entirely generated from solid fuel burning.
- Solid fuel burning dominated the emissions profile for domestic sources, representing 93 per cent of the emissions risk.
- VOC emissions were also found to be a significant pollutant, with higher emissions occurring in areas with greater population and dwelling density.
- With heavy metals emissions representing the highest risk, the spatial distribution of emission risk was focused in areas with the highest wood consumption. Wood consumption was generally higher in areas with older housing or those not connected to the natural gas reticulation system.

This study’s outcomes should be viewed in the wider context of other major emission sources (natural, commercial and industrial, on-road vehicles, off-road mobile sources) that were also part of the Perth Air Emissions Study 2011–2012.

Appendices

Appendix A — Toxic equivalency potential score

Table 46 – NPI substance TEP rating

Substance	Non-Cancer Risk Score (TEP)[1]
Acetaldehyde	9.3
Acetic acid (ethanoic acid)	N/A
Acetone	0.05
Acetonitrile	30
Acrolein	1,600
Acrylamide	2,000
Acrylic acid	62
Acrylonitrile (2-propenenitrile)	38
Ammonia (total)	3.8
Aniline (benzenamine)	91
Antimony and compounds	8,100
Arsenic and compounds	84,000
Benzene	8.1
Benzene hexachloro- (HCB)	21,000
Beryllium and compounds	24,000
Biphenyl (1,1-biphenyl)	0.98
Boron and compounds	N/A
Butadiene (vinyl ethylene)	2.2
Cadmium and compounds	1,900,000
Carbon disulfide	1.2
Carbon monoxide	0.14
Chlorine and compounds	N/A
Chlorine dioxide	N/A
Chloroethane (ethyl chloride)	0.02
Chloroform (trichloromethane)	14
Chlorophenols (di, tri, tetra)	51
Chromium (III) compounds	N/A
Chromium (VI) compounds	3,100
Cobalt and compounds	31,000

Substance	Non-Cancer Risk Score (TEP)[1]
Copper and compounds	13,000
Cumene (1-methylethylbenzene)	0.41
Cyanide (inorganic) compounds	580
Cyclohexane	0.02
Dibromoethane	1,500
Dibutyl phthalate	11
Dichloroethane	4.2
Dichloromethane	7
Ethanol	N/A
Ethoxyethanol	N/A
Ethoxyethanol acetate	N/A
Ethyl acetate	0.09
Ethyl butyl ketone	N/A
Ethylbenzene	0.14
Ethylene glycol (1,2-ethanediol)	0.25
Ethylene oxide	56
Di-(2-Ethylhexyl) phthalate (DEHP)	33
Fluoride compounds	3.6
Formaldehyde (methyl aldehyde)	16
Glutaraldehyde	N/A
Hexane	N/A
Hydrochloric acid	12
Hydrogen sulfide	34
Lead and compounds	580,000
Magnesium oxide fume	N/A
Manganese and compounds	780
Mercury and compounds	5,000,000
Methanol	0.09
Methoxyethanol	N/A
Methoxyethanol acetate	N/A
Methyl ethyl ketone	0.05
Methyl isobutyl ketone	0.03
Methyl methacrylate	0.53

Substance	Non-Cancer Risk Score (TEP)[1]
Methylene-bis(2-chloroaniline) (MOCA)	N/A
Methylene bis (phenylisocyanate)	N/A
Nickel and compounds	3,200
Nickel carbonyl	N/A
Nickel subsulfide	N/A
Nitric acid	2.1
Organo-tin compounds	N/A
Oxides of nitrogen	2.2
Particulate matter ≤ 2.5 µm	17
Particulate matter ≤ 10 µm	1.5
Phenol	0.38
Phosphoric acid	16
Polychlorinated biphenyls	2,000,000
Polychlorinated dioxins and furans (TEQ)	880,000,000,000
Polycyclic aromatic hydrocarbons (B[a]Peq)	N/A
Selenium and compounds	2,400
Styrene (ethenylbenzene)	0.08
Sulfur dioxide	3.1
Sulfuric acid	N/A
Tetrachloroethane	56
Tetrachloroethylene	65
Toluene (methylbenzene)	1
Toluene-2,4-diisocyanate	N/A
Total nitrogen	N/A
Total phosphorus	N/A
Total volatile organic compounds	1
Trichloroethane	4.9
Trichloroethylene	0.63
Vinyl chloride monomer	69
Xylenes (individual or mixed isomers)	0.27
Zinc and compounds	190

1 based on toluene equivalent

Appendix B Emission and speciation factor references

Table 47 – Barbecues emission and speciation factor references

Substance	Emission source	Emission and speciation factor source
Carbon monoxide, oxides of nitrogen, particulate matter ≤ 10µm, particulate matter ≤ 2.5 µm, sulfur dioxide, total volatile organic compounds	Natural gas combustion	USEPA (1998a)
	LPG combustion	USEPA (2008)
	Butane combustion	
	Briquette combustion	USEPA (1998b)
	Wood combustion	USEPA (1996); PMPROF 424 CARB (2008)
Speciated VOC and metal air toxics	Natural gas combustion	USEPA (1998a)
	LPG combustion	
	Butane combustion	
	Briquette combustion	USEPA (1998b)
	Wood combustion	Average values from profile numbers 4642, 3831, 3832, 3833, 3885, 3846 & 3856 – Pechan (2011)
Polycyclic aromatic hydrocarbons (B[a]P)eq	Natural gas combustion	USEPA (1998a); DoEE (2015)
	LPG combustion	
	Butane combustion	
	Briquette combustion	USEPA (1998b); DoEE (2015)
	Wood combustion	USEPA (1996); DoEE (2015)
Polychlorinated dioxins and furans (TEQ)	Natural gas combustion	Bawden et al. (2004)
	LPG combustion	
	Butane combustion	
	Briquette combustion	
	Wood combustion	
Ammonia (total)	Natural gas combustion	Pechan (2004)
	LPG combustion	
	Butane combustion	
	Briquette combustion	
	Wood combustion	

Table 48 – Gaseous fuel combustion emission and speciation factor references

Substance	Emission Source	Emission and speciation factor source
Carbon monoxide, oxides of nitrogen, particulate matter ≤ 10 µm, particulate matter ≤ 2.5 µm, sulfur dioxide, total volatile organic compounds	Natural gas combustion	USEPA (1998a)
	LPG combustion	USEPA (2008)
Speciated VOC and metal air toxics	Natural gas combustion	USEPA (1998a)
	LPG combustion	
Polycyclic aromatic hydrocarbons (B[a]P)eq	Natural gas combustion	USEPA (1998a); DoEE (2015)
	LPG combustion	
Polychlorinated dioxins and furans (TEQ)	Natural gas combustion	Bawden et al. (2004)
	LPG combustion	
Ammonia (total)	Natural gas combustion	Pechan (2004)
	LPG combustion	

Table 49 – Lawn mowing and garden equipment emission and speciation factor references

Substance	Source	Reference
Carbon monoxide, oxides of nitrogen, particulate matter ≤ 10 µm, particulate matter ≤ 2.5 µm, sulfur dioxide	2-stroke, 4-stroke and diesel exhaust	NSW EPA (2012a) derived from USEPA (2009)
Total volatile organic compounds	2-stroke, 4-stroke and diesel exhaust and evaporative	NSW EPA (2012a) derived from USEPA (2009)
Speciated VOC	2-stroke, 4-stroke and diesel exhaust	Pechan (2005)
	Evaporative	DECC (2007)
Polycyclic aromatic hydrocarbons (B[a]P)eq	2-stroke, 4-stroke and diesel exhaust	Pechan (2005); DoEE (2015)
Polychlorinated dioxins and furans (TEQ) and metal air toxics	2-stroke, 4-stroke and diesel exhaust	Pechan (2005)
Ammonia (total)	2-stroke and 4-stroke exhaust	Pechan (2004)

Table 50 – Petrol vapour phase speciation profile

Substance	Speciation (kg/kg VOC)[30]
Benzene	0.0078
Cumene (1-methylethylbenzene)	–
Cyclohexane	0.0005
Ethylbenzene	0.0010
n-Hexane	0.0022
Toluene (methylbenzene)	0.0190
Xylenes (individual or mixed isomers)	0.0055

Table 51 – Residential space heater emission and speciation factor references

Substance	Source	Reference
Carbon monoxide, oxides of nitrogen, particulate matter ≤ 10 µm, sulfur dioxide, total volatile organic compounds, ammonia (total)	Slow combustion heater (compliant), slow combustion heater (non-compliant), open fireplace, potbelly stove	Pechan (2009b)
Particulate matter ≤ 2.5 µm	Slow combustion heater (compliant), slow combustion heater (non-compliant), open fireplace, potbelly stove	PMPROF 424 – CARB (2008)
Speciated VOC	Slow combustion heater (compliant), slow combustion heater (non-compliant), open fireplace, potbelly stove	Pechan (2009b), Profile number 4642 – Pechan (2011)
Polycyclic aromatic hydrocarbons (B[a]P)eq	Slow combustion heater (compliant), slow combustion heater (non-compliant), potbelly stove	Pechan (2009b)
	Open fireplace	USEPA (1996)
Polychlorinated dioxins and furans (TEQ) and metal air toxics	Slow combustion heater (compliant), slow combustion heater (non-compliant), open fireplace, potbelly stove	Bawden et al. (2004)
Metal air toxics	Slow combustion heater (compliant), slow combustion heater (non-compliant), open fireplace, potbelly stove	Average values from profile numbers 3831, 3832, 3833, 3885, 3846 and 3856 – Pechan (2011)

30 *2008 Calendar Year Air Emissions Inventory for the Greater Metropolitan Region in New South Wales –* Commercial Emissions, Tables 3-7 (NSW EPA 2012b)

Table 52 – Surface coatings emission factor references

Substance	Source	Reference
Total volatile organic compounds	Architectural and decorative – water based	Environ (2009)
	Architectural and decorative – solvent based	
	Architectural and decorative – water- and solvent-based timber finishes	
	Architectural and decorative – thinners	EC (2000); CARB (2003)
	Industrial surface coatings	Environ (2009); CARB (1997a)
	Industrial timber finishes	
	Industrial thinners	CARB (1997b)

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