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PREPARED FOR

Bay of Plenty Regional Council

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Rotorua Emission Inventory 2022

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EXECUTIVE SUMMARY

In 2022 an air emission inventory was carried out to assess quantities and sources of air discharges in the Rotorua airshed. The sources included in the inventory were domestic heating, motor vehicles, outdoor burning (including braziers, pizza ovens and solid fuel barbeques), and industrial and commercial activities (including small scale activities). Natural source contributions (for example from geothermal sources, sea salt and soil) are not included because the methodology to estimate emissions is less robust. The evaluation focuses on particles in the air less than 10 microns (PM_{10}), particles in the air less than 2.5 microns ($PM_{2.5}$), sulphur oxides, nitrogen oxides and carbon monoxide.

A domestic home heating and outdoor burning survey was undertaken within the Rotorua airshed to determine heating methods and fuels, the prevalence and characteristics of outdoor burning and the use of braziers, pizza ovens and wood fired barbeque.

Electricity was found to be the most common method of heating the main living area of dwellings with 72% of households using this source. Heat pumps were the most common electric heating option with 78% of households using electric heating in the main living area having these. Wood burners were used by 25% of households and around 106 tonnes of wood was burnt on an average winters night.

Whilst only a small number of households burn garden waste in the outdoors, the prevalence of use of braziers, pizza ovens and wood fired barbeques in Rotorua is high with an average of just under 300 burns per day during summer and around 100 per day during winter.

The evaluation of industrial activities discharging to air found a number of the larger scale activities that had been operating in 2006 had closed or relocated resulting in a decrease in emissions from this sector. Additionally, fuel switching from coal to primarily electricity and wood pellets has occurred across schools in the district.

Across all sources a total 80 tonnes of PM_{10} per year was estimated to be discharged in Rotorua and around 71 tonnes of this was estimated to be in the $PM_{2.5}$ size fraction. Domestic heating was the most significant contributor to annual and daily winter PM_{10} in Rotorua contributing 66% and 86% respectively. Industry and motor vehicles both contributed around 11% of the annual and around 4% of the daily winter PM_{10}. Domestic heating was also the main source of annual and winter $PM_{2.5}$, CO and SOx. Motor vehicles were the main source of NOx in Rotorua in 2022.

A comparison to the previous Rotorua air emission inventory found a significant reduction in PM_{10} emissions from the domestic heating and industrial sectors since 2006. Data suggests an overall reduction of around 77% in annual PM_{10} may have occurred. However, there is some uncertainty around this estimate owing to differences between inventory methods.

1 INTRODUCTION

Emission inventories are used by Governments and Local Government internationally to provide an estimate of the quantities of contaminants from anthropogenic sources that are emitted into the air and the relative contribution of sources to total emissions. The sources that are typically included in emissions inventories in New Zealand are generally the domestic heating, motor vehicle, industrial and commercial and outdoor burning sectors although other sources such as shipping, port activities, off road transport, aviation and rail may also be included in assessments. Emission inventory assessments are based on discharges across an airshed or area and do not include an evaluation of monitoring data at a specific site.

In New Zealand the main air contaminants of concern are $PM_{2.5}$ and PM_{10} as concentrations can exceed the National Environmental Standards for Air Quality (NESAQ) for PM_{10} and the proposed NESAQ for $PM_{2.5}$ (Ministry for the Environment, 2020) in many locations in New Zealand. In September 2021 the World Health Organisation (WHO) released revised guidelines for $PM_{2.5}$ including annual and 24-hour standards lower than the proposed NESAQ.

The Bay of Plenty Region contains two gazetted airsheds (Rotorua and Mount Maunganui) within which concentrations of PM_{10} exceed the NESAQ. In the Rotorua airshed concentrations of PM_{10} prior to 2010 breached the NESAQ more than 20 times each year.

A previous air emission inventory was carried out for Rotorua in 2005 (Iremonger & Graham, 2007). That inventory found that domestic heating was the main source of wintertime PM_{10} (61%) with industrial and commercial activities the next largest contributor (28%).

Air quality management of PM_{10} has focused on domestic heating as it is the main source of winter PM_{10}. The NESAQ includes design standards for woodburners (1.5g/kg emission rate and minimum 65% efficiency). From September 2005, only burners that met this standard could be installed on properties less than two hectares in size in New Zealand. The rules for the Rotorua Airshed are stricter than the NESAQ. Under PC 13, burners installed prior to 1 September 2005 were phased out at 31 January 2020. PC 13 also requires that where it is permitted to install a new burner, it must meet an emission limit of 0.60g/kg when tested to NZS 4013/4012 or meet the ultra-low emission burner standard when tested to the Canterbury Method 1. With the implementation of management measures targeting domestic home heating there has been a significant reduction in exceedances with no NESAQ breaches occurring since 2020. An airshed must record five consecutive years of no breaches before it is no longer considered to be a polluted airshed under the NESAQ.

This report provides an estimate of emissions of particles (PM_{10} and $PM_{2.5}$), carbon monoxide, nitrogen oxides and sulphur oxides from domestic heating, transportation, aviation, industrial and commercial activities and outdoor burning for Rotorua for 2022.

2 INVENTORY DESIGN

The key components of inventory design are selection of the study area, selection of sources and the focus/extent of investment in data collection for each, contaminants to be included, the spatial resolution (within the study area what breakdowns might be required), temporal resolution (hourly, daily or annual emissions).

2.1 Key issues

The main air quality issue for most urban areas of New Zealand, including Rotorua, is particles in the air that are typically associated with solid fuel burning for domestic home heating.

2.2 Selection of contaminants

The scope of the inventory with respect to contaminants is:

- particles (PM_{10})
- fine particles ($PM_{2.5}$)
- carbon monoxide (CO)
- sulphur oxides (SOx)
- nitrogen oxides (NOx)

Emissions of PM_{10}, CO, SOx and NOx are included as these contaminants are NESAQ contaminants because of their potential for adverse health impacts. $PM_{2.5}$ has been included in the inventory because this size fraction has significance in terms health and is included in the proposed revisions to the NESAQ for $PM_{2.5}$.

2.3 Selection of sources

The inventory will include emission estimates from the following sources:

- Industry including small scale industrial and commercial activities.
- Domestic heating
- Motor vehicles
- Outdoor burning
- Small scale domestic sources - including lawn mowing and power tool use

Marine aerosol emissions and dusts are not well characterized using inventory techniques and are not included in the emissions assessment. Geothermal features within the airshed can also contribute to particulate and gaseous emissions, these features and associated emission are not included within this assessment. Other methods such as receptor modelling and source apportionment will provide a more robust approach for these sources.

2.4 Selection of inventory area

The Rotorua inventory area is based on the 208 SA2 geographical boundary areas for the following: Pleasant Heights, Pukehangi North, Selwyn Heights, Western Heights (Rotorua District), Mangakakahi West, Kawaha, Fairy Springs, Mangakakahi Central, Koutu, Kuirau, Rotorua Central, Inland water Lake Rotorua, Owhata West, Owhata East, Holdens Bay-Rotokawa, Pukehangi South, Sunnybrook, Fordlands, Pomare, Springfield South, Utuhina, Hillcrest (Rotorua District), Springfield North, Victoria, Glenholme North, Glenholme South, Tihiotonga-Whakarewarewa, Fenton Park, Ngapuna and Lynmore. These areas are illustrated in Figure 2.1 which shows the inventory area is closely aligned with the Rotorua Airshed area.

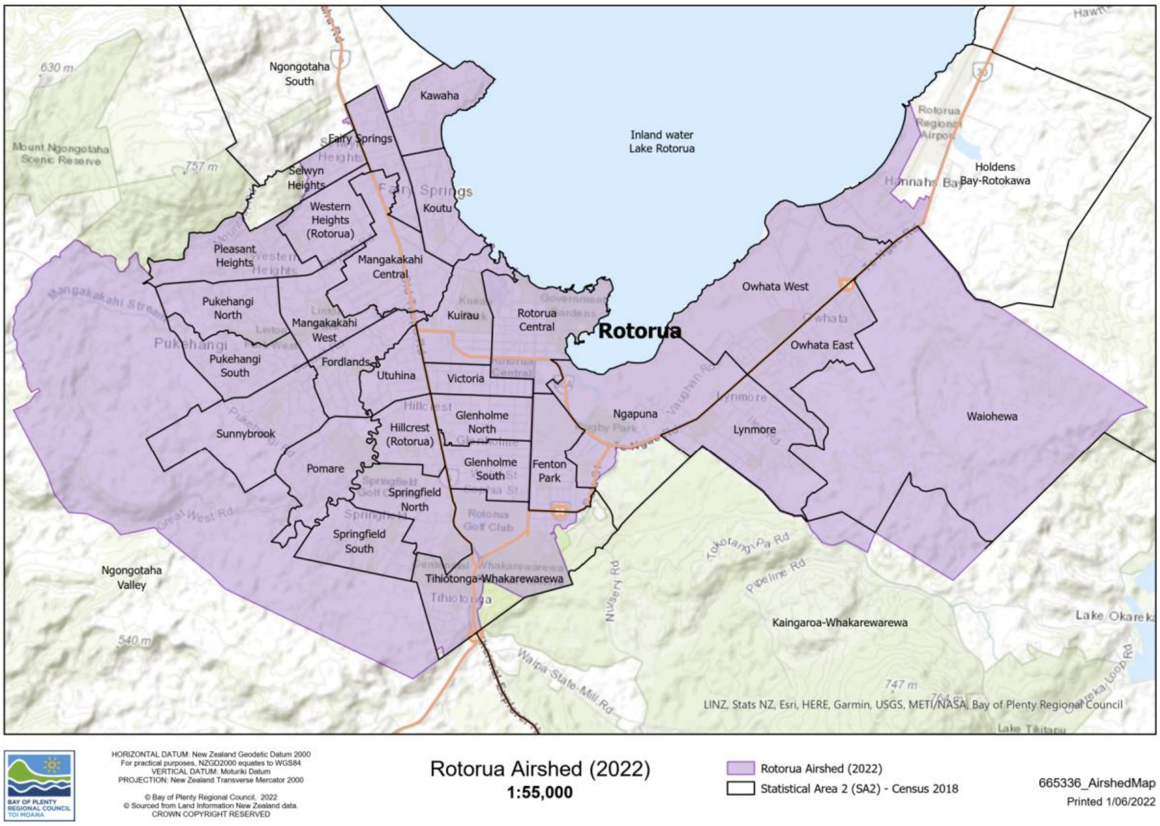

Figure 2.1: Rotorua Emission Inventory Area (source Bay of Plenty Regional Council, 2022).

2.5 Temporal distribution

The inventory is based on emission estimates for 2022. For domestic heating and outdoor burning the method includes a 2022 survey. For other sources, estimates are based on 2022 where available. For sources where 2022 data are not available, activity data are based on the most recent year information is available (for example, year ending June 2022) for adjusted for 2022 where trends are evident.

The temporal distribution of the inventory information is annual, monthly and daily where appropriate. Domestic heating data are presented as average and worst-case wintertime scenarios and by month of the year. Motor vehicle data are based on annualised vehicle movements as seasonal variations are not available.

No differentiation is made for weekday and weekend sources.

3 DOMESTIC HEATING

3.1 Methodology

Domestic heating methods and fuel used by households were collected using a household phone survey carried out by Symphony Research during June 2022 (Appendix A). Table 3.1 shows the number of households based on 2018 census data adjusted for projected population increases of 0.8% per year for Rotorua (Heyes & Brunsdon, 2020).

Table 3.1: Summary household, area and survey data.

	No. of Dwellings	Sample size	Area (ha)	Sample error
Rotorua	19530	350	3932	5%

Home heating methods were classified as; electricity, open fires, wood burners, pellet fires, multi fuel burners, gas burners and oil burners.

Emission factors were applied to these data to provide an estimate of emissions for each study area. The emission factors used to estimate emissions from domestic heating are shown in Table 3.2. The basis for these is detailed in Appendix B.

Table 3.2: Emission factors for domestic heating methods.

	PM_{10} g/kg	$PM_{2.5}$ g/kg	CO g/kg	NOx g/kg	SO_2 g/kg
Open fire - wood	7.5	7.5	55	1.2	0.2
Open fire - coal	21	18	70	4	8
Pre 2006 burners	10	10	140	0.5	0.2
Post 2006 but pre 2019 burners	4.5	4.5	45	0.5	0.2
Post 2019 burners	3.25	3.25	32	0.5	0.2
Pellet burners	2	2	20	0.5	0.2
Multi-fuel[1] - wood	10	10	140	0.5	0.2
Multi-fuel[1] – coal	19	17	110	1.6	8
Oil	0.3	0.22	0.6	2.2	3.8
Gas	0.03	0.03	0.18	1.3	7.56E-09

[1] - includes potbelly, incinerator, coal range and any enclosed burner that is used to burn coal

The average weight for a log of wood is one of the assumptions required for this inventory to convert householder's estimates of fuel use in logs per evening to a mass measurement required for estimating emissions. This was converted into average daily fuel consumption based on an average log weight of 1.6 kg per piece of wood and integrating seasonal and weekly usage rates. The value of 1.6 kg/log was selected as the mid-point of the range found from different New Zealand evaluations (Wilton & Bluett, 2012, Wilton, Smith, Dey, & Webley, 2006, Metcalfe, Sridhar, & Wickham, 2013). The log weight recommended for this work (1.6 kg/ piece) is the midpoint and average of the range of values.

Emissions for each contaminant were calculated based on the following equation:

Equation 3.1 CE (g/day) = EF (g/kg) * FB (kg/day)

Where:

CE = contaminant emission

EF = emission factor

FB = fuel burnt

The main assumptions underlying the emissions calculations are as follows:

- The average weight of a log of wood is 1.6 kilograms.

3.2 Home heating methods and fuels

Trends in household heating methods/fuels in Rotorua from 2006 to 2018 from census data are shown in Figure 3.1. This shows a reduction of around a third in the number of households using wood or coal as their main fuel for home heating from 2006 to 2018.

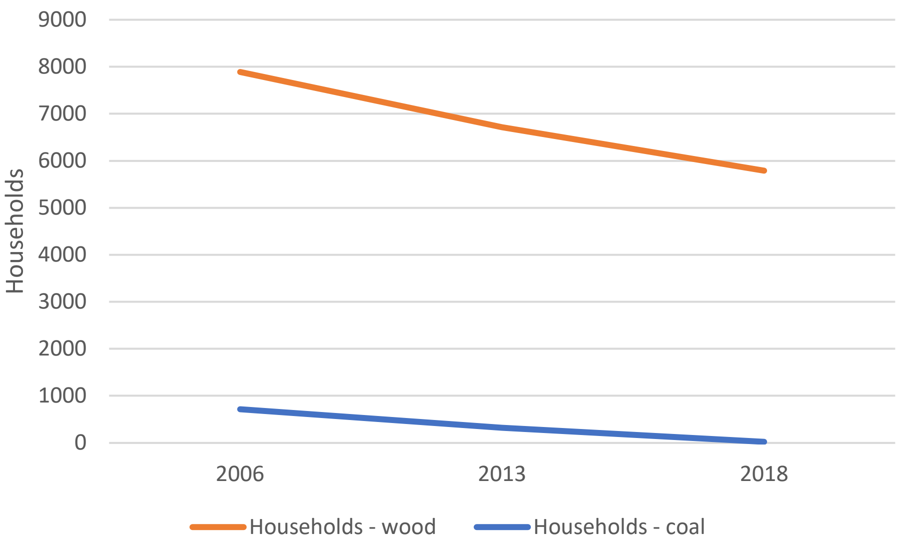

Figure 3.1: Trends in wood or coal use for home heating in Rotorua from census data 2006, 2013 and 2018.

The 2022 domestic heating survey for Rotorua found in 2022 that the most popular form of heating the main living area of homes is electricity with around 72% of households using that method. Wood burners are the next most common method at 25% of households (around 5000 homes). Only a very small number of wood burners were reported as being pre 2006 models. This is consistent with a high level of compliance with the PC 13 rules. A small number of households reported using open fires and multi fuel burners. These methods are no longer compliant with PC 13 rules. Table 3.3 also shows that households rely on more than one method of heating their main living area during the winter months.

Around 106 tonnes of wood is burnt per typical winter's night in Rotorua. Around half of the wood that is burnt is bought and half obtained free of charge.

Figure 3.2 shows the proportion of households using different electrical heating types in 2022. This shows around 78% of households using electricity in their main living area use heat pumps.

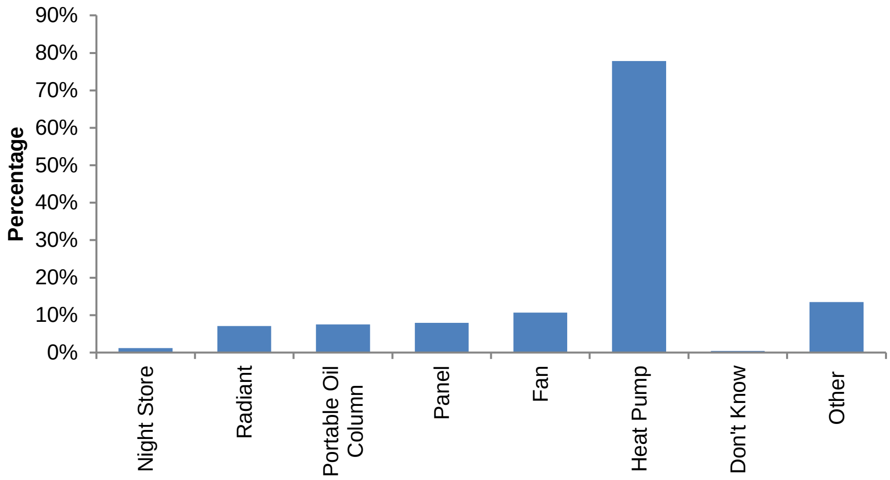

Figure 3.2: Electric heating options for Rotorua households (main living area).

Table 3.3: Home heating methods and fuels in Rotorua.

	Heating methods		Fuel Use	
	%	Households	t/day	%
Electricity	72%	14,117		
Total Gas	9%	1,786		
Flued gas	9%	1,726		
Unflued gas	0%	60		
Oil	1%	167	0.1	0%
Open fire	1%	167		
Open fire - wood	1%	167	6	6%
Open fire - coal	0%	0	0	0%
Total wood burner	25%	4,910	97	91%
Pre 2006 wood burner	1%	194	4	4%
2006-2019 wood burner	12%	2,326	46	43%
Post-2019 wood burner	12%	2,391	47	44%
Multi-fuel burners	1%	112		
Multi-fuel burners-wood	1%	112	1	1%
Multi-fuel burners-coal	0%	0	0	0%
Pellet burners	1%	167	1	1%
Total wood	27%	5,189	106	98%
Total coal	0%	0	0	0%
Total		19,530	106	

3.3 Domestic heating emissions

Around 456 kilograms of PM_{10} is discharged on a typical winter's day from domestic home heating across Rotorua.

Figure 3.3 shows that the majority (45%) of the PM_{10} emissions are from burners installed from 2006 to 2019. Around 8% of the PM_{10} is estimated to come from burners installed prior to 2005. These burners should have been phased out under the PC 13 (Air Quality) rules. Wood burners installed after 2019 contribute 34% of the daily winter PM_{10}.

Tables 3.4 and 3.5 show the estimates of emissions for different heating methods under average and worst-case scenarios respectively. Emissions are shown in kilograms per day (kg/day) and in grams per hectare (g/ha/day). Days when households may not be using specific home heating methods are accounted for in the daily winter average emissions[1]. Under the worst-case scenario that all households are using a burner on any given night around 536 kilograms of PM_{10} is likely to be emitted.

The seasonal variation in contaminant emissions is shown in Table 3.6. Figure 3.4 indicates that the majority of the annual PM_{10} emissions from domestic home heating occur during June, July and August.

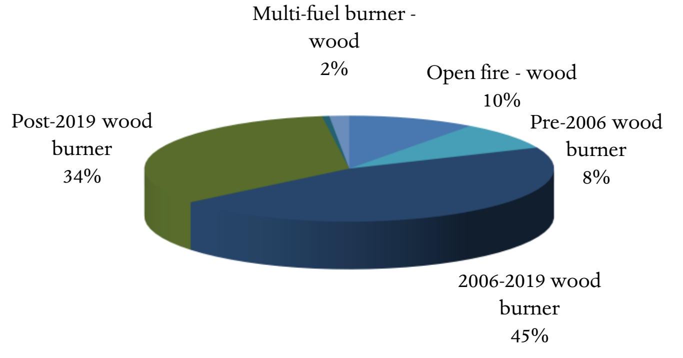

Figure 3.3: Relative contribution of different heating methods to average daily PM_{10} (winter average) from domestic heating in Rotorua.

[1] Total fuel use per day is adjusted by the average number of days per week wood burners are used (e.g.,6/7) and the proportion of wood burners that are used during July (e.g.,95%).

Table 3.4: Rotorua winter daily domestic heating emissions by appliance type (winter average).

	Fuel Use		PM_{10}			CO			NO_x			SO_x			$PM_{2.5}$		
	t/day	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%
Open fire																	
Open fire - wood	6.1	6%	46	12	10%	337	86	7%	7	2	12%	1	0	6%	46	12	10%
Open fire - coal	0.0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Wood burner	98.7																
Pre 2006 wood burner	3.8	4%	38	10	8%	539	137	12%	2	0	3%	1	0	4%	38	10	8%
2006-2019 wood burner	46.2	43%	208	53	46%	2077	528	45%	23	6	39%	9	2	43%	208	53	46%
Post 2019 wood burner	47.4	44%	154	39	34%	1542	392	33%	24	6	40%	9	2	44%	154	39	34%
Pellet Burner	1.3	1%	2.6	1	1%	26	6	1%	1	0	1%	0	0	1%	3	1	1%
Multi fuel burner																	
Multi fuel– wood	0.7	1%	7	2	2%	100	25	2%	0	0	1%	0	0	1%	7	2	2%
Multi fuel – coal	0.0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Gas	1.6	2%	0.05	0	0%	0	0	0%	2	1	4%	0	0	0%	0	0	0%
Oil	0.1	0%	0.04	0	0%	0	0	0%	0	0	0%	0	0	2%	0	0	0%
Total Wood	105.6	98%	456	116	100%	4620	1175	100%	57	15	96%	21	5	98%	456	116	100%
Total Coal	0.0	0%	0.00	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Total	106		456	116		4621	1175		59	15		22	5		456	116	

Table 3.5: Rotorua winter daily domestic heating emissions by appliance type (worst case).

	Fuel Use		PM_{10}			CO			NO_x			SO_x			$PM_{2.5}$		
	t/day	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%	kg	g/ha	%
Open fire																	
Open fire - wood	6.4	5%	48	12	9%	354	90	6%	8	2	11%	1	0	5%	48	12	9%
Open fire - coal	0.0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Wood burner	114.9																
Pre 2006 wood burner	4.5	4%	45	12	8%	635	162	12%	2	1	3%	1	0	4%	45	12	8%
2006-2019 wood burner	54.4	43%	245	62	46%	2450	623	45%	27	7	40%	11	3	43%	245	62	46%
Post 2019 wood burner	56.0	45%	182	46	34%	1819	462	33%	28	7	41%	11	3	44%	182	46	34%
Pellet Burner	1.3	1%	3	1	0%	27	7	0%	1	0	1%	0	0	1%	3	1	0%
Multi fuel burner																	
Multi fuel– wood	1.2	1%	12	3	2%	175	44	3%	1	0	1%	0	0	1%	12	3	2%
Multi fuel – coal	0.0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Gas	1.6	1%	0	0	0%	0	0	0%	2	1	3%	0	0	0%	0	0	0%
Oil	0.1	0%	0	0	0%	0	0	0%	0	0	0%	0	0	2%	0	0	0%
Total Wood	124	99%	536	136	100%	5459	1388	100%	66	17	97%	25	6	98%	536	136	100%
Total Coal	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%	0	0	0%
Total	126		536	136		5459	1388		69	18		25	6		536	136	

Table 3.6: Total annual and monthly variations in contaminant emissions from domestic heating in Rotorua.

	PM_{10} kg/day	CO kg/day	NOx kg/day	SOx kg/day	$PM_{2.5}$ kg/day
January	0	0	0	0	0
February	1	8	0	0	1
March	5	53	1	0	5
April	40	398	7	2	40
May	224	2298	30	11	224
June	434	4392	54	20	434
July	456	4621	59	21	456
August	419	4262	54	19	419
September	106	1090	15	5	106
October	39	407	5	2	39
November	9	94	1	0	9
December	0	0	0	0	0
	PM_{10} tonnes/year	CO tonnes/year	NOx tonnes/year	SOx tonnes/year	$PM_{2.5}$ tonnes/year
Total domestic heating	53	540	7	2	53

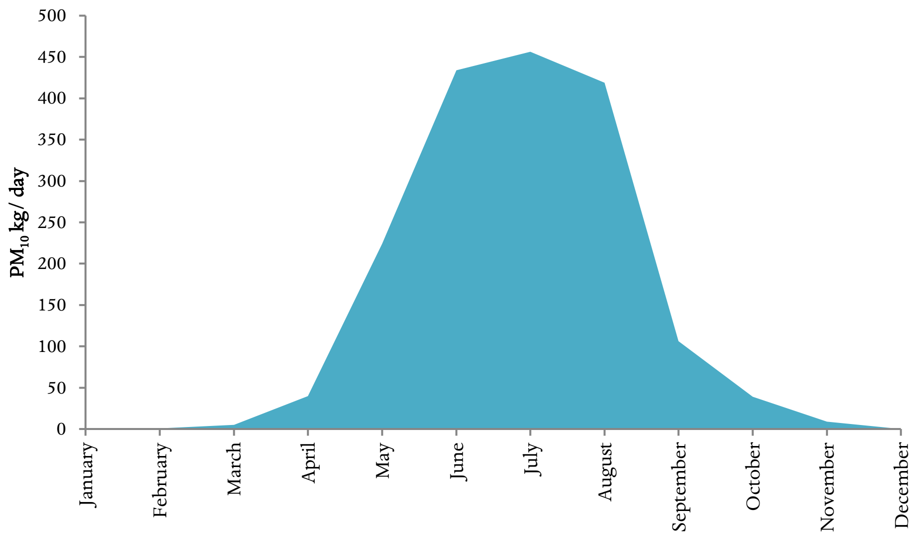

Figure 3.4: Monthly variations in PM_{10} emissions from domestic heating in Rotorua.

3.4 Other domestic sources of emissions

Lawn mowers, leaf blowers and chainsaws can also contribute small amounts of particulate. These are not typically included in emission inventory studies owing to the relatively small contribution, particularly in areas where solid fuel burning is a common method of home heating. Wilton, (2019) provides an assessment of potential emissions from small domestic appliances such as lawn mowers, chain saws and leaf blowers that which indicates a range of 0.0012 to 0.05 g/household/day for PM_{10}. This indicates a range of 0.02 to 1 kilogram of PM_{10} per day in Rotorua. Because of the negligible quantities from these sources, they have not been included in the subsequent emission estimates.

4 MOTOR VEHICLES

4.1 Methodology

Motor vehicle emissions to air include tailpipe emissions of a range of contaminants and particulate emissions occurring as a result of the wear of brakes and tyres. Assessing emissions from motor vehicles involves collecting data on vehicle kilometres travelled (VKT) and the application of emission factors to these data.

Emission factors for motor vehicles are determined using the Vehicle Emission Prediction Model (VEPM 6.0) developed by Auckland Council. Emission factors for PM_{10}, $PM_{2.5}$, CO and NOx for this study have been based on VEPM 6.0. Default settings were used for all variables except for the temperature data and the vehicle fleet profile which was based on Rotorua vehicle registration data for the year ending December 2021 (Table 4.1). The default input data including the national fleet profile was used for the regional vehicle emissions assessment. Temperature data were based on an average winter temperature for Rotorua of 7.4 degrees. Resulting emission factors are shown in Table 4.2.

Emission factors for SOx were estimated for diesel vehicles based on the sulphur content of the fuel (10ppm) and the assumption of 100% conversion to SOx. The g/km emission factor was estimated using VEPM 6.0 using the fuel consumption per VKT for the parameters described above.

The number of vehicle kilometres travelled (VKT) for each area were estimated using the New Zealand Transport Authority VKT data (Table 4.3) for urban areas of Rotorua.

In addition to estimates of tailpipe emissions and brake and tyre emissions using VEPM an estimate of the non-tailpipe emissions (including brake and tyre wear and re-suspended road dusts) was made using the EMEP/EEA air pollutant emission inventory guidebook (2016). The emission factors from this method are shown in Table 4.4. It is noted that emission factors for fugitive sources such as resuspended dusts can have a high level of uncertainty.

Table 4.1: Vehicle registrations for Rotorua for the year ending December 2021.

Rotorua	Petrol	Diesel	Hybrid/electric	LPG	Other	Total
Cars	44,120	4,111	852	58	185	9
LCV	2,423	12,184	0	0	1	8
Bus	187	435	0	0	0	2
HCV		5,516			6	
Miscellaneous	656	734	1	0	15	10
Motorcycle	2,646					
Total	50,032	22980	853	58	207	29

Table 4.2: Emission factors for Rotorua vehicle fleet (2022).

2022	CO g/VKT	PM_{10} g/VKT	PM brake & tyre g/VKT	NOx g/VKT	NO_2 g/VKT	$PM_{2.5}$ g/VKT	$PM_{2.5}$ brake & tyre g/VKT
Rotorua	1.6	0.022	0.022	0.703	0.138	0.022	0.012

Table 4.3: VKT daily and annual (NZTA, 2021).

	Total VKT per day	Annual VKT
Rotorua	425425	155280000

Emissions were calculated by multiplying the appropriate average emission factor by the VKT:

Emissions (g) = Emission Rate (g/VKT) * VKT

Table 4.4: Road dust TSP emissions (from EMEP/EEA guidebook, EEA, 2016).

	TSP g/KVT
Two wheeled vehicles	0.01
Passenger car	0.02
Light duty trucks	0.02
Heavy duty trucks	0.08
Weighted vehicle fleet factor	0.018
PM_{10} size fraction	0.5
$PM_{2.5}$ size fraction	0.27

4.2 Motor vehicle emissions

Around 23 kilograms per day of PM_{10} are estimated to be emitted from motor vehicles daily in Rotorua.

Around 41% of the PM_{10} and 56% of the $PM_{2.5}$ from motor vehicles is estimated to occur as a result of the tailpipe emissions with the remainder estimated from brake and tyre wear and road dust (Figure 4.1). Tables 4.5 and 4.6 show the daily and annual estimates of emissions from motor vehicles in Rotorua.

Table 4.5: Summary of daily motor vehicle emissions (kg/day)

	PM_{10}		CO		NOx		SOx		$PM_{2.5}$	
	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha
Tailpipe	9	2	682	173	299	76	0.3	0.07	9	2
Brake and tyre	9	2							5	1
Road dust	4	1							2	1
Total	23	6	682	173	299	76	0	0.07	17	4

Table 4.6: Summary of annual motor vehicle emissions (tonnes/year)

	PM_{10}		CO		NOx		SOx		$PM_{2.5}$	
	tonnes	kg/ha	tonnes	kg/ha	tonnes	kg/ha	tonnes	kg/ha	tonnes	kg/ha
Tailpipe	3	0.9	249	63	109	28	0.1	0.02	3	1
Brake and tyre	3	0.9							2	0
Road dust	2	0.4							1	0
Total	8	2.1	249	63	109		0.1	0.02	6	2

Figure 4.1: Motor vehicle PM_{10} (left) and $PM_{2.5}$ (right) emissions by source.

5 INDUSTRIAL AND COMMERCIAL ACTIVITIES

5.1 Methodology

Industrial and commercial activities to be included in the inventory were identified by searching a range of databases and through the Council's resource consent database.

Information on activities with resource consents for discharges to air in Rotorua were provided by the Bay of Plenty Regional Council. These included a range of surface coating activities, landfills, farming activities, combustion activities, abrasive blasting, asphalt production and crematorium.

Surface coating activities (e.g., spray painters) were a relatively predominant consented industrial activity. The main discharge from surface coatings is volatile organic compounds (VOC) which is a contaminant not included in the inventory. Particle emissions may occur if coatings are applied using spray guns in an uncontrolled environment. However, they are not typically included in emission inventory assessments as they are comparatively small in relation to those from other sources (Environment Australia, 1999). In this assessment emissions from these activities are included in the small scale industrial and commercial activity assessment.

The general approach was to identify activities discharging to air and collect site specific information relevant to the discharge type (activity data) as well as information on seasonal variability and hours of operation where relevant.

For industries for which relatively recent site-specific emissions data were available from compliance testing or the resource consent application, emissions were estimated based on equation 5.1.

Equation 5.1 Emissions (kg/day) = Emission rate (kg/hr) x hrs per day (hrs)

Where site specific emissions data were not available, emissions were estimated using activity data and emission factor information, as indicated in Equation 5.2. Activity data from industry includes information such as the quantities of fuel used, or in the case of non-combustion activities, materials used or produced. Activity data was collected by direct contact with industry, using data from the resource consents or compliance monitoring or a combination of these methods. Maximum consent limits are not typically used but in some instances where they are relied on it may result in an overestimate of emissions.

Equation 5.2 Emissions (kg) = Emission factor (kg/tonne) x Fuel/Material use (tonnes)

The emission factors used to estimate the quantity of emissions discharged are shown in Table 5.1. Site specific information was available for a number of sources. The emissions factors used are from the USEPA AP42 database[2] with the exception of the animal cremation factors which are from (EEA, 2016) and the pellet boiler PM_{10} emission factor which is from Wilton & Baynes, (2010). In addition, AP 42 database was used to assess the proportion of PM_{10} emissions that were likely to be $PM_{2.5}$ for a range of sources. Fugitive dust emissions from industrial and commercial activities were generally not included in the inventory assessment because of difficulties in quantifying the emissions.

Table 5.1: Emission factors for industrial discharges.

AP 42 Chapter	AP 42 Source Category Code	Discharge Type	PM_{10} g/kg	CO g/kg	NOx g/kg	SOx g/kg	$PM_{2.5}$ g/kg

[2] http://www.epa.gov/ttn/chief/ap42/index.html

11.12	3-05-011-04,-21,23	Aggregate loading/ unloading uncontrolled	0.0017				0.0005
13.2.6	3-09-002-04	Abrasive blasting – garnet fabric filter	0.69				0.069
		Pellet boiler (conversion)	0.8	6.8	0.8	0.0	0.7
EEA 2016 5.c.1.v Table 3.1		Crematoria kg/body	0.0347	0.14	0.824	0.113	0.0347
5.c.1.b	(EEA, 2016)	Crematorium – animal (kg per tonne of material cremated)	0.6				0.5
Ap42 Vol 1, Chp 2.5, Table 2.5-5		Outdoor burning of grasses- unspecified	8	50			8

For 1% Sulphur content but adjusted for S content percentage where available

5.2 Small scale activities

An additional assessment of PM_{10} and $PM_{2.5}$ discharges from small scale industry is included in this report based on the methodology described in the Bay of Plenty Regional Council Rotorua Air Emission Inventory (Iremonger & Graham, 2007). The methodology used for this assessment as per Iremonger & Graham, 2005 was to sort small scale activities into category groupings and to apply an across the board hourly emission rate for each activity in each category. The groupings and emission rates from that study and applied here were:

Facilities with highest potential for PM emissions (assumed to emit 0.1 kg/hr)

Joinery factories, heavy engineering, panel beaters, light metal fabrication, metal finishers (powder coating), bakeries, bone/stone/wood grinding or carving.

Facilities with lower potential for PM emissions (0.02 kg/hr)

Light vehicle workshops, printing works, packaging manufacturers, tanneries, paint and other solvents, metal finishers/ electroplating, appliance repairs.

Facilities with very little potential for PM_{10} emissions (no emissions)

Retail facilities, car dealers, food and beverage facilities.

Facilities with the potential for yard emissions (0.1 kg/day)

Wreckers, scrap metal dealers, waste management, timber yards.

The assignment of these emission factors to these groupings was made by Graham, (2006) and reported in (Iremonger & Graham, 2007) based on the emission test data reported in Appendix D. It is noted that these factors will be TSP and the main size fractions of interest are PM_{10} and $PM_{2.5}$. To estimate emissions by size data on size fraction distributions from AP 42 (Appendix B.2, table B2.2 mechanically generated sources for aggregate/ unprocessed ores) were adopted. This indicated PM_{10} at around 51% of TSP and $PM_{2.5}$ at 15% of TSP.

Iremonger & Graham, (2007) note a very high degree of uncertainty in the method to the point of it providing only an indication for the purposes of assessing whether further evaluation is required. We concur with this view because of the very small number of test results available for the different discharge types, no specificity of method associated with the test results (e.g., controlled or uncontrolled) and some significant variations in test results for seemingly the same discharge type (e.g., the two results for spray painting are 0.03 kg/hr and 0.14 kg/hr). In addition, these test data are extrapolated to other industry to provide rough groupings and we have applied an across the board size distribution allocation that does not take into account the different particulate formation processes.

Small scale industrial and commercial activities were identified based on a Regional Council audit database which included around 49 activities. The activity types were compared to those described in Graham (2006) and those consistent with the categories listed were included based on the emission rates specified. Activities not specified in the existing emission categorisation were generally assumed to fall into the “no likely emission” category except in instances where additional information indicated otherwise (e.g., a number of “yard emissions” activities were identified based on comments provided in the audit). A total of 31 small scale industrial and commercial activities were included in the assessment.

5.3 Industrial and commercial emissions

A number of industrial activities previously operating in Rotorua had relocated or ceased to operate. Additionally, surveys of schools that previously used coal for heating had switched fuels primarily to electricity, gas or pellet fuel. Red Stag Timber Limited, one of the largest timber processing sites in the region is located just outside of the Rotorua Airshed. Air dispersion modelling has shown it to have no more than minor impact on the Rotorua Airshed. Table 5.2 shows the estimated emissions to air from industrial and commercial activities in Rotorua. Around nine tonnes of PM_{10} and seven tonnes of $PM_{2.5}$ is estimated to be discharged to air per year in Rotorua. The average daily amount during winter is 24 kg/day and 20 kg/day for PM_{10} and $PM_{2.5}$ respectively (Table 5.2).

Table 5.2: Industrial and commercial emissions in Rotorua.

	PM_{10}		CO		NOx		SOx		$PM_{2.5}$	
	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha	kg	g/ha
Industrial & commercial activities	24	6	129	33	47	12	5	1	20	5
	PM_{10}		CO		NOx		SOx		$PM_{2.5}$	
	t/year	kg/ha	t/year	kg/ha	t/year	kg/ha	t/year	kg/ha	t/year	kg/ha
Industrial & commercial activities	9	2	47	12	17	4	2	0	7	2

5.4 Small scale activity emissions

The total estimated emissions from small scale industrial and commercial activities comprising industry for which emission factors are not readily available was 20 kilograms PM_{10} per day and 5 tonnes per year. The $PM_{2.5}$ estimates are six kilograms per day and 1.5 tonnes per year. The estimates were based on the assumption that discharges would occur for six hours a day and five days per week at the rates specified for each location.

6 OUTDOOR BURNING EMISSIONS

Outdoor burning of green wastes or household material can contribute to PM_{10} concentrations and also discharge other contaminants to air. In some urban areas of New Zealand outdoor burning is prohibited because of the adverse health and nuisance effects associated with these emissions. Outdoor burning includes any burning in a drum, incinerator or open air on residential properties in the study area.

PC 13 bans outdoor burning within 100 metres of a neighbouring dwelling house unless for recreational/ cultural purposes (Rule AIR-R2) or if the activity meets requirements of rules AIR-OBURN-R22 and AIR-OBURN-R23 which provide for fire-fighting, and emergency disposal of diseased carcasses and vegetation. Notwithstanding this, the source has been included in the inventory because of the potential for the activity to be carried out without households realising that it was not a permitted activity.

An additional source of burning in the outdoors that can contribute to air pollution is the use of braziers, pizza ovens and wood fired barbeques. This source is also evaluated in this section.

6.1 Methodology

Outdoor burning emissions for Rotorua were estimated for all seasons based on data collected during the 2022 domestic home heating survey. This included questions relating to the burning of garden waste in the outdoors as well as the frequency of and quantities of materials burnt in braziers, wood fired barbeques and pizza ovens.

Emissions were calculated based on the assumption of an average weight of material per burn of 159 kilograms per cubic metre of material[3] and using the emission factors in Table 6.1 with an average fire size of 2 m^3 (size based on survey responses). The AP42 emission factor database includes estimates for a wide range of materials including different tree species, weeds, leaves, vines and other agricultural material. The factors selected are based on a combination of refuse (AP42 table 2.5.1), weeds and prunings (AP42 table 2.5.5). Emission factors for SOx are based on residential wood burning in the absence of emission factors for these contaminants within the AP42 database for outdoor burning. AP42 emission factors were selected in preference to European Environment Agency air pollution emission inventory guidebook (EEA, 2016) tier one assessment emission factors as the latter are based on tree slash for two species and tree pruning for two species only. Emission factors for burning of wood on braziers, pizza ovens and barbeques also used the emission factors in Table 6.1.

Table 6.1: Outdoor burning emission factors (AP42, 2002).

Source AP 42	PM_{10} g/kg	$PM_{2.5}$ g/kg	CO g/kg	NOx g/kg	SOx g/kg
Tables 2.5- 1 and 2.5-5	8	8	42	3	0.5

[3] Based on the average of low and medium densities for garden vegetation from (Victorian EPA, 2016)

6.2 Outdoor burning emissions

Table 6.2 shows that around nine kilograms of PM_{10} from outdoor burning could be expected per day during the winter months on average in Rotorua. Survey responses for Rotorua indicated a slight greater prevalence of outdoor burning during the winter and spring than other seasons of the year.

It should be noted, however, that there are a number of uncertainties relating to the calculations. In particular it is assumed that burning is carried out evenly throughout each season, whereas in reality it is highly probable that a disproportionate amount of burning is carried out on days more suitable for burning. Thus, on some days no PM_{10} from outdoor burning may occur and on other days it might be many times the amount estimated in this assessment. Outdoor burning emissions include a higher degree of uncertainty relative to domestic heating, motor vehicles and industry owing to uncertainties in the distribution of burning and potential variabilities in material density.

Table 6.2: Outdoor burning (garden waste) emission estimates for Rotorua.

	PM_{10} kg/ day	CO kg/ day	NOx kg/ day	SOx kg/ day	$PM_{2.5}$ kg/day
Summer (Dec-Feb)	2	12	1	0	2
Autumn (Mar-May)	5	27	2	0	5
Winter (June-Aug)	9	45	3	1	9
Spring (Sept-Nov)	8	41	3	0	8
	PM_{10} tonnes/ year	CO tonnes/ year	NOx tonnes/ year	SOx tonnes/ year	$PM_{2.5}$ tonnes/ year
Annual emissions	2	11	0.8	0.1	2

6.3 Brazier, pizza oven and wood fired barbeque emissions

Around 15 kilograms of PM_{10} and $PM_{2.5}$ from braziers, pizza ovens and outdoor barbeques could be expected per day during the winter months from these sources Rotorua. In summer this increases to around 42 kilograms (Table 6.3).

Table 6.3: Brazier, pizza oven and wood fired barbeque emission estimates for Rotorua.

	PM_{10} kg/ day	CO kg/ day	NOx kg/ day	SOx kg/ day	$PM_{2.5}$ kg/day
Summer (Dec-Feb)	42	218	16	3	42
Autumn (Mar-May)	16	83	6	1	16
Winter (June-Aug)	15	77	6	1	15
Spring (Sept-Nov)	19	101	7	1	19
	PM_{10} tonnes/ year	CO tonnes/ year	NOx tonnes/ year	SOx tonnes/ year	$PM_{2.5}$ tonnes/ year
Annual emissions	8	44	3	1	8

6.4 Total emissions from outdoor burning

Table 6.4 shows the combined outdoor garden waste burning and burning of wood in braziers, pizza ovens and wood fired barbeques in Rotorua for 2022 by season and per year. Around 23 kilograms per day and around 10 tonnes per year of PM_{10} and $PM_{2.5}$ are estimated from burning in the outdoors.

Table 6.4: Total outdoor burning emission estimates for Rotorua.

	PM_{10} kg/ day	CO kg/ day	NOx kg/ day	SOx kg/ day	$PM_{2.5}$ kg/day
Summer (Dec-Feb)	44	231	16	3	44
Autumn (Mar-May)	21	110	8	1	21
Winter (June-Aug)	23	122	9	1	23
Spring (Sept-Nov)	27	141	10	2	27
	PM_{10} tonnes/ year	CO tonnes/ year	NOx tonnes/ year	SOx tonnes/ year	$PM_{2.5}$ tonnes/ year
Annual emissions	10	55	4	1	10

7 UNCERTAINTY

The uncertainties associated with the input variables for domestic heating include the emission factors for each appliance type, the fuel quantities used and the number of households using different heating methods. The sampling uncertainty for the household survey of 5% was used for the latter variable (assuming no systemic bias) and expert judgement for emission factors (30%) and fuel quantities (25%).

The emissions from domestic home heating were estimated to have a medium level of uncertainty based on the above assessment

There are several areas of uncertainty around the emissions estimates from motor vehicles. The fleet weighted average emission factors contain assumptions around average speeds, cold starts and the distribution of diesel and petrol vehicles as well as the allocation of vehicles to different engine capacity or weight classes. The NZTA VKT data provide another source of potential uncertainty.

The authors of VEPM provide an expert judgement on the uncertainty being in the range of 20-100% depending on the make-up of the fleet being investigated. In particular it notes that *"It is anticipated that if the fleet consisted entirely of European vehicles uncertainty would be close to 20%. Conversely, if the fleet was predominantly of Japanese origin with a high proportion of HDVs then the uncertainty could be as high as 100%"* (EFRU, 2008).

An estimate of the uncertainty of the PM_{10} motor vehicle tailpipe emissions was made based on the following uncertainties: fleet weighted average emissions – exhaust 40% and brake and tyre wear 60% and VKT estimates 20%. Road dust PM_{10} estimates were assumed to contain an uncertainty of 50%.

The emissions for motor vehicle exhaust, brake and tyre wear emissions and road dust were estimated to have a medium level of uncertainty based on the above assessment.

The uncertainty for the industrial and commercial emissions was estimated for PM_{10} based on the kg/day emissions for the months of July. The emission estimates include a range of uncertainties. The uncertainty has been quantified based on the statistical approach outlined in Appendix C. The uncertainties used varied depending on the nature of the industrial information available. Lower uncertainties were assigned (15%) for continuous emission sampling compared with 40%- 50% for emission factors depending on AP42 rating. Activity data uncertainty ranged from 10% to 30% depending on the source of the information. Smaller industrial contributors were collated and allocated an emission uncertainty estimate of 40%.

The PM_{10} uncertainties from industrial and commercial activities were estimated to be medium.

The small-scale activity emissions have been treated as a separate source for the purposes of assessing uncertainty. The uncertainty has been estimated to be high based on expert judgement.

The key areas of uncertainty regarding emissions estimates from outdoor burning are the quantities of material burnt per day and the emission factors. The uncertainty around the quantities has been estimated at around 80% because of potential errors in householder estimates of quantities burnt and the potential for burning not to be spread evenly across the seasons (i.e., more emissions on some days and less on others). The uncertainty around emission factors of 50% was assumed.

The combined uncertainty around outdoor burning emissions was estimated to be high.

8 TOTAL EMISSIONS FOR ROTORUA

The total PM_{10} and $PM_{2.5}$ emissions per year for Rotorua for 2022 was 88 and 79 tonnes respectively. Domestic heating was the most significant contributors to annual and daily winter PM_{10} in Rotorua (Figure 8.1). Outdoor burning (dominated by use of braziers, pizza ovens and wood fired barbeques) contributed 12% of the annual PM_{10}. Industry and motor vehicles both contributed around 10% of the annual PM_{10}. Outdoor burning, industry, motor vehicles and small-scale activities each contributed 4-5% of the daily winter PM_{10}. Domestic heating is also the main source of annual and winter $PM_{2.5}$ (Figure 8.2).

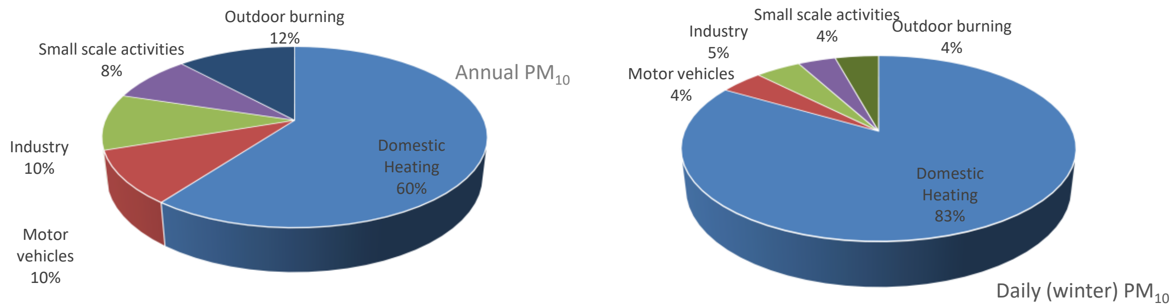

Figure 8.1: Relative contribution of sources to annual PM_{10} and daily winter PM_{10} emissions in Rotorua.

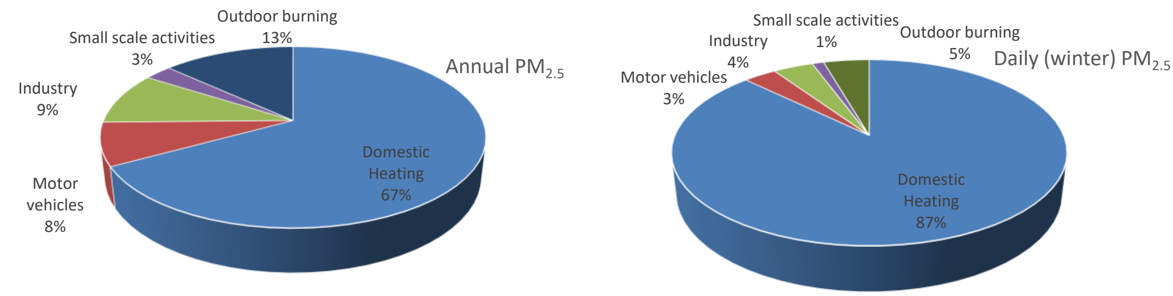

Figure 8.2: Relative contribution of sources to annual $PM_{2.5}$ and daily winter $PM_{2.5}$ in Rotorua.

Figures 8.3 to 8.5 show domestic heating is the main source of CO and SOx and motor vehicles are the main source of NOx emissions in Rotorua.

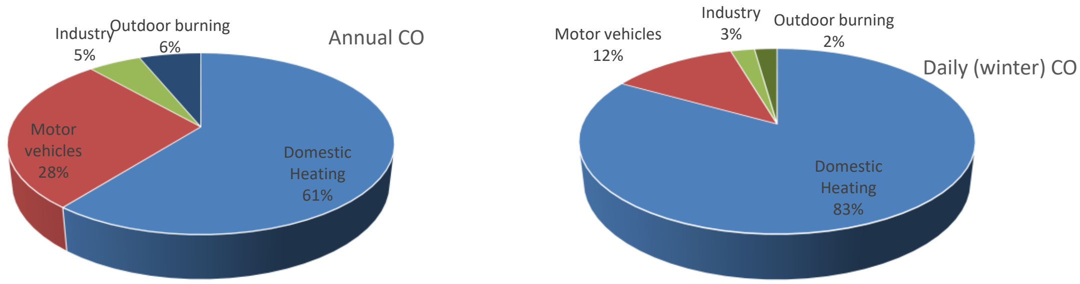

Figure 8.3: Relative contribution of sources to daily winter and annual average CO, emissions in Rotorua

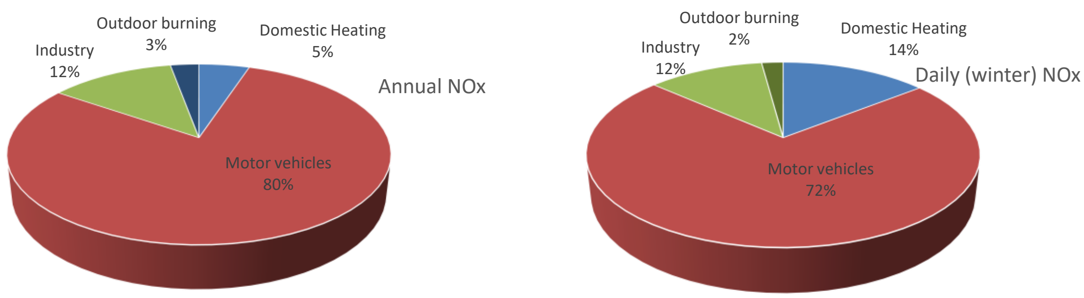

Figure 8.4: Relative contribution of sources to annual (left) and daily winter (right) NOx emissions in Rotorua.

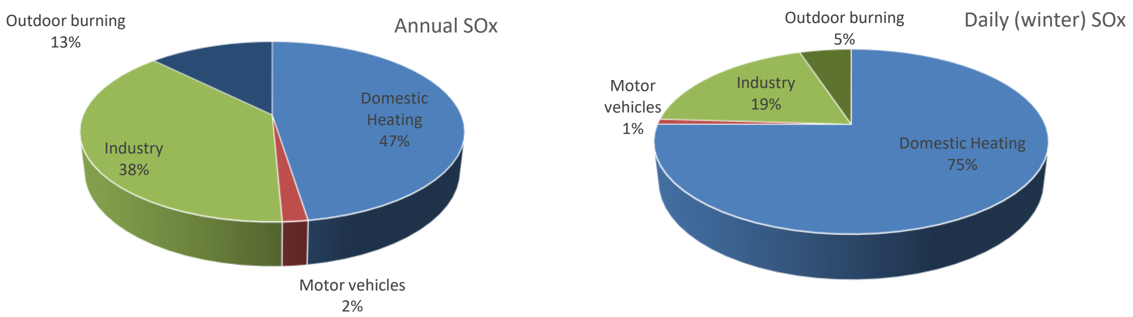

Figure 8.5: Relative contribution of sources to daily winter and annual average SOx, emissions in Rotorua

Seasonal variations in PM_{10} emissions are shown in Table 8.3. This suggests the main sources of summertime anthropogenic PM_{10} are industry, small scale activities and motor vehicles, and the main source of winter time anthropogenic PM_{10} is domestic home heating. Seasonal variations in emissions of other contaminants are shown in Tables 8.4 to 8.7.

Table 8.1: Annual average emissions in Rotorua by source and contaminant (tonnes/year)

	PM_{10} tonnes/year	CO tonnes/year	Nox tonnes/year	Sox tonnes/year	$PM_{2.5}$ tonnes/year
Domestic Heating	53	540	7	2	53
Motor vehicles	8	249	109	0	6
Industry	9	47	17	2	7
Small scale activities	7				2
Outdoor burning	10	55	4	1	10
Total	88	891	137	5	79

Table 8.2: Daily (winter) average emissions in Rotorua by source and contaminant (kg/day)

	PM_{10} kg/day	CO kg/day	Nox kg/day	Sox kg/day	$PM_{2.5}$ kg/day
Domestic Heating	456	4621	59	21	456
Motor vehicles	23	682	299	0	17
Industry	24	129	47	5	20
Small scale activities	20			0	6
Outdoor burning	23	122	9	1	23
Total	547	5555	414	28	522

Table 8.3: Monthly variations in PM_{10} emissions in Rotorua by source (kg/day)

	Domestic Heating kg/day	Motor vehicles kg/day	Industry kg/day	Small scale activities kg/day	Outdoor burning kg/day	Total kg/day
January	0	23	24	20	44	111
February	1	23	24	20	44	112
March	5	23	24	20	21	93
April	40	23	24	20	21	128
May	224	23	24	20	21	313
June	434	23	24	20	23	525
July	456	23	24	20	23	547
August	419	23	24	20	23	510
September	106	23	24	20	27	201
October	39	23	24	20	27	134
November	9	23	24	20	27	103
December	0	23	24	20	44	111

Table 8.4: Monthly variations in CO emissions in Rotorua by source (kg/day)

	Domestic Heating kg/day	Motor vehicles kg/day	Industry kg/day	Small scale activities kg/day	Outdoor burning kg/day	Total kg/day
January	0	682	128	0	231	1041
February	8	682	128	0	231	1049
March	53	682	128	0	110	973
April	398	682	128	0	110	1318
May	2298	682	128	0	110	3219
June	4392	682	129	0	122	5326
July	4621	682	129	0	122	5555
August	4262	682	129	0	122	5195
September	1090	682	128	0	141	2042
October	407	682	128	0	141	1359
November	94	682	128	0	141	1046
December	0	682	128	0	231	1041

Table 8.5: Monthly variations in NOx emissions in Rotorua by source (kg/day)

	Domestic Heating kg/day	Motor vehicles kg/day	Industry kg/day	Small scale activities kg/day	Outdoor burning kg/day	Total kg/day
January	0	299	47	0	16	362
February	0	299	47	0	16	362
March	1	299	47	0	8	354
April	7	299	47	0	8	361
May	30	299	47	0	8	384
June	54	299	47	0	9	409
July	59	299	47	0	9	414
August	54	299	47	0	9	409
September	15	299	47	0	10	371
October	5	299	47	0	10	361
November	1	299	47	0	10	357
December	0	299	47	0	16	362

Table 8.6: Monthly variations in SOx emissions in Rotorua by source (kg/day)

	Domestic Heating kg/day	Motor vehicles kg/day	Industry kg/day	Small scale activities kg/day	Outdoor burning kg/day	Total kg/day
January	0	0	5	0	3	8
February	0	0	5	0	3	8
March	0	0	5	0	1	7
April	2	0	5	0	1	9
May	11	0	5	0	1	18
June	20	0	5	0	1	27
July	21	0	5	0	1	28
August	19	0	5	0	1	26
September	5	0	5	0	2	12
October	2	0	5	0	2	9
November	0	0	5	0	2	8
December	0	0	5	0	3	8

Table 8.7: Monthly variations in $PM_{2.5}$ emissions in Rotorua by source (kg/day)

	Domestic Heating kg/day	Motor vehicles kg/day	Industry kg/day	Small scale activities kg/day	Outdoor burning kg/day	Total kg/day
January	0	17	20	6	44	87
February	1	17	20	6	44	88
March	5	17	20	6	21	69
April	40	17	20	6	21	104
May	224	17	20	6	21	288
June	434	17	20	6	23	500
July	456	17	20	6	23	522
August	419	17	20	6	23	485
September	106	17	20	6	27	176
October	39	17	20	6	27	109
November	9	17	20	6	27	79
December	0	17	20	6	44	87

8.1.1 Uncertainty

The uncertainty for the total PM_{10} emission estimate was assessed by combining the individual source uncertainties addition as per Appendix C. The total uncertainty for the inventory PM_{10} emission estimate for Rotorua is medium (around 28%).

8.2 Trends in emissions

A comparison of the annual PM_{10} emission estimates in 2022 to those made in 2005 (Iremonger & Graham, 2007) is shown in Figure 8.6 with the latter adjusted for differences in methodology. Data suggests an overall reduction of around 77% in annual PM_{10} emissions may have occurred. However, there is some uncertainty around this estimate owing to differences between inventory methods. It is also noted that reductions in measured concentrations are unlikely to be of the same magnitude owing to the contribution of natural sources which are not included in the estimate.

The main areas where emissions are estimated to have decreased are industry, domestic heating and motor vehicle emissions. Domestic heating emissions have reduced as a result of the phase out of open fires and older wood burners not meeting emission limits. Industrial emissions have also reduced significantly as a result of a number of large-scale dischargers no longer discharging into the Rotorua Airshed. Motor vehicle emissions have also decreased significantly since 2005 as a result of improvements in vehicle technology.

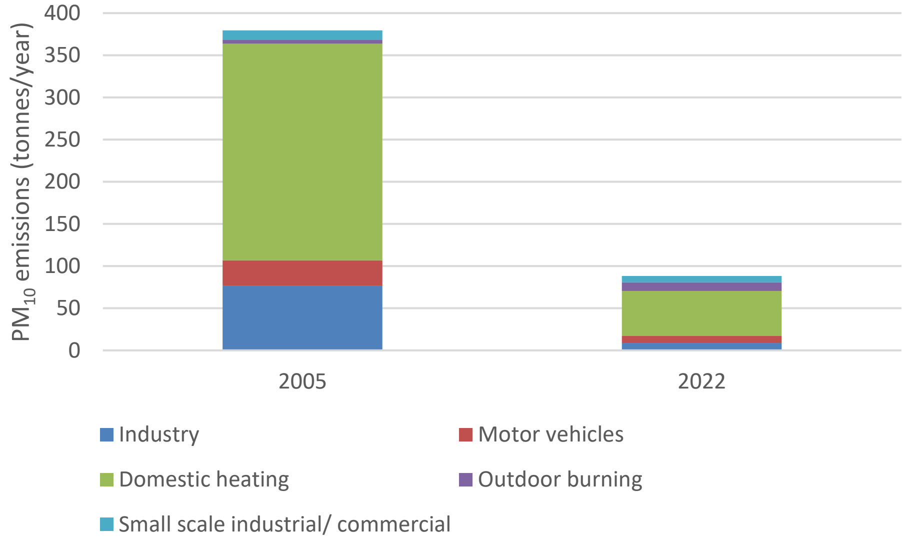

Figure 8.6: Comparison of annual PM_{10} emissions in Rotorua 2005 to 2022.

8.3 Spatial distribution in emissions across Rotorua

The spatial distribution of contaminant emissions (as tonnes/km^2/year) across the Rotorua Airshed is shown in Figures 8.7 to 8.10. This distributes the emissions occurring within a geographical area, defined by Statistics New Zealand as SA1 (2018), evenly throughout the area. Factors influencing emission density include variables such as the density of wood burning households, the prevalence of major roads or industrial discharges. In the case of wood burning houses the emission sources are typically located across the SA1 area whereas an industrial discharge will typically be a point source. Even with the point source discharges the emission estimates are spread across the whole SA1 area in the map below because this illustrates the total emission across the area rather than providing a more detailed spatial disaggregation. If the emissions data were integrated into a dispersion model to estimate the resulting concentrations, the point source discharge location would be used in preference to the distribution illustrated below. Significant point source (industrial) discharges are indicated on the figures below. Note area of impact from the emission is not illustrated, just the SA1 where the emission occurs.

The emission quantities for the colour classifications shown in SA1 areas are illustrated in the figure legend. These have been selected using the natural breaks – Jenks protocol within the spatial system software. This selects legend categories based on natural groupings inherent in the data. Class breaks are created in a way that best groups similar values together and maximizes the differences between classes. Natural breaks are data-specific classifications and not useful for comparing multiple maps built from different underlying information.

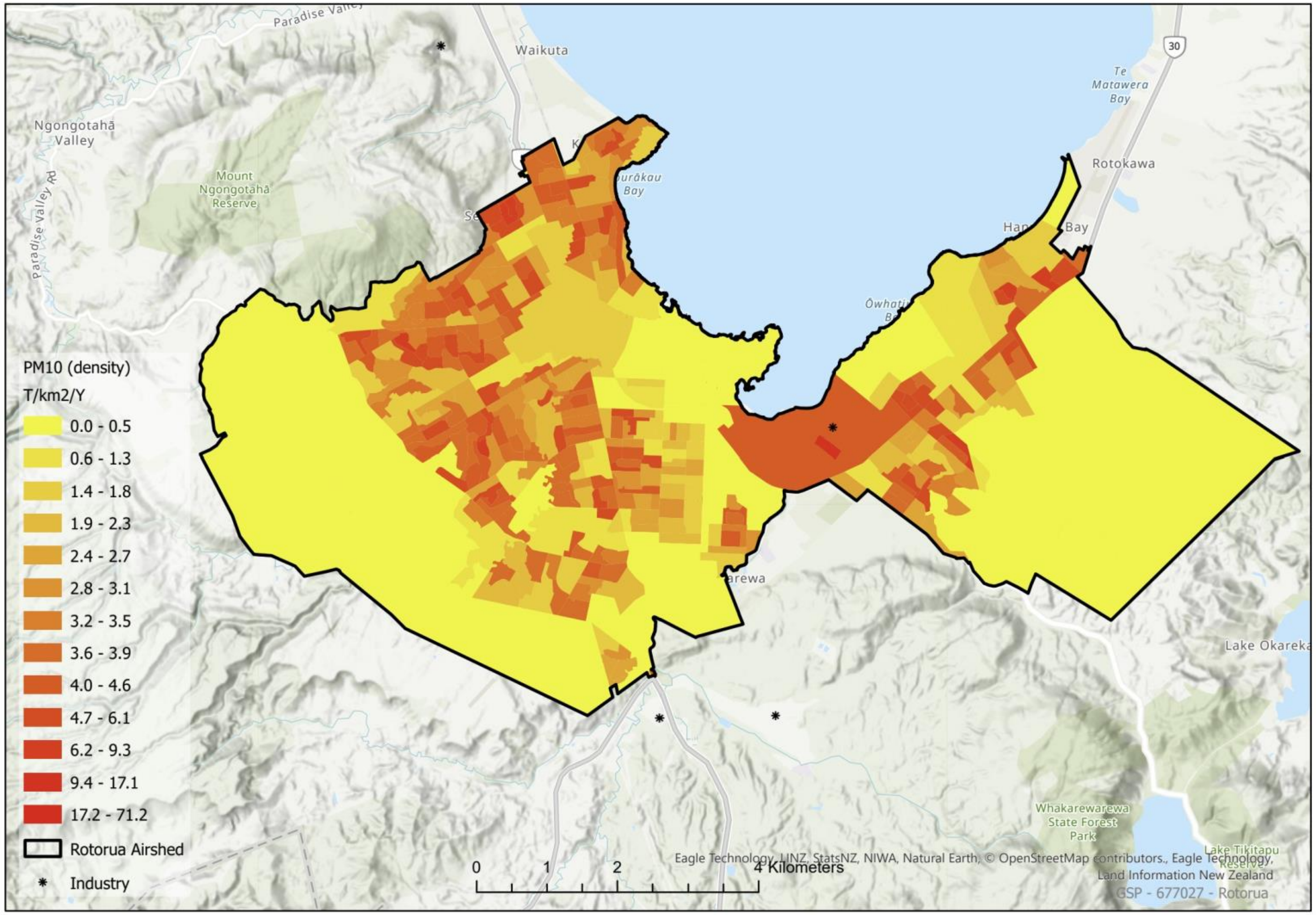

Figure 8.7: Spatial distribution in PM_{10} emissions for Rotorua - 2022

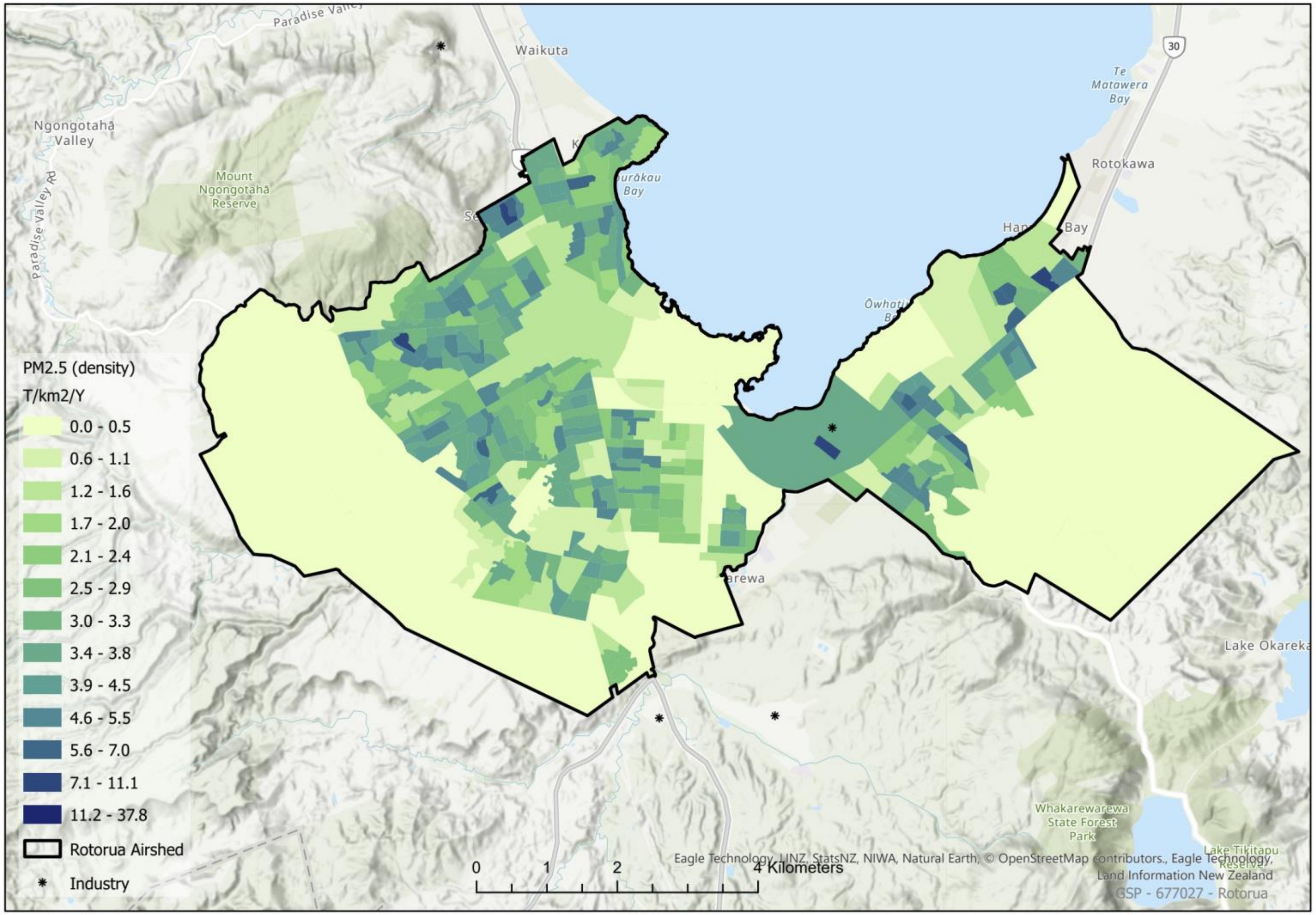

Figure 8.8: Spatial distribution in $PM_{2.5}$ emissions for Rotorua - 2022

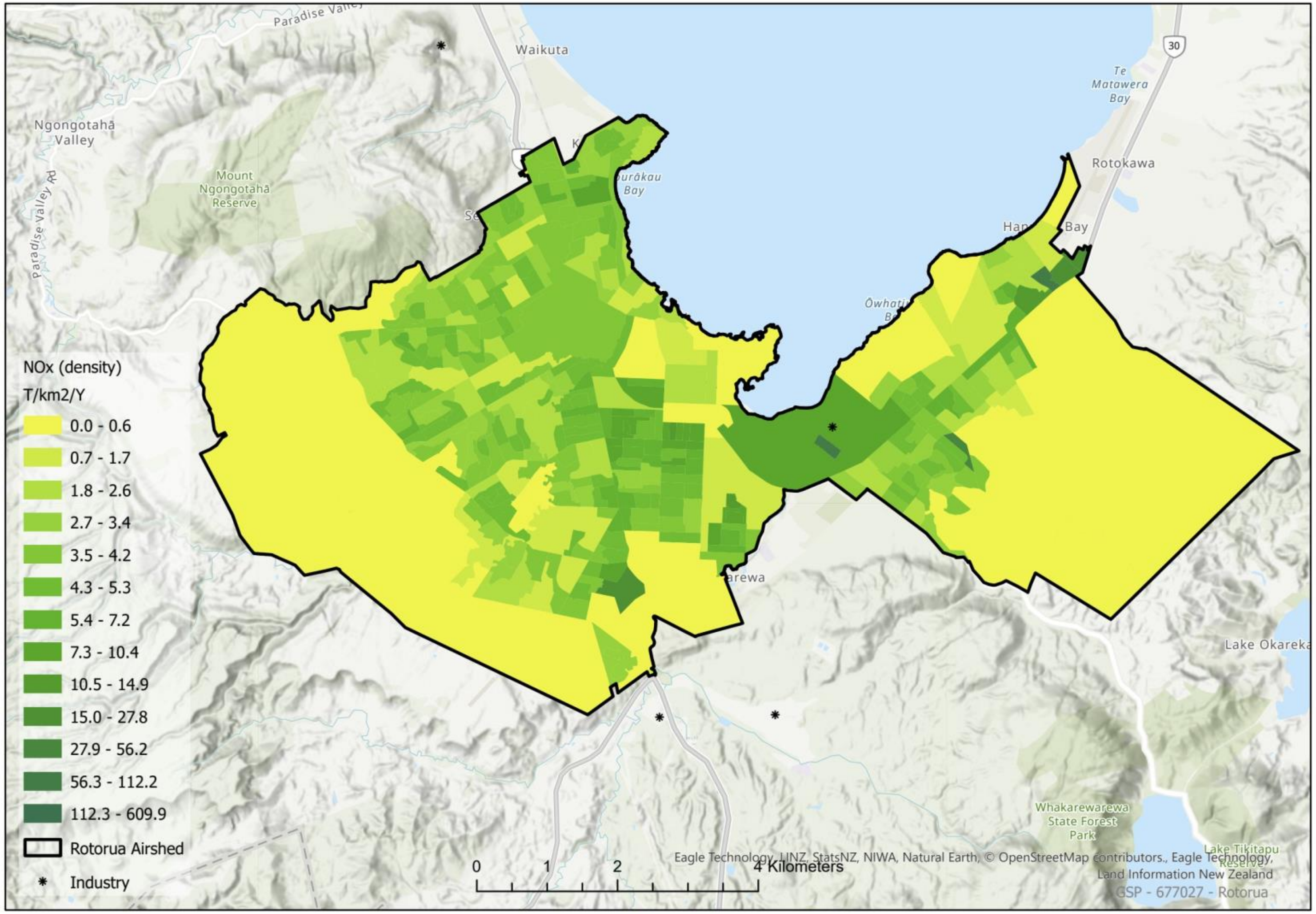

Figure 8.9: Spatial distribution in NOx emissions for Rotorua - 2022

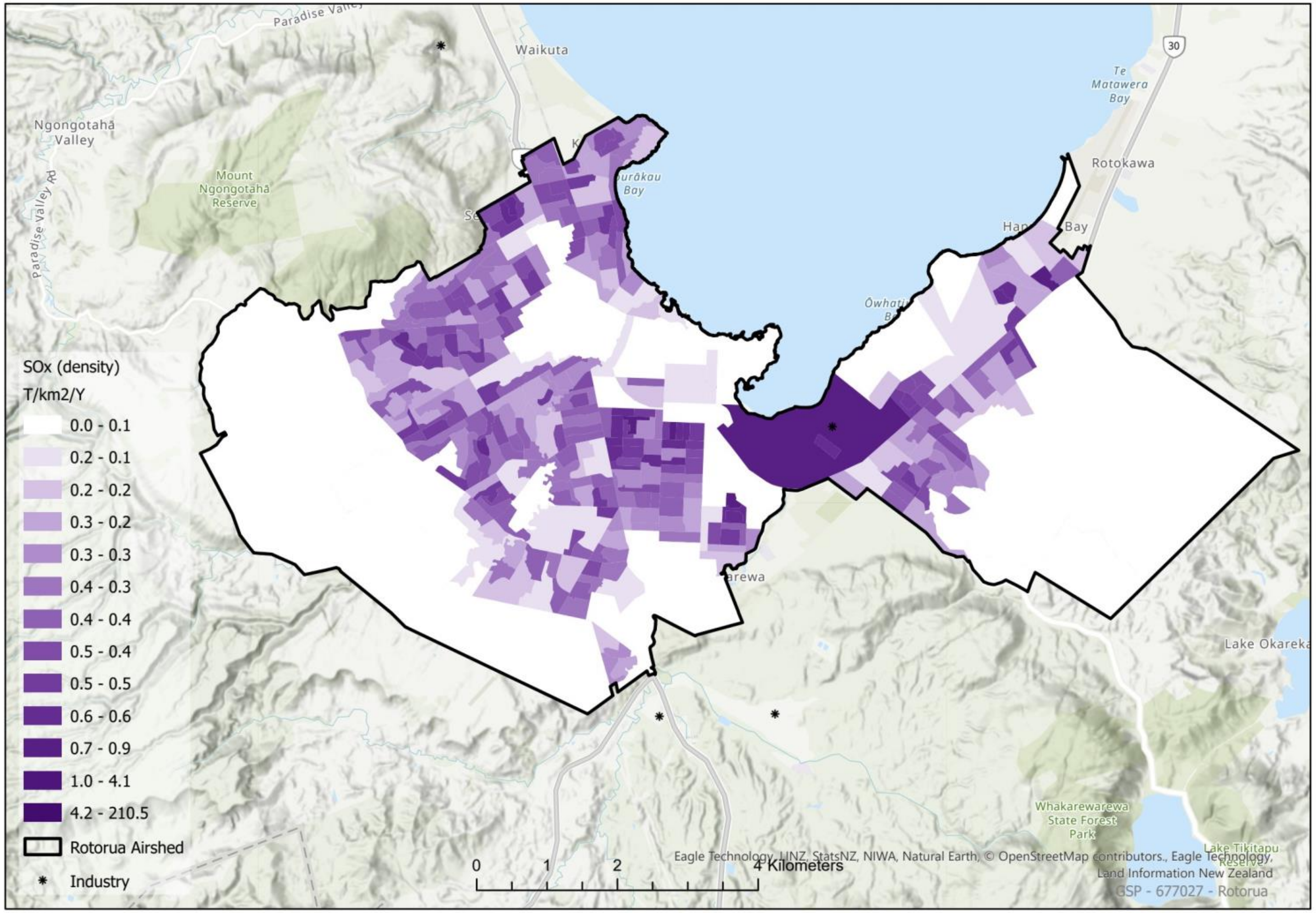

Figure 8.10: Spatial distribution in SOx emissions for Rotorua - 2022

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APPENDIX A: HOME HEATING QUESTIONNAIRE

1a.) Do you use any type of electrical heating in your MAIN living area during a typical year?

1b.) What type of electrical heating do you use? Would it be...

- Night Store
- Radiant
- Portable Oil Column
- Panel
- Fan
- Heat Pump
- Central heating system/ radiators
- Other (specify)
- Don't Know/Refused

1c.) Off the top of your head approximately how much would you spend, on average, per month during the winter, on electricity for space heating?

1d.) Do you use any other heating system in your main living area in a typical year? *(*

2a.) Do you use any type of gas heating in your MAIN living area or a gas fired central heating system during a typical year?

2b.) Is it flued or unflued gas heating?

2c.) Which months of the year do you use your gas burner/ heating system?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

2d.) How many days per week would you use your gas burner/ heating system during?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

2e.) Do you use mains or bottled gas for home heating?

2f.) Off the top of your head approximately how much would you spend, on average, per month during the winter, on gas for your gas burner/ heating system?

3a.) Do you use a log burner (wood burner) in your MAIN living area during a typical year? This is a fully enclosed burner but does not include multi fuel burner that burns coal or burns coal and wood

3b.) Which months of the year do you use your log burner

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

3c.) How many days per week would you use your log burner during? *(*

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

3d.) During the winter what times of the day do you use your log burner? 6am – 11am

- 11am - 4pm
- 4pm - 10pm
- 10pm - 6am

3e.) Approximately what time during the evening would you put your last load on the fire.

3f.) How old is your log burner?

- 17 years+
- Between 2 and 16 years old
- Less than 2 years old

3f1.) Is your burner an ultra-low emission burner (ULEB)?

3h.) How many pieces of wood do you use per day on an average winters day?

3h2.) How many pieces of wood do you use per day during the other months?

3i.) In a typical year, how much wood would you use per year on your log burner?

3j.) Do you buy wood for your log burner, or do you receive it free of charge?

3k.) What percentage would be bought

3l.) Off the top of your head approximately how much would you spend, on average, per month during the winter, on wood for your log burner?

3m.) If you placed your hand on your burner first thing in the morning (e.g., 6am-7am) after having used it the night before would it be…

- Cold to touch (no feeling of leftover heat)
- Warm to touch (if you held your hands there for a bit it would warm them up)
- Hot to touch (too hot to hold a hand on for more than a few seconds)

4a.) Do you use an enclosed burner which can burn coal as well as wood – i.e., a multi fuel burner in your MAIN living area during a typical year?

4b.) Which months of the year do you use your multi fuel burner?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

4c.) How many days per week would you use your multi fuel burner during?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

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4d.) How old is your multi fuel burner?

- 17 years+

- Between 5 and 16 years old
- Less than 5 years old

4e.) Do you use wood on your multi fuel burner?

4f2.) How many pieces of wood do you use per day on average on a typical winters day

4h.) How many pieces of wood do you use per day during the other months

4i.) In a typical year, how much wood would you use per year on your multi fuel burner?

4j.) Do you use coal on your multi fuel burner?

4l.) How many buckets of coal do you use per day on average on a typical winters day?

4n.) How many buckets of coal do you use per day during the other months

4o.) Do you buy wood for your multi fuel burner, or do you receive it free of charge? *(*

4p.) What percentage would be bought?

5a.) Do you use an open fire in your MAIN living area during a typical year?

5b.) Which months of the year do you use your open fire

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

5c.) How many days per week would you use your open fire during?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

5d.) Do you use wood on your open fire?

5f.) How many pieces of wood do you use per day on average on a typical winters day?

5h.) How many pieces of wood do you use per day during the other months

5i.) In a typical year, how much wood would you use per year on your open fire?

5j.) Do you use coal on your open fire?

5k.) How many buckets of coal do you use per day during the winter? (

5l.) How many buckets of coal do you use per day during the other months?

5m.) Do you buy wood for your open fire, or do you receive it free of charge?

5n.) What percentage would be bought?

) 5o.) Off the top of your head approximately how much would you spend, on average, per month during the winter, on wood and coal for your open fire?

6a.) Do you use a pellet burner in your MAIN living area or pellet fired central heating system during a typical year?

6b.) Which months of the year do you use your pellet burner

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

6c.) How many days per week would you use your pellet burner during?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

6d.) How old is your pellet burner?

- 17 years+
- Between 5 and 16 years old
- Less than 5 years old

6f.) How many kilograms of pellets do you use per day on average on a typical winters day?

6h.) How many kgs of pellets do you use per day during the other months

6i.) In a typical year, how many kilograms of pellets would you use per year on your pellet burner?

6j.) Off the top of your head approximately how much would you spend, on average, per month during the winter, on pellets for your pellet burner?

7a.) Do you use any other heating system in your MAIN living area during a typical year?

7b.) What type of heating system do you

8a.) Do you use an indoor wood fuelled cooking appliance during a typical year? (This is an appliance primarily used for cooking and includes an oven and hot plate)

8b.) Which months of the year do you use your wood fuelled cooker?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

8c.) How many days per week would you use your wood fuelled cooker during?

☐ Jan	☐ Feb	☐ March	☐ April	☐ May	☐ June
☐ July	☐ Aug	☐ Sept	☐ Oct	☐ Nov	☐ Dec

8d.) How old is your wood fuelled cooker?

- 17 years+
- Between 5 and 16 years old
- Less than 5 years old

8e.) In a typical year, how many pieces of wood do you use on an average winter's day on your wood fuelled cooker?

9. Does your home have insulation?

Where do you have insulation in your home?

- Ceiling
- Under floor

- Wall
- Cylinder wrap
- Double glazing
- Other
- None

10. Do you burn rubbish or garden waste outside in the open or an incinerator or rubbish bin?

10a.) How many days would you burn waste or garden rubbish outdoors during winter

10b.) How many days would you burn waste or garden rubbish outdoors during Spring?

10c.) How many days would you burn waste or garden rubbish outdoors during Summer?

10d.) How many days would you burn waste or garden rubbish outdoors during Autumn?

10e.) How many cubic metres of garden waste or other material would be burnt per fire on average?

11) Do you use a wood fired bbq, pizza oven, brazier or outdoor fire for outdoor recreation or cooking purposes.

11a) How many days would you use an oven, brazier or outdoor fire during winter?

11b.) How many days would you use a wood fired bbq, pizza oven, brazier or outdoor fire during Spring?

11c.) How many days would you use a wood fired bbq, pizza oven, brazier or outdoor fire during Summer?

11d.) How many days would you use a wood fired bbq, pizza oven, brazier or outdoor fire during Autumn?

11 e) How many pieces of wood would you use on your bbq, pizza oven, brazier or outdoor fire per burn

APPENDIX B: EMISSION FACTORS FOR DOMESTIC HEATING.

Emission factors were based on the review of New Zealand emission rates carried out by Wilton et al., (2015) for the Ministry for the Environments air quality indicators programme. This review evaluated emission factors used by different agencies in New Zealand and where relevant compared these to overseas emission factors and information. Preference was given to New Zealand based data where available including real life testing of pre 1994 and NESAQ compliant wood burners (Wilton & Smith, 2006; Smith, et. al., 2008) and burners meeting the NESAQ design criteria for wood burners (Bluett et al., 2009; Smith et al., 2009).

The emission factor for the post 2019 burners was derived based on the average of the ULEB emission factor and the NESAQ wood burner emission factors. It is unclear what proportion of the new installations are ULEB as opposed to the 0.6 g/kg wood burners and to what extent, if any, the latter group should be represented by an emission factor lower than the post 2006 wood burners. It is also uncertain to what extent the original emission factor for ULEB, which was based on real life testing of down draught burners, is representative of the broader range of burners that now meet this criterion. It is my view that the ULEB emission factors for the broader group would likely be higher than the original down draught appliances and that an emission factor of around 3 g/kg for PM_{10} for this combination of appliance types may take into account the range of variables and uncertainties identified.

The PM_{10} open fire emission factor was reduced in the review relative to previous factors. Some very limited New Zealand testing was done on open fires during the late 1990s. Two tests gave emissions of around 7.2 and 7.6 g/kg which at the time was a lot lower than the proposed AP42 emission factors (http://www.rumford.com/ap42firepl.pdf) for open fires and the factors used in New Zealand at the time (15 g/kg). An evaluation of emission factors for the 1999 Christchurch emission inventory revised the open fire emission factor down from 15 g/kg to 10 g/kg based on the testing of Stern, Jaasma, Shelton, & Satterfield, (1992) in conjunction with the results observed for New Zealand (as reported in Wilton, 2014). The proposed AP42 emission factors (11.1 g/kg dry) now suggest that the open fire emission factor may be lower still and closer to the result of the limited testing carried out in New Zealand. Consequently a factor of 7.5 g/kg for PM_{10} (wet weight) is proposed to be used for open fires in New Zealand based on the likelihood of the Stern et al., (1992) data being dry weight (indicating a lower emission factor), the data supporting a proposed revised AP 42 factor and the results of the New Zealand testing being around this value. It is proposed that other contaminant emissions for open fires be based on the proposed AP42 emission factors adjusted for wet weight.

The emission factor for wood use on a multi fuel burner was also reduced from 13 g/kg (used in down to the same value as the pre 2004 wood burner emission factor (10 g/kg). The basis for this was that there was no evidence to suggest that multi fuel burners burning wood will produce more emissions than an older wood burner burning wood.

Emission factors for coal use on a multi fuel burner are based on limited data, mostly local testing. Smithson, (2011) combines these data with some further local testing to give a lower emission factor for coal use on multi fuel burners. While these additional data have not been viewed, and it uncertain whether bituminous and subbituminous coals are considered, the value used by Smithson has been selected. The Smithson, (2011) values for coal burning on a multi fuel burner have also been used for PM_{10}, CO and NOx as it is our view that many of the more polluting older coal burner (such as the Juno) will have been replaced over time with more modern coal burners.

No revision to the coal open fire particulate emission factor was proposed as two evaluations (Smithson, (2011) and Wilton 2002) resulted in the same emission factor using different studies. Emissions of sulphur oxides will vary depending on the sulphur content of the fuel, which will vary by location. A value of 8 g/kg is proposed for SOx based on an assumed average sulphur content of 0.5 g/kg and relationships described in AP42 for handfed coal fired boilers (15.5 x sulphur content).

Emission factors for $PM_{2.5}$ are based on 100% of the particulate from wood burning being in the $PM_{2.5}$ size fraction and 88% of the PM_{10} from domestic coal burning. The $PM_{2.5}$ component of PM_{10} is typically expressed as a proportion. The AP42 wood stove and open fire proportion is based on 1998 data and given as 93% of the PM_{10} being $PM_{2.5}$ (http://www.epa.gov/ttnchie1/efdocs/rwc_pm25.pdf). Smithson, (2011) uses a proportion of 97% which is more consistent with current scientific understanding that virtually all the particulate from wood burning in New Zealand is less than 2.5 microns in diameter (Perry Davy, pers comm, 2014). Literature review of the proportion of PM_{10} that was $PM_{2.5}$ returns minimal information for domestic scale wood use. The technical advisory group to the Ministry for the Environment (2014) air quality indicators project on emissions advised their preference for a value of 100% and we have opted for this value for subsequent work because information is indicative of a value nearing 100%. Further investigations into this may be warranted in the future given the focus towards $PM_{2.5}$. A value of 88% from Ehrlich & Kalkoff, (2007) was used for the proportion of PM_{10} in the $PM_{2.5}$ size fraction for small scale coal burning.

An emission factor of 0.5 g/kg was proposed for NOx from wood burners based on the AP42 data because the non-catalytic burner measurements were below the detection limit but the catalytic converter estimates (and conventional burner estimates) weren't. This value is half of the catalytic burner NOx estimate.

A ratio of 14 x PM_{10} values was used for CO emission estimates as per the AP42 emissions table for wood stoves. This is selected without reference to any New Zealand data owing to the latter not being in any publically available form.

APPENDIX C: ASSESSMENT OF UNCERTAINTY

Statistical methods can be used to quantify the uncertainty associated with the emission estimates. Typically, this involves the collating of base uncertainties on variables in the emission calculation (e.g., emission factors or activity data) although EMEP/EEA also give the option of a more sophisticated stochastic simulation (Monte Carlo) analysis.

The uncertainties on variables may have been quantitatively determined (through testing) or based on expert judgement. A 95% confidence interval is used.

Formulae given in the EMEP/EEA guidebook (EEA, 2016) for carrying out a tier one statistical assessment of uncertainty are shown below. These gave the same uncertainty estimates as the equations used previously by the author (e.g., Wilton, 1998) and detailed in Topping, (1971).

Tier one statistical uncertainty from EMEP/EEA guidebook

Calculation of uncertainty when quantities are combined by adding:

$$U_{total} = \frac{\sqrt{(U_1 \times x_1)^2 + (U_2 \times x_2)^2 + \cdots + (U_n \times x_n)^2}}{x_1 + x_1 + \cdots + x_n}$$

Where:

x_i are the quantities.

U_i are the percentage uncertainties associated with the quantities (half the 95% confidence interval). And

U_{total} is the percentage uncertainty in the sum of the quantities (half the 95% confidence interval divided by the total (i.e. mean) and expressed as a percentage).

Calculation of uncertainty when quantities are combined by multiplication

$$U_{total} = \sqrt{U_1^2 + U_2^2 + \cdots + U_n^2}$$

U_i are the percentage uncertainties associated with the quantities (half the 95% confidence interval). and

U_{total} is the percentage uncertainty in the product of the quantities (half the 95% confidence interval divided by the total and expressed as a percentage)

These rules are based on the assumptions that variables are uncorrelated with a standard deviation of less than about 30% of the mean. The guidebook recognises that in practice these assumptions are often not valid, but states that under these circumstances the rules may still be used to obtain an approximate result.

Statistical uncertainty estimates

Where quantitative uncertainty data were not available uncertainty was estimated using the following table from in EEA (2016) as guidance.

Rating	Description	Typical Range
A	An estimate base on a large number of measurements made at a large number of facilities that fully represent this sector.	10-30%
B	An estimate based on a number of measurements made at a large number of facilities that represent a large part of the sector	20-60%

C	An estimate based on a number of measurements made at a small number of representative facilities, or an engineering judgement based on a number of relevant facts.	50-200%
D	An estimate based on single measurement, or an engineering calculation derived from a number of relevant facts.	100-300%
E	An estimate based on an engineering calculation derived from assumptions only.	Order of magnitude

APPENDIX D: EMISSION TEST DATA SMALL SCALE ACTIVITIES

The following tables summaries the test data used by Graham (2006) to derive emission estimates for small scale activities.

Industry type	kg/hr
timber & joinery, good control	0.07, 0.07
timber & joinery, poor control	1.8, 3.6
spray painting	0.14, 0.03
abrasive blasting	0.05, 0.04
metal fabrication, etc	0.04, 0.07, 0.14, 0.01
printing	0.05
packaging	0.36, 0.72
coffee roasting	0.11
coffee drying	1.37
bakeries	0.04
tyre retreads	0.01
sand dryer	1.08
concrete plant	0.11
roofing tiles	0.02
coal-fired boiler	2.16

Facilities with the highest potential for PM emissions:	assigned a rate of 0.1 kg/hr
Heavy engineering/maintenance Joinery factories Panel beaters Light metal fabrication	Metal finishers – powder coating Bakeries Stone/bone/wood grinding or carving
Facilities with lower potential for PM emissions:	assigned a rate of 0.02 kg/hr
Light vehicle workshops Printing works Packaging manufacturers Tanneries (small specialty products)	Paint and other solvents Metal finishers – electroplating Appliance repairs
Facilities with very little potential for PM emissions:	assigned a rate of 0.0 kg/hr
Abattoirs	Photographic developing/printing
Facilities with the potential for 'yard' emissions:	assigned a rate of 0.1 kg/hr
Wreckers Scrap metal dealers	Waste management Timber yards