Timaru Inventory of Total Emissions

June 1998

NIWA CLIENT REPORT NO. AK98082
Project No. CRC60102 and CRC80516

Timaru Inventory of Total Emissions

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prepared for the Canterbury Regional Council

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TIMARU EMISSIONS INVENTORY REPORT – CONTEXT

An emissions inventory is a method of establishing the nature and amount of pollutants discharged to air from a range of sources and the relative contribution from different sources.

The information contained in this report will be integrated with air quality monitoring data and other related investigations to provide the information required for consultation with the Timaru community, industry, the Timaru District Council, and other interested parties on an air quality management plan for Timaru.

The emissions inventory for Timaru follows a similar study for Christchurch and is based primarily on the contaminants discharged to air during the winter months. This is because air quality monitoring indicates that pollution concentrations exceed health guidelines during this period.

The emissions addressed in this report are suspended particulate (referred to as PM_{10}); carbon monoxide; sulphur dioxide; nitrogen oxides; volatile organic carbon; and carbon dioxide. From air quality monitoring results obtained from a centrally located continuous monitoring station (Timaru Main School) the contaminant of primary concern in Timaru is PM_{10} – the same as for Christchurch.

While data is presented in this report on a suburb by suburb basis for the 3 main sources of air pollutants – industry, transport and home heating emissions, a major focus of the study is the emissions for the overall urban area of Timaru.

In the above context the summary of results as presented in section 6 of the report (including table and figure 6.1) could be somewhat skewed by the inclusion of data for the Washdyke industrial area. Because of its separate geographical location and meteorological factors further investigations are expected to indicate that Washdyke should be considered as a separate ‘air shed area’. The result of this for the emissions inventory data presented in this report is a significant reduction in the proportion of emissions in urban Timaru attributed to industrial emissions and a significant increase in the contribution from home heating – from 66% to 88% for PM_{10} and 14% to 48% for sulphur dioxide.

The impact of industrial emissions on air quality in the Washdyke area will be subject to further investigation and possibly separate air quality monitoring in this location as investigations proceed.

Until further investigations are completed this report should be considered as an interim report on air pollution sources in Timaru.

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EXECUTIVE SUMMARY

The reliable assessment of the air polluting loads generated by each source, or a group of similar sources, within a study area is essential for the identification of the nature, magnitude and origin of the existing pollution problem, and for the formulation of rational pollution abatement strategies.

This research, which represents the first stage in the preparation of air quality management scenarios for smaller urban areas of the Canterbury Region, makes up one of the most detailed studies ever undertaken on the emissions to air of the more important air pollutants across Timaru. The results are consistent with expectations and with previous studies on other New Zealand locations but several significant new factors have been identified (such as what causes emissions to vary from area to area and the relative contribution to air pollution of home heating, motor vehicles and industry).

Key Results

Methods of Home Heating:

- Multiple methods of home heating occur within main living area of the same household on a typical winter's day.
- Electricity is used by almost two thirds (63%) of household across the total study area of Timaru to heat the main living area on a typical winter’s day.
- Approximately 940 households use an open fire on a typical winter’s day to heat the main living area. This equates to approximately 10% of the total number of households in the total study area, and nearly 17% of solid fuel burning appliances in use.
- Approximately 4240 households use woodburners to heat the main living area on a typical winter’s day (approximately 43% of the total number of households across Timaru and just over three quarters of solid fuel burning appliances in use).

Wood and Coal Use:

- By weight, the use of wood on a typical winter’s day within the total study area is approximately seven times greater that the use of coal (90 tonnes of wood compared to 12 tonnes of coal).
- Nearly half (42%) of the daily coal consumption is burnt on open fires while 41% is burnt on woodburners. Sixteen percent of the daily coal consumption is burnt on enclosed coal burners and on pot bellies (8% each). Three quarters (77%) of the daily firewood consumption is burnt on woodburners, 18% on open fires, 3% on enclosed coal burners and 2% on pot bellies.

Home Heating Emissions:

- The burning of wood and coal on open fires across the total study area is estimated to produce nearly a third (31%) of the home heating PM_{10} emissions while the burning of wood on woodburners produces half. Only a small proportion (5%) of PM_{10} emissions stem from the burning of wood and coal on enclosed coal burners.
- Open fires are responsible for just over a quarter of home heating CO, NO_x and VOC emissions (27%, 28% and 27% respectively), 40% of SO_x emissions, and 23% of CO_2 emissions. Of those emissions, wood burning on an open fire produces between a fifth and a quarter of CO, VOC and NO_x (23%, 23% and 22% respectively), 1% of SO_x emissions, and 15% of CO_2 emissions. Coal burning on an open fire makes up the difference.
- The burning of wood and coal on woodburners across Timaru produces approximately two thirds of home heating CO, NO_x, VOC and CO_2 emissions (65%, 63% 65% and 70% respectively), and 45% of SO_x emissions. Of those emissions, wood burning on a woodburner produces nearly two-thirds the CO, NO_x, VOC and CO_2 (63%, 59%, 63% and 62% respectively), and only 6% of the SO_x. Coal burning on a woodburner makes up the difference.

- Across the total study area, less that 10% of CO, NO_x, VOC and CO_2 emissions stem from other burners (pot bellies and enclosed coal burners only). In the case of SO_x, 14% of emissions stem from the burning of coal on pot bellies and enclosed coal burners.
- The total study area is estimated to produce approximately 1347 kilograms of PM_{10} per day, 8612 kilograms of CO, 126 kilograms of NO_x, 240 kilograms of SO_x, 2153 kilograms of VOC and 188023 kilograms of CO_2.
- On a grams per hectare basis (g/ha), the total study area is estimated to produce approximately 675 g/ha of PM_{10} per day, 4317 g/ha of CO, 63 g/ha of NO_x, 120 g/ha of SO_x, 1079 g/ha of VOC and 94247 g/ha of CO_2.
- On an individual suburb basis, PM_{10} emissions per hectare in Maori Hill can be as much as eight times larger than those in Washdyke. CO, VOC, CO_2 and NO_x can be as much as seven times larger and SO_x 13 times greater.
- Across the total study area, between 58% and 64% of PM_{10}, CO, NO_x, SO_x, VOC, and CO_2 are emitted between 4pm and 6am on a typical winter's night. The next highest period of emissions occurs between 10am and 4pm across all pollutants (approximately a fifth of each pollutant released during this time).
- Estimated PM_{10}, CO, NO_x, SO_x, VOC, and CO_2 emissions are lowest between the hours of 6am and 10am when around 10% of the total daily emissions are released.

Motor Vehicle Emissions:

- Suburbs with larger vehicle kilometres travelled (VKT) values and more major traffic routes display higher emissions of the six pollutants than suburbs with lower VKTs values.
- Light duty petrol vehicles are the main emitters of CO (88%), VOC (83%), and CO_2 (~70%). Heavy duty diesel vehicles tend to emit larger quantities of PM_{10} (67%) and SO_x (88%). A further fifth (21%) of CO_2 emissions stem from heavy duty diesel vehicles while just over a quarter (26%) of PM_{10} emissions are derived from light duty petrol vehicles. Both light duty petrol vehicles and heavy duty diesel vehicles release approximately half the NO_x (50% and 45% respectively).
- The total study area is estimated to produce approximately 110 kilograms of PM_{10} per day, over 8400 kilograms of CO, approximately 2100 kilograms of NO_x and VOC, 93 kilograms of SO_x, 2071 kilograms of VOC and nearly 235,000 kilograms of CO_2. On a grams per hectare basis (g/ha), the total study area emits approximately 55 g/ha of PM_{10} per day, 4230 g/ha of CO, around 1100 g/ha of NO_x, 47 g/ha of VOC, 1038 g/ha of SO_x, and nearly 118,000 g/ha of CO_2.
- On an individual suburb basis, PM_{10}, SO_x, and CO_2 emissions per hectare in Maori Hill are approximately four times larger than those in Western Residential. Carbon Monoxide can be as much as eight times larger, NO_x three times larger and VOC six times greater.
- On average, approximately 40% of all motor vehicle emissions of PM_{10}, CO, NO_x, SO_x, VOC and CO_2 are released between the hours of 10am and 4pm across the total study area. The next highest period of emissions occurs between 4pm and 10pm, during which just over a third (35%) of contaminants are emitted. A further 17%-19% of pollutants are emitted between 6am and 10am. Less than 10% of all pollutants are emitted overnight (between 10pm and 6am).

Industrial Emissions:

- Part C industrial and commercial premises are the main emitters of CO and NO_x (39% each) and SO_x (41%) while Part B industries emit larger quantities of VOC (78%) and CO_2 (48%). Part A, B and C industries emit relatively equal quantities of PM_{10} (31%, 34% and 34% respectively).
- Part A industries across Timaru emit nearly a fifth of PM_{10} and CO_2, almost a third of CO, NO_x and SO_x, and only 4% of VOC emissions from the combustion of solid fuels. For Part B industries, 8 of the 11 premises (73%) contribute to 15% of PM_{10}, 31% of CO, 32% of NO_x, 29% of SO_x, 16% of VOC and 48% of CO_2 emissions from the combustion of solid fuels. Two thirds of the Part C industries across Timaru (55 in total) emit a quarter (26%) of PM_{10} emissions, 39% of CO and NO_x, 41% of SO_x, 7% of VOC and a third (32%) CO_2 emissions from the combustion of solid fuels.

- The total study area is estimated to produce approximately 585 kilograms of PM_{10} per day, 185 kilograms of CO, 681 kilograms of NO_x, 1321 kilograms of SO_x, 35 kilograms of VOC and 260104 kilograms of CO_2 per day. On a grams per hectare basis (g/ha), the total study area of Timaru produces 293 g/ha of PM_{10}, 93 g/ha of CO, 341 g/ha of NO_x, 662 g/ha of SO_x, 18 g/ha of VOC and 130378 g/ha of CO_2 per day.
- On an individual suburb basis, industrial emissions vary considerably from suburb to suburb. The suburb of Washdyke consistently recorded the highest emissions of all six pollutants under study whereas Maori Hill consistently recorded the lowest. When comparing these two suburbs, PM_{10} emissions per hectare within Washdyke are approximately 1700 times larger than those estimated for the Maori Hill. Carbon monoxide can be as much as 560 times larger, NO_x over 2000 times larger, SO_x nearly 4000 times greater, VOC approximately 100 times larger and CO_2 around 800000 times larger.
- The number and type of industries within a study area largely determine pollutant emissions. Suburb areas with few or no industries tend to exhibit lower pollutant emissions per day whereas suburbs with a larger number of industries displayed higher pollutant emissions.
- Across the total study area, ~35% of CO, NO_x, SO_x and CO_2, and ~40% of PM_{10} and VOC are released between the hours of 10am and 4pm on a typical winter's day. A further 30% of CO, NO_x, SO_x, VOC and CO_2 are emitted between 4pm and 10pm. Just over a quarter (26%) of PM_{10} are also released during this time period. A further quarter (24%) of PM_{10} and VOC, and 22% of CO, NO_x, SO_x, and CO_2 are released between 6am and 10am. All pollutants displayed a low period of emissions between the hours of 10pm and 6am.
- On an individual suburb basis, PM_{10}, CO, NO_x, SO_x, VOC and CO_2 emissions tended to peak between the hours of 10am and 4pm in all suburbs except the Industrial area.
- Five of the eight suburbs (Highfield Residential, Northern Residential, Southern Residential, Westend and Inner City and Western Residential) recorded the next highest peak in PM_{10}, CO, NO_x, SO_x, VOC and CO_2 emissions between the hours of 6am and 10am. For Maori Hill and Washdyke, the secondary peak in all pollutant emissions tended to be between 4pm and 10pm. PM_{10} emissions in Maori Hill however, recorded the secondary peak between 6am and 10am.
- The industrial area recorded the highest PM_{10} and CO emissions between 10am and 4pm but for NO_x, SO_x, VOC and CO_2, emissions peaked between the hours of 10pm and 6am. The secondary peak for PM_{10} and CO emissions occurred between the hours of 6am and 10am while for the other pollutants the secondary peak was recorded between the hours of 10am and 10pm.
- Low PM_{10} and CO emissions were displayed between 10pm and 6am in all eight suburbs. The remaining pollutants also recorded their lowest emissions between 10pm and 6am in all suburbs except the Industrial area. Within the Industrial area, the lowest period of NO_x, SO_x, VOC and CO_2 emissions tended to occur between the hours of 6am and 10am.

Combined Emissions:

- Across the total study area of Timaru, two thirds of PM_{10} emissions, half of CO and VOC, and just over a quarter (27%) of CO_2 emissions to the air on a typical winter's day result from domestic solid fuel heating. Approximately 73% of NO_x, 49% of CO and VOC, and just over a third (35%) of CO_2 emissions are derived from motor vehicles. Nearly all SO_x emissions (80%), 38% of CO_2, 29% of PM_{10} and 23% of NO_x are derived from industrial sources.
- In three-quarters of the suburbs, more PM_{10} emissions to the air on a typical winter's day result from domestic solid fuel heating than from motor vehicles or industry. Motor vehicles emit more NO_x and CO_2 than home heating or industry in 88% and 63% of the suburbs respectively. Highfield, Northern, Southern and Western Residential areas emit more CO and VOC from home heating than from motor vehicles or industry. In the Industrial area, Maori Hill, Washdyke and Westend and Inner City, more CO and VOC's are emitted from motor vehicles than from home heating or industry. Half of the suburbs (Highfield, Northern and Southern Residential areas, and Maori Hill) emit more SO_x from home heating, just over a third (38%) of the suburbs emit more

SO_x from industry (the Industrial area, Washdyke and Westend and Inner City) while Western Residential emits more SO_x from motor vehicles.

- Combined home heating, motor vehicle and industrial PM_{10}, CO, SO_x, VOC and CO_2 emissions peak between the hours of 4pm-10pm (which also coincides with the onset of temperature inversion conditions). Combined NO_x emissions peak between 10am and 4pm (which coincides with high VKTs). Combined PM_{10}, CO, NO_x, SO_x, VOC and CO_2 emissions are at their lowest between 10pm-6am (which also coincides with lower VKTs and reduced industry operation).
- Across the individual suburbs, combined motor vehicle, solid fuel heating and industrial emissions of PM_{10}, CO, VOC and CO_2 peak between the hours of 4pm-10pm in all suburbs except Industrial and Washdyke (Appendix III). Combined NO_x and SO_x emissions from Highfield, Northern, Southern and Western Residential areas, and in Westend and Inner City and Maori Hill, peak between 10am and 10pm. Within the Industrial area and Washdyke, combined emissions peak between 10am and 4pm. The only exception to this is combined CO and VOC emissions in Washdyke (which peak between 4pm and 10pm). Combined emissions of all six pollutants tended to be lowest between the hours of 10pm and 6am across all suburbs except for PM_{10} and CO emissions in Western Residential, and SOx emissions in Industrial (which displayed the low between 6am and 10am).

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1. INTRODUCTION

1.1 Purpose Of Study

The main objective of this emissions inventory is to provide information on various emission sources across the main urban and industrial areas of Timaru. This information will then be used to develop management strategies to reduce present ambient contaminant concentrations, and provide for longer-term management of air contaminants within acceptable levels.

The monitoring of meteorological variables and air pollutants in Timaru began in January 1997. Results to date indicate that temperature inversions tend to form over Timaru on clear calm frosty winter evenings, thus trapping air and pollutants underneath. Under these condition, Christchurch usually experiences pollution concentrations well above the 24-hour Canterbury Regional Council (CRC) monitoring and reporting air quality guideline of 50 micrograms per cubic metre ($\mu g/m^3$).

Based on the similarity in temperature inversion conditions between Christchurch and Timaru, and on measured Christchurch pollutant concentrations under inversion conditions, it is expected that Timaru also experiences periods of high air pollution concentrations over the winter months (from May-August) between the hours of 4pm and midnight. Monthly maximum 24-hour concentrations of fine particulate matter less than 10 microns in diameter (PM_{10}) and average hourly concentrations of sulphur dioxide (SO_2), carbon monoxide (CO) and PM_{10} for high pollution days in Timaru over 1997, certainly display this pattern (Figure 1.1 and Figure 1.2).

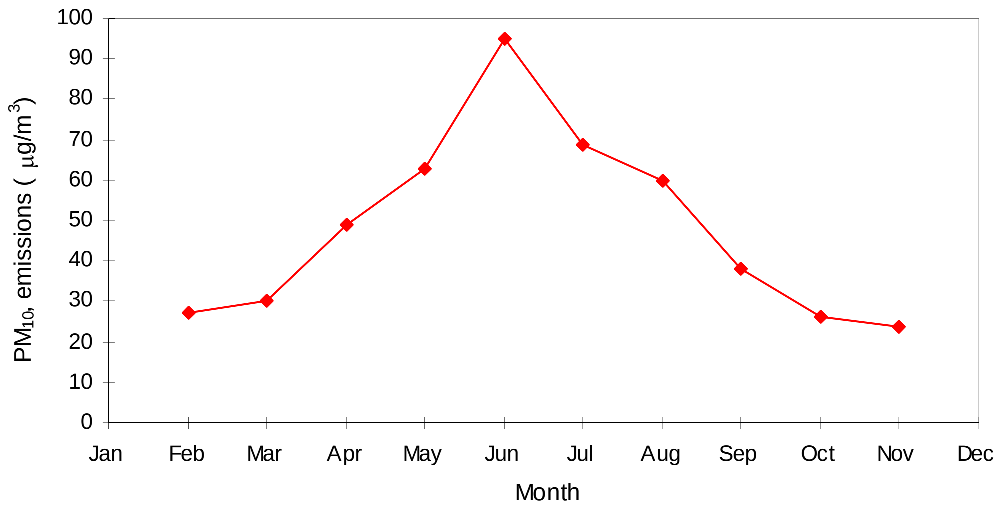


Figure 1.1 Monthly maximum 24 hour concentrations of PM_{10} in 1997, Timaru.

The contaminants of immediate concern are PM_{10} and CO. Under "worst case" conditions in 1997, the maximum 24-hour PM_{10} concentration recorded in Timaru was 95 $\mu g/m^3$. Furthermore, the 24-hour CRC monitoring and reporting air quality guideline of 50 $\mu g/m^3$ was exceeded on 22 occasions. However, other contaminants that may require addressing are nitrogen oxides (NO_x), sulphur oxides (SO_x), carbon dioxide (CO_2) and volatile organic compounds (VOCs).

Previous research conducted in Christchurch (Brady and Pullen 1985, CRC 1997), identify domestic fires and motor vehicles as significant sources of PM_{10}, CO, NO_x, SO_x, VOC and CO_2 emissions during the times of temperature inversion conditions (evening and overnight). This is also expected to be the case for Timaru. However, from the air quality management perspective more detailed information is required on the relative contribution from various sources at different periods of the day, including times of likely temperature inversion.

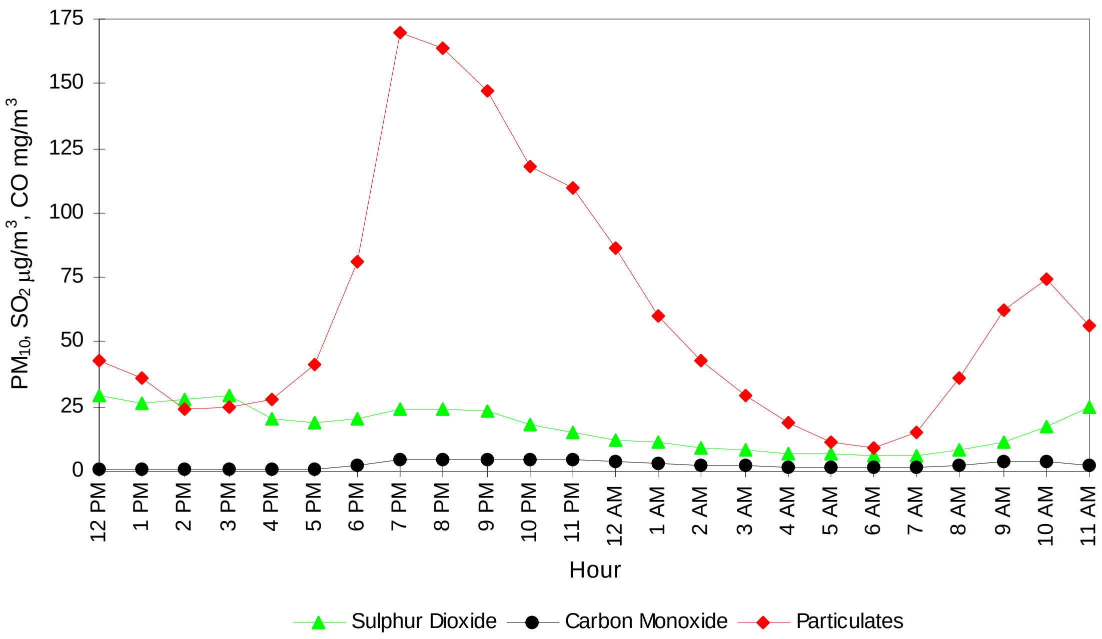


Figure 1.2 Average hourly concentrations of SO_2, CO and PM_{10} for high pollution days in 1997, Timaru.

To assess the impact of potential management options on various methods of domestic heating, information is also required on the use of wood, coal, oil, gas and electricity, and any variations in the use of these energy sources in different areas of Timaru.

To gather all the necessary information, this study has been designed to examine:

- Variations in different methods of home heating and in fuel use for different areas of Timaru.
- Typical winter's day emissions resulting from the burning of wood and coal on the various solid fuel-burning appliances in use for domestic heating.
- Typical winter's day exhaust emissions from motor vehicles for different classes of diesel and petrol-fuelled vehicles.
- Typical winter's day emissions from different industry types.
- Variations in emissions from home heating on a suburb-by-suburb basis for subsequent integration with emissions from motor vehicles and industrial processes.
- Variations in exhaust emissions from motor vehicles on a suburb-by-suburb basis for subsequent integration with emissions from home heating and industrial processes.
- Variations in industrial emissions on a suburb-by-suburb basis for subsequent integration with emissions from home heating and motor vehicles.
- Variations in home heating (solid fuel burning) emissions, motor vehicle emissions and industrial for different time periods during the day.

This information will then be used to:

- Compare estimated pollutant emissions to actual monitored pollutant levels.
- Identify the relative contribution of the emissions from various sources.
- Examine the possible effect of various management scenarios to reduce pollutant emissions.
- Aid in the maintenance of future air quality at an acceptable level.
- Establish the boundaries of the area within which reductions in emissions are required to achieve the purposes of the Resource Management Act 1991 (RMA).

1.2 What Suburb Areas Were Studied?

In July 1996, over 500 households across Timaru were surveyed about their home space heating habits. In order to assess the relative contributions of motor vehicles and industry to home heating, information on traffic density and industry operation were required. VKT (vehicle kilometres travelled) data were obtained for eight suburb areas of Timaru from CRC - Transport. Timaru industry information was gathered from CRC resource consent records. From all of this information, fine particulate matter less than 10 micrograms in diameter (PM_{10}), carbon monoxide (CO), nitrogen oxide (NO_x), sulphur oxide (SO_x) volatile organic compounds (VOC) and carbon dioxide (CO_2) emissions to the air from home heating appliances, motor vehicles and industry were estimated for a typical winter's day.

Home space heating surveys were conducted in Washdyke, Northern Residential, Maori Hill, Westend and Inner City, Highfield Residential and Southern Residential. As there were no households in the industrial suburb, no surveys were conducted within the study area.

The various study areas are shown in Figure 1.3, and their sampling details presented in Table 1.1. Suburb boundaries are identified on a 1991 census map contained in Appendix I. The home heating survey questionnaire can be found in Appendix II.

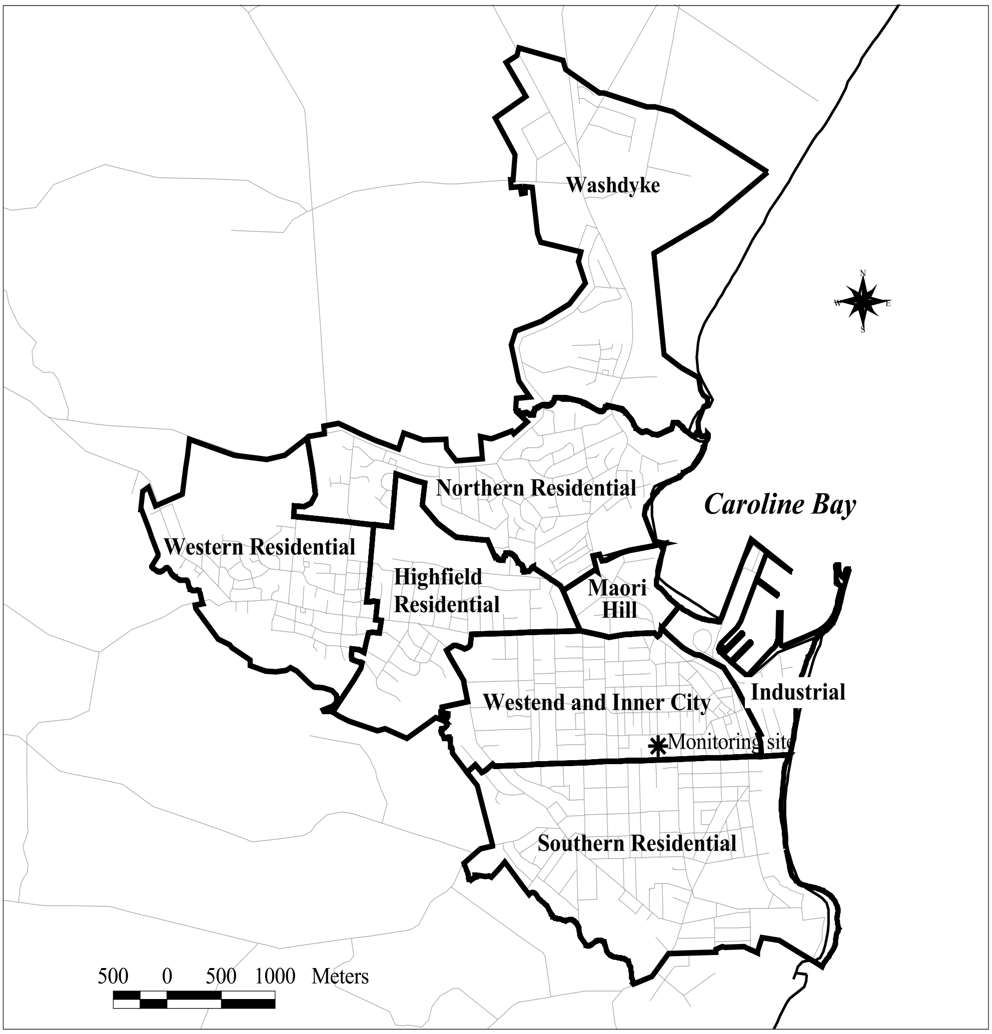


Figure 1.3 Map showing the location of the various study areas across Timaru.

Table 1.1 Sampling details of the various study areas across Timaru.

Suburb Area	Area (ha)	Total Number of Households	Housing Density (houses/ha)	Total Households Surveyed	Household Survey Method	Average Daily VKT (km)	Number of Industries
Highfield Residential	228	1290	5.7	72	phone	55242	4
Industrial	79	0	0.0	0	-	14502	8
Maori Hill	56	462	8.3	72	phone	42918	1
Northern Residential	321	1845	5.7	72	phone	86597	10
Southern Residential	447	2256	5.0	72	phone	88345	18
Washdyke	287	324	1.1	72	phone	94785	23
Westend and Inner City	282	2316	8.2	72	phone	147732	37
Western Residential	295	1296	4.4	72	phone	59386	1
Total	1995	9732	5.1	504	phone	589507	102

NB: % Sampled = (Sampled No.of Households ÷ Total No.of Households) x 100%

Information was collected on a suburb-by-suburb basis so that variations in emission sources and methods of home heating could be identified. Results were also grouped into an additional area (the total study area). This larger study area has been included to provide a more representative basis for the comparison of emissions and monitored air quality than that available on an individual suburb basis.

The body of this report consists of six main sections. The first section (Section 2) examines various methods of domestic space heating used in households across Timaru. The results of home heating, motor vehicle, and industrial emissions for a typical winter's day, and for various times of the day, are addressed in Sections 3, 4 and 5 respectively.

Within Section 6, home heating, motor vehicle and industrial emissions are combined and results presented for a typical winter's day and for various times of the day. Finally, key results are outlined in Section 7.

2. HOME HEATING METHODS

2.1 Appliance Use

Breakdowns of home heating methods used by households across the various study areas of Timaru are provided in Table 2.1 over. The industrial area does not have any households within the suburb boundaries and hence no home heating methods. For this reason, the industrial area will not be discussed in this section.

These figures (Table 2.1) do not include households which, at the time of the survey may have used solid fuel burning appliances 'occasionally' or which used solid fuel burning appliances to heat other areas of the dwelling. (Multiple methods of home heating, and the time of day of appliance use, are taken into account in calculating emissions.)

Survey results indicate that multiple methods of home heating occur within main living area of the same household on a typical winter's day. This occurs both for the use of gas and electricity (some heater models are combined gas/electricity) and for the use of solid fuel burning appliances together with gas or electricity, and also with other solid fuel burning appliances. Therefore, while many households use non or low polluting methods of home heating, such as electricity or gas, many of the households also use an open fire, woodburner, or other solid fuel burning appliance in the main living area.

The suburbs with the greatest percentage of households using solid fuel burning appliances are Washdyke (68%) and Highfield Residential (67%), followed by Maori Hill (57%) and Westend and Inner City (56%) (Table 2.1). The suburbs of Western, Northern and Southern Residential recorded the lowest percentage of households using solid fuel burning appliances (51%, 53% and 54% respectively).

Across the total study area approximately 940 households use an open fire on a typical winter's day to heat the main living area. This equates to approximately 10% of the total number of households in the total study area, and 17% of solid fuel burning appliances in use (Table 2.1).

The suburbs with the greatest percentage of households using open fires on a typical winter's day to heat the main living area are Southern Residential and Maori Hill (13% and 15% respectively), followed by Highfield Residential and Northern Residential (10%). Less than 10% of households in Westend and Inner City (8%), Washdyke (7%) and Western Residential (6%) use an open fire.

Across the total study area approximately 4200 households use woodburners to heat the main living area on a typical winter's day (43% of the total number of households in the total study area and 77% of solid fuel burning appliances in use) (Table 2.1 and Table 2.2). Just over half of these appliances (53%) were installed before 1988. Nineteen percent of appliances were installed between 1989-1992 while 27% have been installed since 1993 (Table 2.3 and Figure 2.1).

The number of woodburners installed prior to 1989, from 1989-1992 and after 1993 varies from suburb to suburb. In the suburb of Northern Residential for example, 308 of the 718 households (43%) had their woodburners installed prior to 1989 whereas in Maori Hill 122 of the 186 households (66%) had woodburners installed before 1989 (Table 2.3). In all suburbs, except Northern Residential, between a half and two thirds of woodburners were installed before 1988 while the remaining third to a half were installed after 1988. In Northern Residential, nearly a fifth (18%) of woodburners were installed between 1989 and 1992 (incl) while a further fifth (21%) were installed after 1993.

In addition to open fires and woodburners, there are 181 households across the total study area using enclosed coal burners to heat the main living area on a typical winter's day and 126 households using pot bellies. This equates to 2% and 1% of the total number of households in the total study area respectively, and to 3.3% and 2.3% of solid fuel burning appliances in use respectively (Table 2.1). Results indicate that no households in Timaru use incinerators to heat their main living area on a typical winter's day.

Table 2.1 Methods of home heating across various study areas of Timaru.

Suburb Area	Total Number of Households	Electricity		Gas (LPG)		Oil fire		Open fire/Visor		Woodburner		Enclosed Coal Burner		Pot Belly		Incinerator	
		Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Highfield Residential	1290	950	74	197	15	18	1	125	10	717	56	18	1	0	0	0	0
Industrial	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maori Hill	462	411	89	51	11	6	1	71	15	186	40	6	1	0	0	0	0
Northern Residential	1845	1025	56	538	29	77	4	179	10	718	39	0	0	77	4	0	0
Southern Residential	2256	1253	56	658	29	0	0	282	13	752	33	157	7	31	1	0	0
Washdyke	324	149	46	45	14	0	0	23	7	198	61	0	0	0	0	0	0
Westend and Inner City	2316	1480	64	643	28	97	4	193	8	1094	47	0	0	0	0	0	0
Western Residential	1296	918	71	180	14	54	4	72	6	576	44	0	0	18	1	0	0
Total	9789	6185	63	2313	24	252	3	945	10	4240	43	181	2	126	1	0	0

<u>**NB**</u> The number of households with solid fuel burning appliances can be found in Table 2.2. It is not appropriate to add the heating method totals in this table as multiple methods of home heating can be used within the same household.

Table 2.2 Number and percentage of households using electricity or gas, solid fuel burners (open fires/visors, woodburners, enclosed coal burners, pot bellies, incinerators), and oil burners across various study areas of Timaru.

Suburb Area	Total Number of Households	Electricity or Gas		Solid Fuel Burners		Oil Burners	
		Number	%	Number	%	Number	%
Highfield Residential	1290	1057	82	860	67	18	1
Industrial	0	0	0	0	0	0	0
Maori Hill	462	417	90	263	57	6	1
Northern Residential	1845	1307	71	974	53	77	4
Southern Residential	2256	1723	76	1222	54	0	0
Washdyke	324	171	53	221	68	0	0
Westend and Inner City	2316	1737	75	1287	56	97	4
Western Residential	1296	990	76	666	51	54	4
Total	9789	7402	76	5492	56	252	3

Table 2.3 Differences in age of woodburners by suburb.

Suburb Area	Total Number of Households using a Woodburner	Pre 1989 Woodburner Households		1989-1992 Woodburner (incl) Households		Post 1993 Woodburner Households	
		Number	%	Number	%	Number	%
Highfield Residential	717	376	53	179	25	161	23
Industrial	0	0	0	0	0	0	0
Maori Hill	186	122	66	26	14	39	21
Northern Residential	718	308	43	128	18	282	39
Southern Residential	752	439	58	157	21	157	21
Washdyke	198	108	55	32	16	59	30
Westend and Inner City	1094	547	50	225	21	322	29
Western Residential	576	360	63	72	13	144	25
Total	4240	2259	53	818	19	1162	27

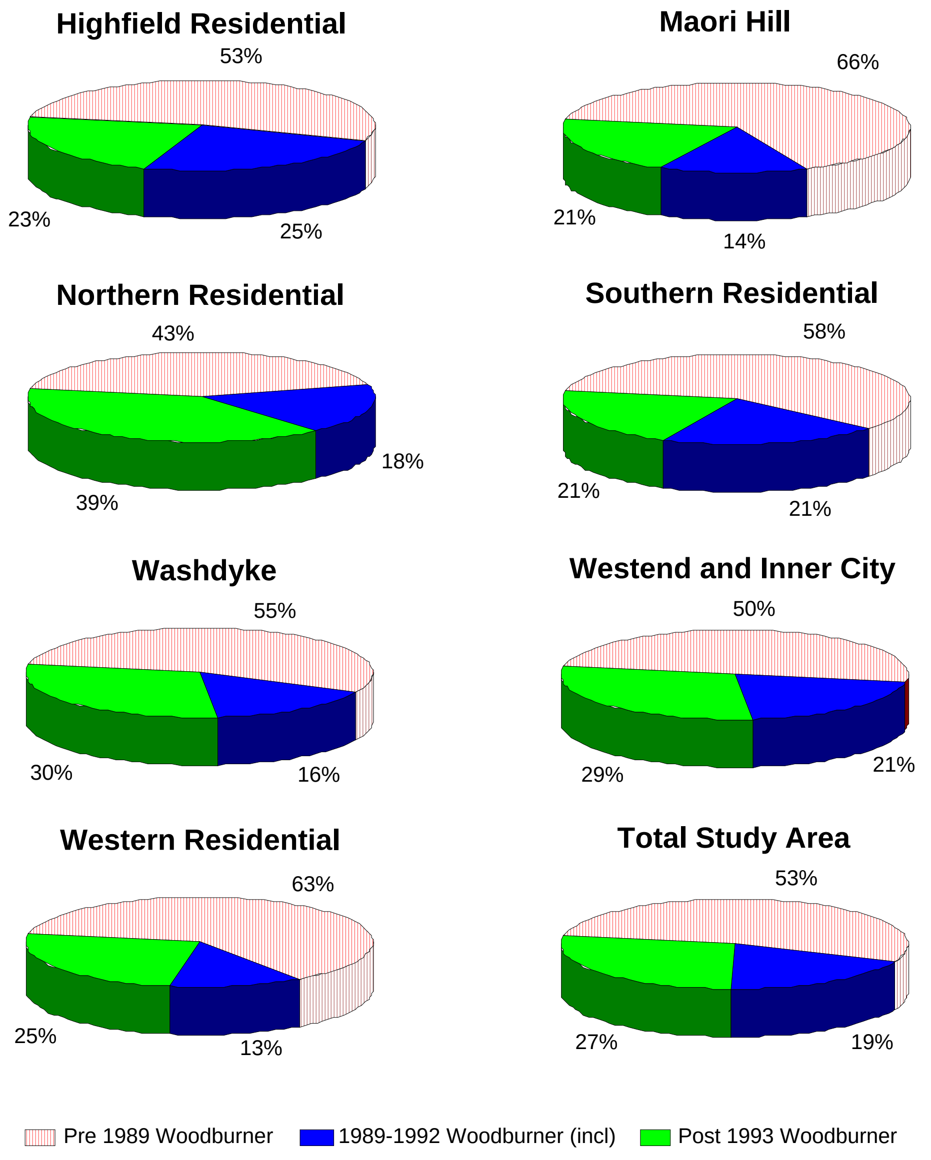


Figure 2.1 Woodburner age breakdown for the various study areas of Timaru.

It is difficult to prove if the variation in solid fuel burning appliance use is linked to the average dwelling age.

2.2 Wood And Coal Consumption

Wood and coal consumption for the total study area of Timaru, and their use on different types of solid fuel burning appliances, are contained in Table 2.4 below. By weight, the use of wood on a typical winter's day within the total study area is approximately seven times greater that the use of coal (90 tonnes of wood compared to 12 tonnes of coal) (Table 2.4).

Table 2.4 Wood and coal consumption by appliance type for the total study area of Timaru.

Appliance & Fuel	Daily Fuel Quantity Total Study Area Kg/day	t/day	% of Fuel Use
Open fire			
- Wood	16486	16.5	18
- Coal	5234	5.2	42
Pre 1989 Woodburner			
- Wood	37789	37.8	42
- Coal	3068	3.1	25
1989-1992 (incl) Woodburner			
- Wood	12393	12.4	14
- Coal	1274	1.3	10
Post 1992 Woodburner			
- Wood	18772	18.8	21
- Coal	772	0.8	6
Enclosed Coal Burner			
- Wood	3109	3.1	3
- Coal	999	1.0	8
Pot Belly			
- Wood	1761	1.8	2
- Coal	973	1.0	8
Incinerator			
- Wood	0	0.0	0
- Coal	0	0.0	0
Total Wood	90309	90.3	88
Total Coal	12320	12.3	12
Total Gas	1716	1.7	
Total Oil	533	0.5	
Total (Wood and Coal only)	102630	102.6	

Nearly half (42%) of the daily coal consumption within the total study area is burnt on open fires while 41% is burnt on woodburners. Sixteen percent of the daily coal consumption is burnt on enclosed coal burners and on pot bellies (8% on each). Approximately three quarters (77%) of the daily firewood consumption is burnt on woodburners, 18% on open fires, 3% on enclosed coal burners and 2% on pot bellies (Table 2.4 and Figure 2.2). Survey results indicate that coal and wood are not burnt on incinerators.

On an individual suburb basis (Table 2.5 and Table 2.6), fuel and appliance use can vary considerably from suburb to suburb. Of the households in Southern Residential with solid fuel burning appliances, approximately half burn coal. Almost a third (29%) of households in Northern Residential, a quarter (24%) in Maori Hill, 15% in Highfield Residential, 14% in Washdyke, 13% in Westend and Inner City and 5% in Western Residential burn coal on their solid fuel burning appliances. Likewise, the appliance on which coal is burnt on can also vary. Coal consumption on open fires/visors ranges from 0% to 60% across the suburbs, 40% to 71% on woodburners, 0% to 15% on enclosed coal burners and 0% to 50% and pot bellies. Coal is not burn on incinerators.

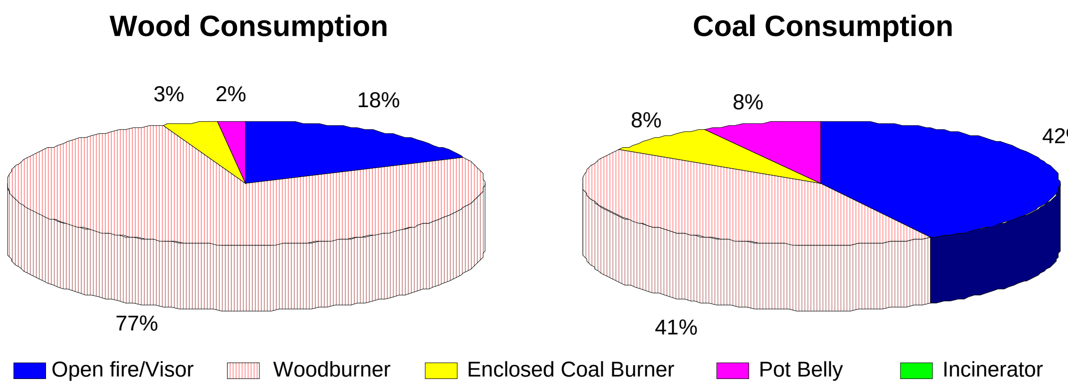


Figure 2.2 Wood and coal consumption across the total study area of Timaru.

Nearly all households across Timaru that have and use a solid fuel burning appliance burn wood (95% - 100%) (Table 2.6). Wood consumption on open fire/visor ranges from 10% of households to 23%, 62% to 90% on woodburners, 0% to 13% on enclosed coal burners, and 0% to 5% on pot bellies. Wood is not burnt on incinerators.

The CRC may authorise or prohibit the use of any class of fuel and any class of fuel burning equipment within Clean Air Zones. Outside these zones, there are no restrictions on the type of heating appliance used and the type of fuel consumed. Within Timaru no Clean Air Zones exist. Survey results suggest that coal is burnt on appliances specifically designed for the burning of wood only. Approximately 40% of the daily coal consumption across the total study area occurred on woodburners. It is assumed that some of these appliances were designed to burn both wood and coal but not all.

Table 2.5 Coal use on various appliances (in the main living area) across various study areas of Timaru.

Suburb Area	Number of Households using Solid Fuel Burning Appliances	Coal Use		Open fire/visor		Woodburner		Enclosed Coal Burner		Pot belly		Incinerator	
		Households		Households		Households		Households		Households		Households	
		Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Highfield Residential	860	125	15	36	29	72	57	18	14	0	0	0	0
Industrial	0	0	0	0	0	0	0	0	0	0	0	0	0
Maori Hill	263	64	24	39	60	32	50	0	0	0	0	0	0
Northern Residential	974	282	29	128	45	128	45	0	0	26	9	0	0
Southern Residential	1222	627	51	251	40	251	40	94	15	31	5	0	0
Washdyke	221	32	14	9	29	23	71	0	0	0	0	0	0
Westend and Inner City	1287	161	13	64	40	97	60	0	0	0	0	0	0
Western Residential	666	36	5	0	0	18	50	0	0	18	50	0	0
Total	5492	1326	24	526	40	620	47	112	8	75	6	0	0

Table 2.6 Wood use on various appliances (in the main living area) across various study areas of Timaru.

Suburb Area	Total Number of Solid Fuel Burning Appliances	Wood Use		Open fire/visor		Woodburner		Enclosed Coal Burner		Pot belly		Incinerator	
		Households		Households		Households		Households		Households		Households	
		Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Highfield Residential	860	860	100	125	15	717	83	18	2	0	0	0	0
Industrial	0	0	0	0	0	0	0	0	0	0	0	0	0
Maori Hill	263	250	95	58	23	186	71	6	3	0	0	0	0
Northern Residential	974	948	97	179	19	718	74	0	0	51	5	0	0
Southern Residential	1222	1222	100	282	23	752	62	157	13	31	3	0	0
Washdyke	221	221	100	23	10	198	90	0	0	0	0	0	0
Westend and Inner City	1287	1287	100	193	15	1094	85	0	0	0	0	0	0
Western Residential	666	648	97	72	11	576	86	0	0	18	3	0	0
Total	5492	5436	99	932	17	4240	77	181	3	101	2	0	0

3. HOME HEATING EMISSIONS

3.1 Home Heating Emission Factors, Calculation Techniques And Assumptions

The home heating emission factors used in this inventory (Table 3.1 and Table 3.2) were developed from a literature survey (United States Environmental Protection Agency (USEPA) 1994, Economopoulos 1993, Brady & Pullen 1985, and Todd 1994) and are assumed to represent typical emissions from solid fuel burning appliances under normal operating conditions. Further separation of woodburner appliances into three age categories (which correspond to the implementation of different solid fuel emissions standards) was conducted initially for the Christchurch Inventory of Total Emissions (CRC 1997). Telephone contact with woodburner appliance retailers in Timaru revealed that appliances which meet solid fuel appliance emissions criteria in Christchurch were primarily sold in Timaru. Because no formal standards or Clean Air Zones exist in Timaru yet the appliances being sold meet Christchurch's emissions criteria, it was also assumed that the same age separation could be applied thus producing more detailed results for Timaru.

The factors in Table 3.1 below outline the differing pollutant emissions for various fuel sources. For example, when comparing the emissions from one kilogram of gas to those from one kilogram of wood, wood produces 100 times the quantity of PM_{10} and VOC, 200 times the amount of CO, 20 times the amount of SO_x, just over half the amount of NO_x (55%) and about two thirds the amount of CO_2 (68%).

Compared to burning one kilogram of wood, burning one kilogram of coal produces over two times the emissions of PM_{10}, nearly twice the emissions of CO_2, is responsible for almost all of the SO_x emissions (90%) and emits only half the VOCs and CO. Yet to produce the same degree of heat from a given quantity of wood only about half the amount of coal is required (e.g. wood releases approximately 10 MJ/kg whereas sub-bitumnal coal releases approximately 20 MJ/kg).

Table 3.1 The fuel factors used to calculate home heating emissions.

Fuel Factor	PM_{10}	CO	NO_x	SO_x	VOC	CO_2
gas (g/kg)	0.1	0.4	2.0	0.01	0.2	2500
oil (g/l)	1.3	0.6	2.2	3.8	0.25	3200
wood (g/kg)	10.0	80.0	1.1	0.2	20.0	1700
coal (g/kg)	22.0	40.0	1.0	18.0	10.0	2800

Table 3.1 however, does not take into account the age and type of appliance on which various solid fuels are being burnt. To compensate for differing appliances (i.e. a typical coal-burning appliance, which is more polluting, compared to a typical woodburner) and incorrect operation, the emissions produced by various fuels need to be multiplied by an 'appliance factor' (Table 3.2).

Table 3.2 The appliance factors used to calculate home heating emissions.

Appliance Factor	PM_{10}	CO	NO_x	SO_x	VOC	CO_2
open fire	1.50	1.50	1.50	1.00	1.50	1.00
woodburner pre 89	1.28	1.28	1.28	1.00	1.28	1.00
woodburner 90-92 (incl)	0.69	0.69	0.69	1.00	0.69	1.00
woodburner 93+	0.59	0.59	0.59	1.00	0.59	1.00
enclosed coal burner	1.43	1.43	1.43	1.00	1.43	1.00
pot belly	1.43	1.43	1.43	1.00	1.43	1.00
incinerator	1.56	1.56	1.56	1.00	1.56	1.00

Generally, typical open fires, incinerators, pot bellies, and enclosed coal burners produce approximately 1.2 times the emissions of PM_{10}, CO, NO_x and VOCs of a pre 1989 woodburner for a given fuel. This value is even greater when compared to later model woodburners (approximately 2.5 times compared to a post-1993 woodburner.

With the exception of CO_2, the emissions from the burning of gas and oil are relatively minor and are not subject to 'appliance' factors.

The following assumptions have been made:

1. typical coal is 1.0 wt% sulphur
2. daily winter fuel consumption in solid fuel appliances e.g. woodburners etc. = a typical winter's night fuel consumption
3. daily winter fuel consumption for natural gas and fuel oil = total weekly fuel consumption / 7 days
4. a "log" of wood = 1.6kg
5. a "bucket" of coal = 10kg

Overall, home heating emissions were calculated for a typical winter's day and aggregated to a total using the following equation:

$$\textit{Home Heating Emissions (g)} = \textit{Fuel Factor} * \textit{Appliance Factor} * \textit{Daily Fuel Use}$$

So, to determine the total PM_{10} emissions from the burning of 20kg of wood on an open fire the calculation would look like:

$$PM_{10}\,\textit{Emissions (g)} = 10.0\ g/kg * 1.5 * 20\ kg.$$

The aggregated total home heating emissions for each pollutant were then divided by the number of hectares within each suburb (1 hectare = 10000m^2). This gave a "normalised" weight per area value (e.g. grams per hectare) and allowed fair comparison of home heating emissions with emissions from other sources.

3.2 Home Heating Emissions On A Typical Winter's Day By Fuel Use And Appliance Type

The main contaminant emissions from the burning of solid fuels on different types of appliances within the total study area of Timaru are outlined in Table 3.4.

As previously mentioned, the contaminant of main concern in Timaru is PM_{10}. Across the total study area of Timaru, the burning of wood and coal on open fires is estimated to produce nearly a third (31%) of the home heating PM_{10} emissions (18% from wood, 13% from coal) while the burning of wood on woodburners produces half (Table 3.3 and Figure 3.1). Of the latter, PM_{10} emissions from pre 1989 woodburners are 2.5 times those of the later models combined. Only a small proportion (5%) of PM_{10} emissions stem from the burning of wood and coal on enclosed coal burners (3% from wood, 2% from coal) while an even smaller amount (4%) stems from pot bellies (2% each from wood and coal).

Table 3.3 Percentage of PM_{10} emissions from the burning of wood and coal on various appliances within the total study area.

Fuel and Appliance	Total Study Area
Open fire	
- Wood	18
- Coal	13
Pre 1989 Woodburner	
- Wood	36
- Coal	6
1989-1992 (incl) Woodburner	
- Wood	6
- Coal	1
Post 1993 Woodburner	
- Wood	8
- Coal	1
Enclosed Coal Burner	
- Wood	3
- Coal	2
Pot Belly	
- Wood	2
- Coal	2
Incinerator	
- Wood	0
- Coal	0

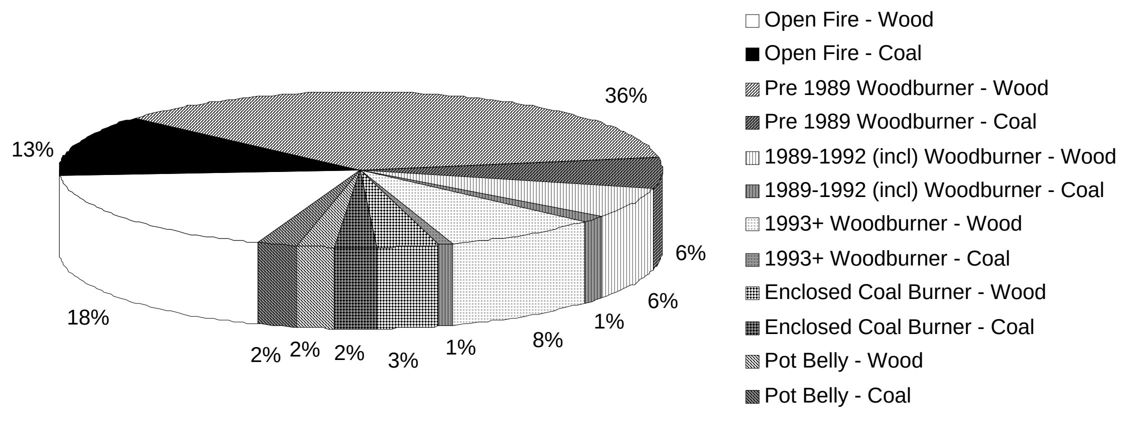


Figure 3.1 Percentage of PM_{10} emissions from the burning of wood and coal on various appliances within the total study area of Timaru.

Table 3.4 Estimated pollutant emissions from various fuels and appliances across the total study area.

	Daily Fuel Quantity			PM_{10}			CO			NO_x			SO_x			VOC			CO_2		
	kg/day	t/day	Use (%)	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Open fire																					
- Wood	16486	16.5	18	247	124	18	1978	992	23	27	14	22	3	2	1	495	248	23	28026	14048	15
- Coal	5234	5.2	42	173	87	13	314	157	4	8	4	6	94	47	39	79	39	4	14656	7346	8
Pre 1989 Woodburner																					
- Wood	37789	37.8	42	484	242	36	3870	1940	45	53	27	42	8	4	3	967	485	45	64242	32201	34
- Coal	3068	3.1	25	86	43	6	157	79	2	4	2	3	55	28	23	39	20	2	8590	4306	5
1989-1992 (incl) Woodburner																					
- Wood	12393	12.4	14	86	43	6	684	343	8	9	5	7	2	1	1	171	86	8	21067	10560	11
- Coal	1274	1.3	10	19	10	1	35	18	0	1	0	1	23	11	10	9	4	0	3568	1788	2
Post 1993 Woodburner																					
- Wood	18772	18.8	21	111	56	8	886	444	10	12	6	10	4	2	2	222	111	10	31912	15996	17
- Coal	772	0.8	6	10	5	1	18	9	0	0	0	0	14	7	6	5	2	0	2161	1083	1
Enclosed Coal Burner																					
- Wood	3109	3.1	3	44	22	3	356	178	4	5	2	4	1	0	0	89	45	4	5285	2649	3
- Coal	999	1.0	8	31	16	2	57	29	1	1	1	1	18	9	7	14	7	1	2798	1402	1
Pot Belly																					
- Wood	1761	1.8	2	25	13	2	202	101	2	3	1	2	0	0	0	50	25	2	2994	1501	2
- Coal	973	1.0	8	31	15	2	56	28	1	1	1	1	18	9	7	14	7	1	2724	1365	1
Incinerator																					
- Wood	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
- Coal	0	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Wood	90309	90.3	88	997	500	74	7975	3998	93	110	55	87	18	9	8	1994	999	93	153526	76955	82
Total Coal	12320	12.3	12	351	176	26	637	319	7	16	8	13	222	111	92	159	80	7	34497	17292	18
Total Gas	1716	1.7		0	0		1	0		3	2		0	0		0	0		4291	2151	
Total Oil	533	0.5		1	0		0	0		1	1		2	1		0	0		1707	856	
Total (Wood and Coal)	102630	102.6		1347	675	100	8612	4317	100	126	63	100	240	120	100	2153	1079	100	188023	94247	100

For the other contaminants, the relative contribution of open fires, woodburners and other appliances to pollutant emissions in the total study area are shown in Table 3.4 and also summarised in Table 3.5. Like PM_{10}, most of the CO, NO_X, SO_X, VOC and CO_2 emissions are produced from the burning of wood and coal (primarily wood) on open fires and woodburners.

Table 3.5 Relative contribution of open fires, woodburners and other burning appliances to pollutant emissions within the total study area.

	Open Fires	Woodburners	Other Burning Appliances
PM_{10}	31	59	10
CO	27	66	8
NO_x	28	64	8
SO_x	41	44	15
VOC	27	66	8
CO_2	23	70	7

Across the total study area, open fires are responsible for just over a quarter of CO, VOC and NO_x emissions (27%, 27% and 28% respectively), 41% of SO_x emissions and 23% of CO_2 emissions (Table 3.5). Of those emissions, wood burning on an open fire produces 23% of CO emissions, 22% of NO_x emissions, 1% of SO_x emissions, 23% of VOC emissions and 15% of CO_2 emissions. Coal burning on an open fire makes up the difference (Table 3.4).

The burning of wood and coal on woodburners across the total study area produces approximately two thirds of CO, NO_x and VOC emissions (65%, 63% and 65% respectively), 45% of SO_x emissions and 70% of CO_2 emissions (Table 3.5). Of those emissions, wood burning on a woodburner produces nearly two thirds of the CO, NO_x, VOC and CO_2 emissions (63%, 59%, 63% and 62% respectively) and only 6% of SO_x emissions. Coal burning on a woodburner makes up the difference (Table 3.4).

Across the total study area, less that a tenth of CO, NO_X, VOC and CO_2 emissions stem from other burners (pot bellies and enclosed coal burners only) (Table 3.5). In the case of SO_x, 14% of emissions stem from the burning of coal on pot bellies and enclosed coal burners (Table 3.4).

Individual suburb results can be found in Appendix III.

3.3 Home Heating Emissions On A Typical Winter's Day - Total

Home heating emissions to the air on a typical winter's day for various study areas of Timaru are presented in Table 3.7 over.

In addition to emissions per household, other factors contribute to the volume and concentration of home heating emissions on a suburb-by-suburb basis. These factors include variations in suburb size, the number of dwellings and the density of housing. For example, on a per household basis the suburb area of Washdyke recorded the third highest PM_{10} emissions, and forth highest CO and SO_x emissions (Table 3.6) but is also an area with low emissions on a suburb basis (Table 3.7).

The total study area is estimated to produce approximately 1347 kilograms of PM_{10} per day, 8612 kilograms of CO, 126 kilograms of NO_x, 240 kilograms of SO_x, 2153 kilograms of VOC and 188023 kilograms of CO_2 (Table 3.7). On a grams per hectare basis (g/ha), the total study area is estimated to produce approximately 675 g/ha of PM_{10} per day, 4317 g/ha of CO, 63 g/ha of NO_x, 120 g/ha of SO_x, 1079 g/ha of VOC and 94247 g/ha of CO_2 (Table 3.7).

On an individual suburb basis (Table 3.7), home heating emissions vary considerably from suburb to suburb. For example, when comparing Washdyke (the suburb with the lowest grams per hectare pollutant emissions) with Maori Hill (the suburb with the highest grams per hectare emissions of PM_{10} CO, VOC, CO_2 and NO_x), PM_{10} emissions per hectare in Maori Hill can be as much as eight times larger than those in Washdyke. CO, VOC, CO_2 and NO_x can be as much as seven times larger and SO_x 13 times greater.

Table 3.6 Average emissions per household from home heating in descending order of PM_{10} for the individual suburb areas of Timaru - Typical winter's day.

Suburb Area	Total No of Households	Housing Density (houses/ha)	Individual Households grams PM_{10}	CO	SOx	% of Households Using Electricity	Gas (LPG)	Oil fire	Open fire/Visor	Woodburner	Enclosed Coal Burner	Pot Belly	Incinerator
Southern Residential	2256	5.0	190	1040	49	56	29	0	13	33	7	1	0
Maori Hill	462	8.3	137	844	26	89	11	1	15	40	1	0	0
Washdyke	324	1.1	129	914	15	46	14	0	7	61	0	0	0
Highfield Residential	1290	5.7	129	933	13	74	15	1	10	56	1	0	0
Westend and Inner City	2316	8.2	128	875	18	64	28	4	8	47	0	0	0
Northern Residential	1845	5.7	123	747	27	56	29	4	10	39	0	4	0
Western Residential	1296	4.4	96	750	3	71	14	4	6	44	0	1	0
Average	1398	5.5	133	872	22	65	20	2	10	46	1	1	0
Median	1296	5.7	129	875	18	64	15	1	10	44	0	0	0

NB The suburb area of industrial has not been included in this section as there are no households, and hence emissions, within the suburb boundaries.

Table 3.7 Typical winter's day emissions from home heating for various suburb areas of Timaru.

		PM_{10}			CO			NO_x			SO_x			VOC			CO_2		
Suburb Area	Area (ha)	kg	% Total	g/ha	kg	% Total	g/ha	kg	% Total	g/ha	kg	% Total	g/ha	kg	% Total	g/ha	kg	% Total	g/ha
Highfield Residential	228	166	12	728	1204	14	5279	17	14	74	17	7	73	301	14	1320	25403	14	111416
Industrial	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maori Hill	56	63	5	1128	390	5	6966	6	5	103	12	5	215	98	5	1742	8194	4	146315
Northern Residential	321	227	17	706	1379	16	4296	20	16	64	50	21	157	345	16	1074	32878	18	102423
Southern Residential	447	429	32	960	2345	27	5246	36	29	80	111	46	248	586	27	1312	52334	28	117079
Washdyke	287	42	3	146	296	3	1032	4	3	15	5	2	17	74	3	258	6450	3	22474
Westend and Inner City	282	296	22	1051	2026	24	7184	29	23	103	41	17	144	506	24	1796	43825	23	155409
Western Residential	295	124	9	421	973	11	3297	13	11	46	4	2	15	243	11	824	18939	10	64201
Total	1995	1347	100	675	8612	100	4317	126	100	63	240	100	120	2153	100	1079	188023	100	94247

3.4 Home Heating Emissions By Time Of Day

Across the total study area, between 58% and 64% of PM_{10}, CO, NO_x, SO_x, VOC, and CO_2 are emitted between 4pm and 6am on a typical winter's night (Table 3.8 and Figure 3.2). The next highest period of emissions occurs between 10am and 4pm across all pollutants (approximately a fifth of each pollutant released during this time). Estimated PM_{10}, CO, NO_x, VOC, and CO_2 emissions tend to be lowest between the hours of 6am and 10am when around a tenth of the total daily emissions are released.

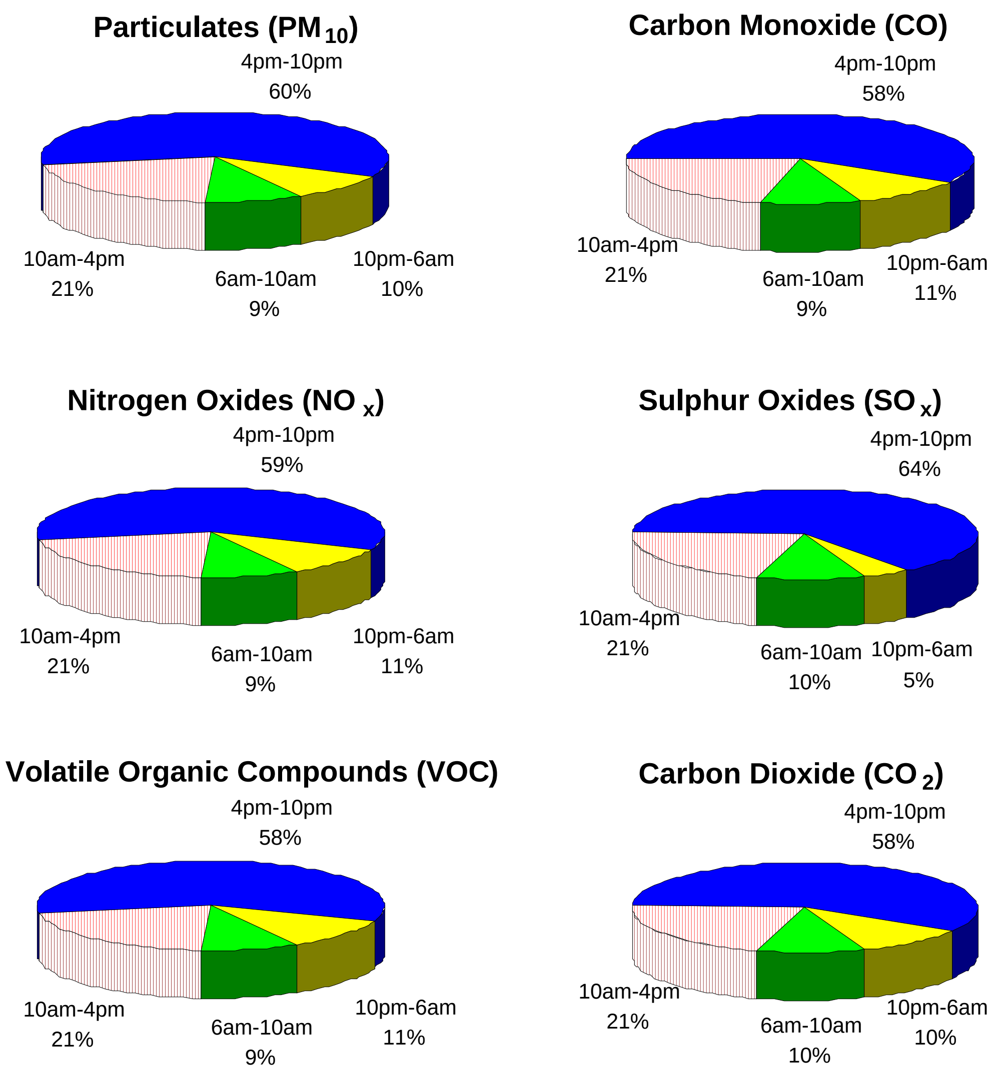


Figure 3.2 Time distribution of home heating emissions across the total study area.

On an individual suburb basis, PM_{10}, CO, VOC, SO_x, NO_x, and CO_2 emissions peaked between 4pm and 10pm (Table 3.9 through to Table 3.14). In approximately two thirds (65%) of the suburbs (five of the eight), the next highest period of emissions occurs between 10am and 4pm. In the suburbs where the secondary peak did not occur between 10am and 4pm it tended to be between 10pm and 6am. For SO_x and NO_x 60% and 68% of the suburbs respectively displayed a low period between 6am and 10am. For PM_{10}, the low period occurred between 6am and 10am in 72% of the suburbs while in over 80% of the suburbs the CO_2, CO, and VOC emissions recorded the lowest emissions between 6am and 10am.

Table 3.8 Estimated home heating emissions for various times of a typical winter's day across the total study area.

	PM_{10}			CO			NO_x			SO_x			VOC			CO_2		
	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
6am-10am	124	62	9	801	401	9	12	6	9	24	12	10	200	100	9	18998	9523	10
10am-4pm	288	144	21	1819	912	21	27	13	21	51	25	21	455	228	21	40419	20260	21
4pm-10pm	805	404	60	5033	2523	58	74	37	59	154	77	64	1258	631	58	108746	54509	58
10pm-6am	129	65	10	956	479	11	13	7	11	11	5	5	239	120	11	19738	9894	10
Total	1347	675	100	8612	4317	100	126	63	100	240	120	100	2153	1079	100	188023	94247	100

Table 3.9 PM_{10} emissions produced at different times of a typical winter's day from home heating across various suburb areas of Timaru.

Suburb Area	Area (ha)	6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
		kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield	228	14	62	9	31	134	18	103	451	62	18	81	11	166	728	100
Industrial	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maori Hill	56	8	136	12	14	258	23	31	555	49	10	179	16	63	1128	100
Northern	321	28	86	12	38	117	17	147	457	65	15	45	6	227	706	100
Southern	447	29	65	7	102	229	24	265	594	62	33	73	8	429	960	100
Washdyke	287	4	16	11	10	34	23	21	75	51	6	20	14	42	146	100
Westend and Inner	282	33	117	11	63	225	21	168	596	57	32	113	11	296	1051	100
Western	295	9	29	7	29	100	24	70	237	56	16	55	13	124	421	100
Total	1995	124	62	9	288	144	21	805	404	60	129	65	10	1347	675	100

Table 3.10 CO emissions produced at different times of a typical winter's day from home heating across various suburb areas of Timaru.

Suburb Area	Area (ha)	6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
		kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield	228	111	485	9	231	1012	19	721	3164	60	141	618	12	1204	5279	100
Industrial	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maori Hill	56	43	761	11	90	1599	23	188	3365	48	69	1240	18	390	6966	100
Northern	321	147	459	11	218	679	16	904	2817	66	109	340	8	1379	4296	100
Southern	447	176	395	8	542	1212	23	1419	3174	60	208	465	9	2345	5246	100
Washdyke	287	34	120	12	70	242	23	145	504	49	44	154	15	296	1032	100
Westend and Inner	282	222	786	11	444	1574	22	1105	3919	55	255	905	13	2026	7184	100
Western	295	68	230	7	225	764	23	550	1866	57	129	438	13	973	3297	100
Total	1995	801	401	9	1819	912	21	5033	2523	58	956	479	11	8612	4317	100

Table 3.11 NO_x emissions produced at different times of a typical winter's day from home heating across various suburb areas of Timaru.

Suburb Area	Area (ha)	6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
		kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield	228	2	7	9	3	14	19	10	45	60	2	9	12	17	74	100
Industrial	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maori Hill	56	1	12	11	1	24	23	3	50	49	1	18	17	6	103	100
Northern	321	2	7	11	3	10	16	13	41	65	2	5	7	20	64	100
Southern	447	3	6	7	8	19	23	22	49	61	3	7	8	36	80	100
Washdyke	287	0	2	11	1	3	23	2	7	49	1	2	15	4	15	100
Westend and Inner	282	3	11	11	6	22	22	16	57	55	4	12	12	29	103	100
Western	295	1	3	7	3	11	23	8	26	57	2	6	13	13	46	100
Total	1995	12	6	9	27	13	21	74	37	59	13	7	11	126	63	100

Table 3.12 SO_x emissions produced at different times of a typical winter's day from home heating across various suburb areas of Timaru.

Suburb Area	Area (ha)	6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
		kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield	228	1	4	6	2	11	15	12	51	69	2	7	10	17	73	100
Industrial	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maori Hill	56	2	37	17	3	46	22	6	112	52	1	20	9	12	215	100
Northern	321	9	28	18	8	25	16	32	101	64	1	3	2	50	157	100
Southern	447	6	13	5	26	59	24	73	163	66	6	13	5	111	248	100
Washdyke	287	0	1	8	1	4	24	3	10	60	0	1	8	5	17	100
Westend and Inner	282	6	20	14	9	31	21	26	92	64	1	2	1	41	144	100
Western	295	0	1	7	2	5	36	2	8	50	0	1	7	4	15	100
Total	1995	24	12	10	51	25	21	154	77	64	11	5	5	240	120	100

Table 3.13 VOC emissions produced at different times of a typical winter's day from home heating across various suburb areas of Timaru.

Suburb Area	Area (ha)	6am-10am kg	6am-10am g/ha	6am-10am % Total	10am-4pm kg	10am-4pm g/ha	10am-4pm % Total	4pm-10pm kg	4pm-10pm g/ha	4pm-10pm % Total	10pm-6am kg	10pm-6am g/ha	10pm-6am % Total	Daily Total kg	Daily Total g/ha	Daily Total % Total
Highfield	228	28	121	9	58	253	19	180	791	60	35	154	12	301	1320	100
Industrial	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maori Hill	56	11	190	11	22	400	23	47	841	48	17	310	18	98	1742	100
Northern	321	37	115	11	55	170	16	226	704	66	27	85	8	345	1074	100
Southern	447	44	99	8	135	303	23	355	794	60	52	116	9	586	1312	100
Washdyke	287	9	30	12	17	61	23	36	126	49	11	39	15	74	258	100
Westend and Inner	282	55	197	11	111	393	22	276	980	55	64	226	13	506	1796	100
Western	295	17	57	7	56	191	23	138	466	57	32	109	13	243	824	100
Total	1995	200	100	9	455	228	21	1258	631	58	239	120	11	2153	1079	100

Table 3.14 CO_2 emissions produced at different times of a typical winter's day from home heating across various suburb areas of Timaru.

Suburb Area	Area (ha)	6am-10am kg	6am-10am g/ha	6am-10am % Total	10am-4pm kg	10am-4pm g/ha	10am-4pm % Total	4pm-10pm kg	4pm-10pm g/ha	4pm-10pm % Total	10pm-6am kg	10pm-6am g/ha	10pm-6am % Total	Daily Total kg	Daily Total g/ha	Daily Total % Total
Highfield	228	2579	11309	10	4961	21758	20	14638	64200	58	3226	14148	13	25403	111416	100
Industrial	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maori Hill	56	1000	17865	12	1856	33135	23	3951	70548	48	1387	24768	17	8194	146315	100
Northern	321	4105	12788	12	5124	15963	16	21363	66552	65	2285	7119	7	32878	102423	100
Southern	447	3903	8731	7	12219	27336	23	31738	71001	61	4475	10011	9	52334	117079	100
Washdyke	287	841	2931	13	1505	5245	23	3016	10508	47	965	3364	15	6450	22474	100
Westend and Inner	282	5099	18082	12	9919	35175	23	23964	84978	55	4843	17174	11	43825	155409	100
Western	295	1471	4985	8	4835	16389	26	10077	34160	53	2557	8667	13	18939	64201	100
Total	1995	18998	9523	10	40419	20260	21	108746	54509	58	19738	9894	10	188023	94247	100

4. MOTOR VEHICLE EMISSIONS

4.1 Motor Vehicle Emission Factors, Calculation Techniques And Assumptions

To calculate emissions from motor vehicles, it was first necessary to calculate vehicle kilometres travelled (VKTs), and estimate average driving speeds for each of the study areas.

The motor vehicle emissions factors used in this inventory (Table 4.1, Table 4.2, and Table 4.3) were developed from a literature survey (United States Environmental Protection Agency (USEPA) 1994, Economopoulos 1993, International Panel on Climate Change 1995, and Gas Association of New Zealand Incorporated 1995).

In order to account for the effect of differing driving speeds, three regimes were adopted. For suburbs with average driving speeds up to 35 km/h, an "urban" driving regime was used to calculate emissions (Table 4.1). For suburbs with average driving speeds in the range 36-70 km/h, a "suburban" driving regime was applied (Table 4.2), and for suburbs with average driving speeds over 71 km/h a "highway" driving regime was used (Table 4.3).

Table 4.1 Vehicle distribution and emission factors per kilometre driven - Urban.

Vehicle Type	Fleet (%)	Total Emissions per km Driven (g)					
		PM_{10}	CO	NO_x	SO_x	VOC	CO_2
Light duty <3.5t **petrol** vehicles	82.30	0.07	21.58	1.93	0.01	4.42	334.00
Light duty <3.5t **diesel** vehicles	4.10	0.15	0.85	0.55	0.20	0.40	400.00
Light duty <3.5t **LPG/CNG** vehicles	2.70	0.00	1.42	1.78	0.00	1.76	290.00
Heavy duty >3.5t **petrol** vehicles	1.60	0.40	70.00	4.50	0.03	7.00	850.00
Heavy duty >3.5t **diesel** vehicles	8.40	1.52	7.03	17.55	1.68	5.61	1000.00
Heavy duty >3.5t **LPG/CNG** vehicles	0.20	0.00	18.86	5.70	0.00	9.69	969.00
2&4 stroke **petrol** motorcycles	0.70	0.07	18.80	0.16	0.16	8.40	93.00
Weighted fleet emission factors	100.00	0.198	19.71	3.22	0.16	4.36	399.00

Table 4.2 Vehicle distribution and emission factors per km driven - Suburban.

Vehicle Type	Fleet (%)	Total Emissions per km Driven (g)					
		PM_{10}	CO	NO_x	SO_x	VOC	CO_2
Light duty <3.5t **petrol** vehicles	82.30	0.05	9.88	2.46	0.01	2.80	334.00
Light duty <3.5t **diesel** vehicles	4.10	0.15	0.85	0.55	0.20	0.40	400.00
Light duty <3.5t **LPG/CNG** vehicles	2.70	0.00	0.84	1.80	0.00	1.68	290.00
Heavy duty >3.5t **petrol** vehicles	1.60	0.45	55.00	7.50	0.02	5.50	850.00
Heavy duty >3.5t **diesel** vehicles	8.40	1.45	3.36	21.85	1.62	2.70	1000.00
Heavy duty >3.5t **LPG/CNG** vehicles	0.20	0.00	18.86	5.70	0.00	9.69	969.00
2&4 stroke **petrol** motorcycles	0.70	0.07	18.80	0.16	0.62	8.40	93.00
Weighted fleet emission factors	100.00	0.18	9.52	4.06	0.15	2.76	399.00

Table 4.3 Vehicle distribution and emission factors per km driven - Highway.

Vehicle Type	Fleet (%)	Total Emissions per km Driven (g)					
		PM_{10}	CO	NO_x	SO_x	VOC	CO_2
Light duty <3.5t **petrol** vehicles	82.30	0.05	7.05	3.37	0.01	2.20	334.00
Light duty <3.5t **diesel** vehicles	4.10	0.15	0.85	0.55	0.20	0.40	400.00
Light duty <3.5t **LPG/CNG** vehicles	2.70	0.00	0.61	2.34	0.00	1.63	290.00
Heavy duty >3.5t **petrol** vehicles	1.60	0.60	50.00	7.50	0.02	3.50	850.00
Heavy duty >3.5t **diesel** vehicles	8.40	1.15	2.72	17.55	1.47	2.13	1000.00
Heavy duty >3.5t **LPG/CNG** vehicles	0.20	0.00	18.86	5.70	0.00	9.69	969.00
2&4 stroke **petrol** motorcycles	0.70	0.07	18.80	0.16	0.62	8.40	93.00
Weighted fleet emission factors	100.00	0.15	7.05	4.47	0.14	2.18	399.00

The factors in Table 4.1, Table 4.2 and Table 4.3 reflect the differences in emissions from the various vehicle types, and take account of the fleet composition. Take PM_{10} and NO_x for example, when compared to light duty <3.5t petrol vehicles on an individual basis

- light duty <3.5t diesel vehicles produce at least twice as much PM_{10};
- heavy duty >3.5t petrol vehicles produce 6-12 times the quantity of PM_{10} and 2-3 times the amount of NO_x;
- heavy duty >3.5t diesel vehicles produce 22-29 times the amount of PM_{10} and 5-9 times the amount of NO_x;
- heavy duty >3.5t LPG/CNG vehicles produce 2-3 times more NO_x and;
- 2 & 4 stroke petrol motorcycles produce 1.4 times the amount of PM_{10}.

With the fleet composition taken into consideration, the pattern is somewhat different. For example, light duty <3.5t petrol vehicles (which represent 82% of the vehicle fleet) produce up to ~9.5 times more PM_{10} and 70-123 times more NO_x than light duty <3.5t diesel vehicles; 33-44 times more NO_x than light duty <3.5t LPG/CNG vehicles; 17-23 times more NO_x and 4-9 times more PM_{10} than heavy duty >3.5t petrol vehicles; 1-2 times more NO_x than heavy duty >3.5t diesel vehicles; 139-243 times more NO_x than heavy duty >3.5t LPG/CNG vehicles and; 84-118 times more PM_{10} and 1418-2476 times more NO_x than 2 & 4 stroke petrol motorcycles.

Likewise, heavy duty >3.5t diesel vehicles, which represent 8.4% of the vehicle fleet, produce approximately 2-3 times more PM_{10} than light duty <3.5t petrol vehicles; 16-21 times more PM_{10} and 65-81 times more NO_x than light duty <3.5t diesel vehicles; 23-38 times more NO_x than light duty <3.5t LPG/CNG vehicles and; 10-20 times more PM_{10} and 12-21 times more NO_x than heavy duty >3.5t petrol vehicles.

The Canterbury Regional Council supplied the average number of vehicle kilometres travelled per day (VKTs) and the average driving speeds for each study area. From this information driving regimes could be designated to various suburb areas (Table 4.4).

Motor vehicle emissions were then calculated for a typical winter's day and aggregated to a total using the following formula:

$$\text{Motor Vehicle Emissions (g)} = \text{Driving Regime Emission Factor(g/km)} * \text{VKT (km)}$$

So, to calculate total PM_{10} emissions from all vehicle types within the "urban" area of Addington Industrial the equation would look like:

$$PM_{10}\ \text{Emissions (g)} = 0.198\ \text{g/km} * 124767\ \text{km}$$

The aggregated total motor vehicle emissions were then divided by the number of hectares within each suburb area (1 hectare = $10000m^2$). This gave a "normalised" weight per area value (e.g. grams per hectare) and allowed fair comparison between differently-sized study areas.

The following assumptions were also made:

1. Typical NZ fuel information is:

unleaded 91:	47.9% sales	Lead (Pb)=0.001 g/l	Sulphur (S)=0.005 wt%
leaded 96:	52.1% sales	Lead (Pb)=0.268 g/l	Sulphur (S)=0.007 wt%
diesel		Lead (Pb)=0.000 g/l	Sulphur (S)=0.240 wt%

2. Fuel technology for NZ cars is:
   70% carburettors
   30% fuel injectors

3. <u>Motorcycle</u> fleet breakdown is:
   <50cc 2-stroke 20%
   >50cc 2-stroke 40%
   >50cc 4-stroke 40%

The emissions factors for heavy duty LPG/CNG vehicles have been developed from fewer sets of data as there is very little information currently available.

Table 4.4 Average speed and vehicle kilometres travelled at different times of a typical winter's day for various study areas of Timaru.

Suburb Area	Average Speed Regime				Vehicle Kilometres Travelled (km)			
	6am-10am	10am-4pm	4pm-10pm	10pm-6am	6am-10am	10am-4pm	4pm-10pm	10pm-6am
Highfield Residential	suburban	urban	urban	suburban	10261	19994	19932	5055
Industrial	urban	urban	urban	suburban	2546	6009	5265	682
Maori Hill	urban	urban	urban	urban	7867	15802	15306	3943
Northern Residential	suburban	suburban	suburban	suburban	16138	32696	30238	7525
Southern Residential	suburban	urban	suburban	suburban	16375	32786	31313	7871
Washdyke	suburban	suburban	suburban	suburban	18197	36513	32005	8070
Westend and Inner City	urban	urban	urban	urban	27387	55270	52128	12947
Western Residential	suburban	suburban	suburban	suburban	11329	21503	21309	5245
Total Study Area	suburban	suburban	suburban	suburban	110100	220573	207496	51338

4.2 Motor Vehicle Emissions On A Typical Winter's Day By Vehicle Type

Across the total study area of Timaru, light duty petrol and heavy duty diesel vehicles tend to be the main emitters of all six pollutants under study (Figure 4.1 and Table 4.5).

Light duty petrol vehicles are the main emitters of CO (88%), VOC (83%), and CO_2 (69%). Heavy duty diesel vehicles tend to emit larger quantities of PM_{10} (67%) and SO_x (88%). A further fifth (21%) of CO_2 emissions stem from heavy duty diesel vehicles while just over a quarter (26%) of PM_{10} emissions are derived from light duty petrol vehicles. Both light duty petrol vehicles and heavy duty diesel vehicles release approximately half the NO_x (50% and 45% respectively).

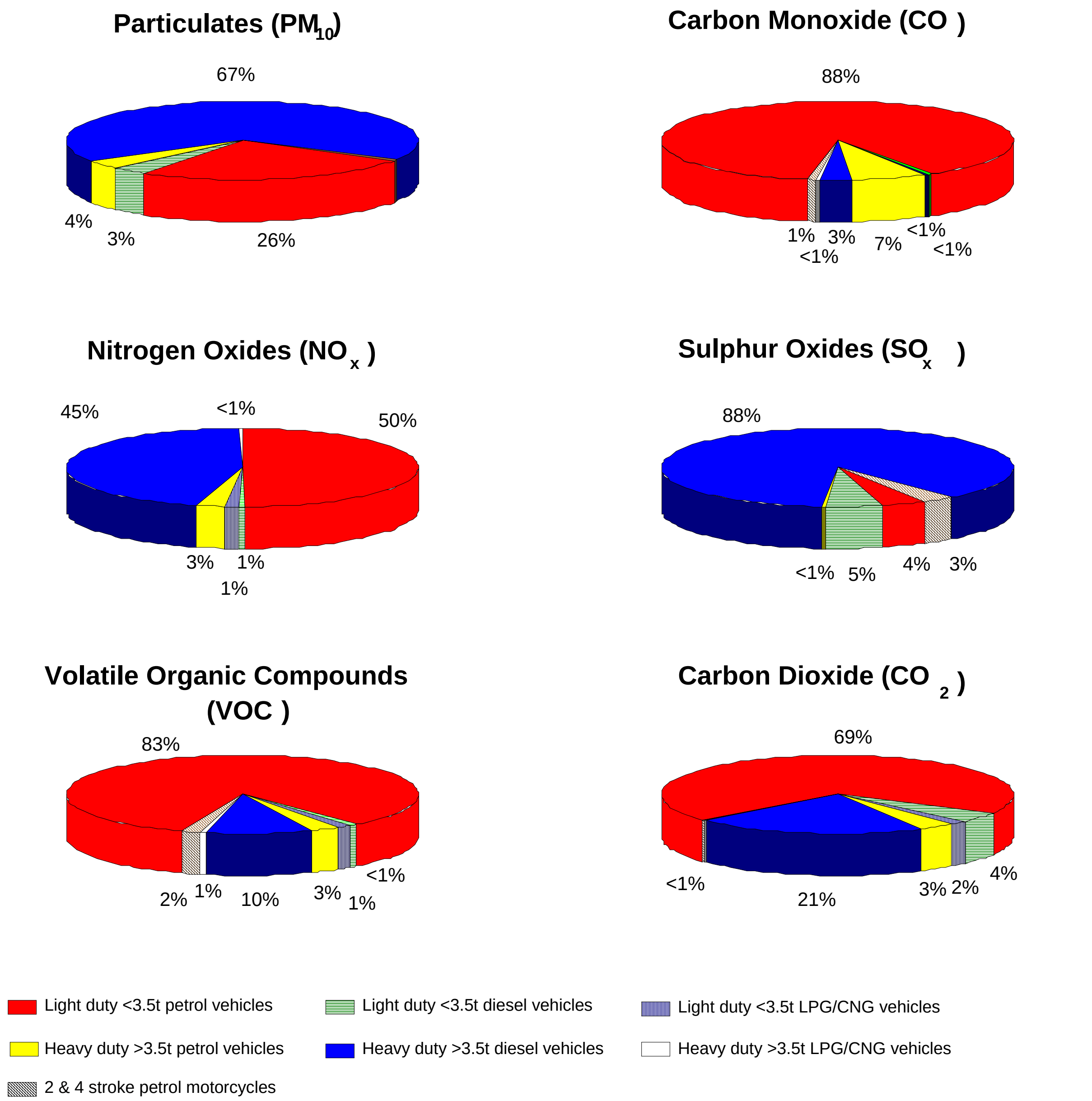


Figure 4.1 Emissions by vehicle type for the total study area of Timaru.

Even though the percentage of emissions by vehicle type are very similar across all suburb areas, estimated quantities released (per day and per hectare) are quite different. On average, Maori Hill produces approximately two to four times the PM_{10} and CO_2, two to nine times the CO, two to three times the amount of NO_x and two to six times the SO_x and VOC per hectare per day when compared to the quantities produced by the other study areas. Individual suburb results can be found in Appendix III.

Table 4.5 Emissions by vehicle type for the total study area.

	PM_{10}			CO			NO_x			SO_x			VOC			CO_2		
	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Light duty <3.5t petrol vehicles	29	14	26	7462	3741	88	1073	538	50	4	2	4	1728	866	83	162045	81225	69
Light duty <3.5t diesel vehicles	4	2	3	21	10	0	13	7	1	5	2	5	10	5	0	9668	4846	4
Light duty <3.5t LPG/CNG vehicles	0	0	0	18	9	0	29	14	1	0	0	0	27	14	1	4616	2314	2
Heavy duty >3.5t petrol vehicles	4	2	4	585	293	7	57	29	3	0	0	0	59	29	3	8017	4019	3
Heavy duty >3.5t diesel vehicles	73	37	67	252	126	3	982	492	45	82	41	88	201	101	10	49519	24821	21
Heavy duty >3.5t LPG/CNG vehicles	0	0	0	22	11	0	7	3	0	0	0	0	11	6	1	1142	573	0
2&4 stroke petrol motorcycles	0	0	0	78	39	1	1	0	0	3	1	3	35	17	2	384	192	0
Total	110	55	100	8438	4229	100	2161	1083	100	93	47	100	2071	1038	100	235391	117990	100

4.3 Motor Vehicle Emissions On A Typical Winter's Day - Total

Motor vehicle emissions to the air on a typical winter's day for various study areas of Timaru are presented in Table 4.6 over.

The total study area is estimated to produce approximately 110 kilograms of PM_{10} per day, over 8400 kilograms of CO, approximately 2100 kilograms of NO_x and VOC, 93 kilograms of SO_x, 2071 kilograms of VOC, and approximately 235,000 kilograms of CO_2. On a grams per hectare basis (g/ha), the total study area emits approximately 55 g/ha of PM_{10}, 4230 g/ha of CO, nearly 1100 g/ha of $NO_{x,}$ 47 g/ha of VOC, 1038 g/ha of SO_x, and nearly 118,000 g/ha of CO_2 per day (Table 4.6).

On an individual suburb basis (Table 4.6), motor vehicle emissions vary considerably from suburb to suburb. For example, when comparing Western Residential (the suburb with the lowest grams per hectare pollutant emissions) with the Maori Hill (the suburb with the highest grams per hectare pollutant emissions), PM_{10}, SO_x, and CO_2 emissions per hectare within Maori Hill are approximately four times larger than those of Western Residential. CO can be as much as eight times larger, NO_x three times greater and VOC six times larger.

Results indicate that pollutant emissions are largely determined by the number of major traffic routes within a study area, the traffic density, the number of VKTs, and driving speeds. Suburb areas with little or no major traffic routes (such as the Industrial area) generally display lower VKTs (Table 4.7). As a result, areas with low VKTs tend to exhibit lower pollutant emissions per day. It is likely that the traffic movements within these areas are primarily associated with localised industrial activity or with local residents commuting to and from their homes to places of employment, recreation, education, shopping and entertainment but *within* their suburb boundaries. On the other hand, suburbs with greater traffic densities and hence higher VKTs (such as the Westend and Inner City, Washdyke, Northern Residential, and Southern Residential) display high emissions of all six pollutants under study. In these cases, more traffic is likely to *cross* suburb boundaries.

Motor vehicle emissions tend to be highest close to traffic routes and decrease exponentially in concentration as distance from the roading system increases. For this reason, the total daily PM_{10}, CO, NO_x, SO_x, VOC, and CO_2 emissions from motor vehicles are more likely to be localised around the traffic routes instead of being uniform across the suburb area (as with home heating emissions). Emissions per hectare standardise the localised total daily emissions across the entire suburb area.

Table 4.6 Typical winter's day emissions from motor vehicles for various study areas of Timaru.

Suburb Area	Area (ha)	PM_{10} kg	PM_{10} % Total	PM_{10} g/ha	CO kg	CO % Total	CO g/ha	NO_x kg	NO_x % Total	NO_x g/ha	SO_x kg	SO_x % Total	SO_x g/ha	VOC kg	VOC % Total	VOC g/ha	CO_2 kg	CO_2 % Total	CO_2 g/ha
Highfield Residential	228	11	10	47	933	11	4092	191	9	836	9	10	39	216	10	949	22058	9	96746
Industrial	79	3	3	36	279	3	3531	47	2	598	2	3	30	62	3	787	5791	2	73300
Maori Hill	56	9	8	152	846	10	15108	138	6	2466	7	7	125	187	9	3344	17137	7	306021
Northern Residential	321	15	14	48	824	10	2568	352	16	1096	13	14	41	239	12	744	34578	15	107720
Southern Residential	447	16	15	37	1175	14	2629	331	15	741	14	15	31	296	14	663	35276	15	78918
Washdyke	287	17	15	58	902	11	3144	385	18	1342	15	16	51	262	13	911	37848	16	131874
Westend and Inner City	282	29	27	104	2912	35	10327	475	22	1686	24	26	85	645	31	2286	58990	25	209183
Western Residential	295	10	10	36	565	7	1917	241	11	818	9	10	31	164	8	555	23713	10	80383
Total Study Area	1995	110	100	55	8438	100	4229	2161	100	1083	93	100	47	2071	100	1038	235391	100	117990

Table 4.7 Typical winter's day emissions from motor vehicles in descending order of PM_{10} for the eight suburb areas of Timaru.

Suburb Area	Daily VKTs	Pollutant (g/day)					
		PM_{10}	CO	NO_x	SO_x	VOC	CO_2
Westend and Inner	147732	29300	2912296	475360	24025	644555	58989535
Washdyke	94785	16757	902384	385173	14579	261525	37847745
Southern Residential	88345	16325	1175263	331268	13878	296340	35276247
Northern Residential	86597	15309	824432	351900	13320	238933	34578269
Highfield Residential	55242	10626	932889	190710	8849	216456	22058186
Western Residential	59386	10499	565374	241324	9134	163854	23712889
Maori Hill	42918	8512	846058	138098	6980	187251	17137200
Industrial	14502	2861	278932	47240	2352	62178	5790663
Average	73688	13774	1054704	270134	11640	258887	29423842
Median	72992	12968	874221	286296	11227	227695	29145579

4.4 Motor Vehicle Emissions By Time Of Day

On average, between 36% and 41% of all motor vehicle emissions of PM_{10}, CO, NO_x, SO_x, VOC and CO_2 are released between the hours of 10am and 4pm across the total study area (Figure 4.2 and Table 4.8). The next highest period of emissions occurs between 4pm and 10pm, during which just over a third (35%) of contaminants are emitted. Nearly a fifth (17%-19%) of pollutants are emitted between 6am and 10am while less than 10% of pollutants are emitted overnight (between 10pm and 6am).

Across all suburbs, PM_{10}, CO, NO_x, SO_x, VOC and CO_2 emissions tend to peak between 10am and 4pm (Table 4.9 to Table 4.14). For Highfield Residential and Western Residential, equal quantities of each of the six pollutants were emitted in the 10am to 4pm time period and the 4pm to 10pm time frame. Within Southern Residential, all pollutants peak between 10am and 4pm except NO_X, which peaks between 10pm and 6am (Table 4.8). Estimated PM_{10}, CO, NO_x, SO_x, VOC and CO_2 emissions are at their lowest between the hours of 10pm and 6am across all suburbs.

Actual traffic flow between 6am and 4pm may give some insight as to why the peak occurs between 10am and 4pm and not 6am to 10am as could be expected. Morning "rush hour" traffic is often erratic and dependent on a number of variables (e.g. weather conditions). Because of this it may only account for a portion of the 6am and 10am time frame. Traffic flow between 10am and 4pm is more likely to be constant. There are also an extra two hours included in the time frame.

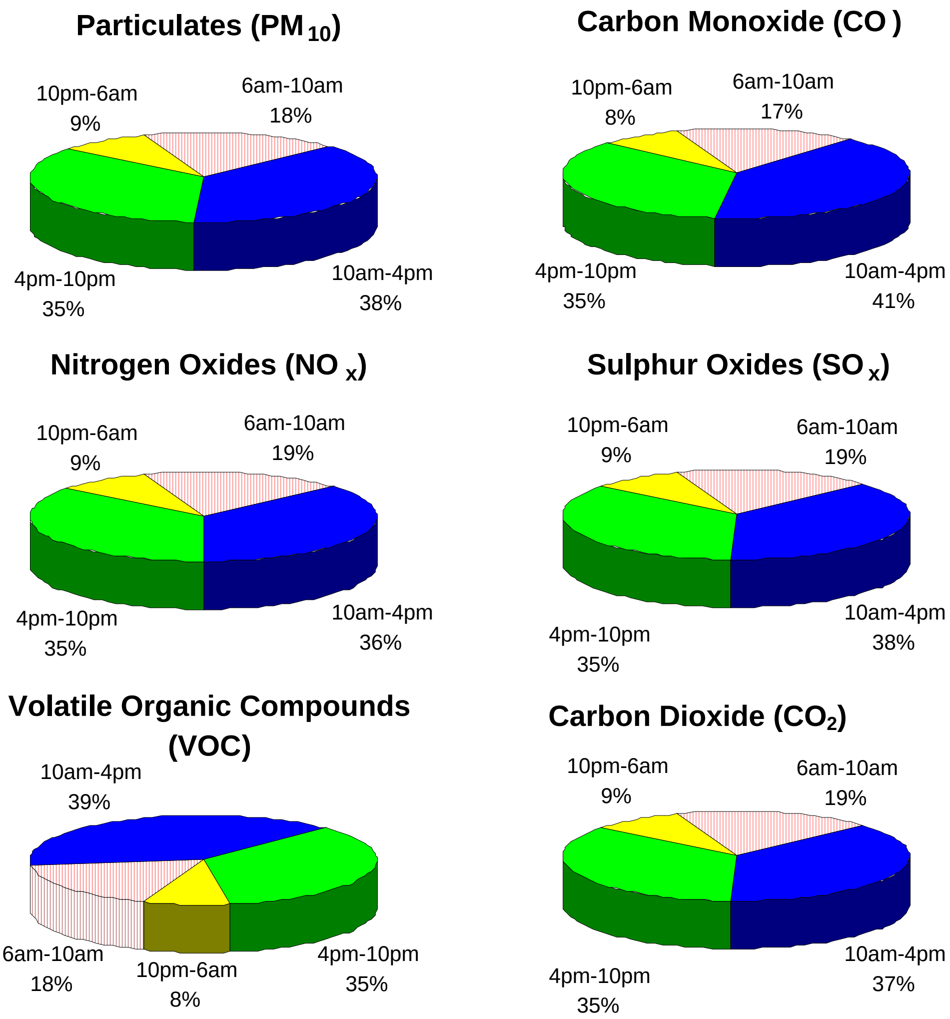


Figure 4.2 Breakdown of motor vehicle emissions for different times of a typical winter's day for the total study area and the inner suburb study area.

Table 4.8 Estimated motor vehicle emissions for various times of a typical winter's day across the total study area of Timaru.

	PM_{10}			CO			NO_x			SO_x			VOC			CO_2		
	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
6am-10am	20	10	18	1433	719	17	415	208	19	17	9	19	364	183	18	43963	22037	19
10am-4pm	42	20	38	3424	1716	41	786	394	36	35	18	38	817	409	39	88075	44148	37
4pm-10pm	39	19	35	2920	1463	35	765	383	35	33	16	35	721	361	35	82853	41531	35
10pm-6am	9	5	9	661	331	8	194	97	9	8	4	9	169	85	8	20499	10275	9
Total	110	55	100	8438	4229	100	2161	1083	100	93	47	100	2071	1038	100	235391	117990	100

Table 4.9 PM_{10} emissions produced at different times of a typical winter's day by motor vehicles across various suburb areas of Timaru.

		6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
Suburb Area	Area (ha)	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield Residential	228	2	8	17	4	17	37	4	17	37	1	4	8	11	47	100
Industrial	79	1	6	18	1	15	42	1	13	36	0	2	4	3	36	100
Maori Hill	56	2	28	18	3	56	37	3	54	36	1	14	9	9	152	100
Northern Residential	321	3	9	19	6	18	38	5	17	35	1	4	9	15	48	100
Southern Residential	447	3	6	18	7	15	40	6	12	34	1	3	9	16	37	100
Washdyke	287	3	11	19	6	22	39	6	20	34	1	5	9	17	58	100
Westend and Inner City	282	5	19	19	11	39	37	10	37	35	3	9	9	29	104	100
Western Residential	295	2	7	19	4	13	36	4	13	36	1	3	9	10	36	100
Total Study Area	1995	20	10	18	42	21	38	39	19	35	9	5	9	110	55	100

Table 4.10 CO emissions produced at different times of a typical winter's day by motor vehicles across various suburb areas of Timaru.

		6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
Suburb Area	Area (ha)	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield Residential	228	98	428	10	394	1729	42	393	1723	42	48	211	5	933	4092	100
Industrial	79	50	635	18	118	1499	42	104	1314	37	6	82	2	279	3531	100
Maori Hill	56	155	2769	18	312	5563	37	302	5388	36	78	1388	9	846	15108	100
Northern Residential	321	154	479	19	311	970	38	288	897	35	72	223	9	824	2568	100
Southern Residential	447	156	349	13	646	1446	55	298	667	25	75	168	6	1175	2629	100
Washdyke	287	173	604	19	348	1211	39	305	1062	34	77	268	9	902	3144	100
Westend and Inner City	282	540	1915	19	1090	3864	37	1028	3644	35	255	905	9	2912	10327	100
Western Residential	295	108	366	19	205	694	36	203	688	36	50	169	9	565	1917	100
Total Study Area	1995	1433	719	17	3424	1716	41	2920	1463	35	661	331	8	8438	4229	100

Table 4.11 NO_x emissions produced at different times of a typical winter's day by motor vehicles across various suburb areas of Timaru.

		6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
Suburb Area	Area (ha)	Kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield Residential	228	42	183	22	64	282	34	64	281	34	21	90	11	191	836	100
Industrial	79	8	104	17	19	245	41	17	214	36	3	35	6	47	598	100
Maori Hill	56	25	452	18	51	908	37	49	879	36	13	227	9	138	2466	100
Northern Residential	321	66	204	19	133	414	38	123	383	35	31	95	9	352	1096	100
Southern Residential	447	67	149	20	105	236	32	127	285	38	32	72	10	331	741	100
Washdyke	287	74	258	19	148	517	39	130	453	34	33	114	9	385	1342	100
Westend and Inner City	282	88	312	19	178	631	37	168	595	35	42	148	9	475	1686	100
Western Residential	295	46	156	19	87	296	36	87	294	36	21	72	9	241	818	100
Total Study Area	1995	415	208	19	786	394	36	765	383	35	194	97	9	2161	1083	100

Table 4.12 SO_x emissions produced at different times of a typical winter's day by motor vehicles across various suburb areas of Timaru.

		6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
Suburb Area	Area (ha)	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield Residential	228	2	7	18	3	14	37	3	14	37	1	3	9	9	39	100
Industrial	79	0	5	18	1	12	42	1	11	36	0	1	4	2	30	100
Maori Hill	56	1	23	18	3	46	37	2	44	36	1	11	9	7	125	100
Northern Residential	321	2	8	19	5	16	38	5	14	35	1	4	9	13	41	100
Southern Residential	447	3	6	18	5	12	38	5	11	35	1	3	9	14	31	100
Washdyke	287	3	10	19	6	20	39	5	17	34	1	4	9	15	51	100
Westend and Inner City	282	4	16	19	9	32	37	8	30	35	2	7	9	24	85	100
Western Residential	295	2	6	19	3	11	36	3	11	36	1	3	9	9	31	100
Total Study Area	1995	17	9	19	35	18	38	33	16	35	8	4	9	93	47	100

Table 4.13 VOC emissions produced at different times of a typical winter's day by motor vehicles across various suburb areas of Timaru.

		6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
Suburb Area	Area (ha)	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield Residential	228	28	124	13	87	383	40	87	381	40	14	61	6	216	949	100
Industrial	79	11	141	18	26	332	42	23	291	37	2	24	3	62	787	100
Maori Hill	56	34	613	18	69	1231	37	67	1193	36	17	307	9	187	3344	100
Northern Residential	321	45	139	19	90	281	38	83	260	35	21	65	9	239	744	100
Southern Residential	447	45	101	15	143	320	48	86	193	29	22	49	7	296	663	100
Washdyke	287	50	175	19	101	351	39	88	308	34	22	78	9	262	911	100
Westend and Inner City	282	119	424	19	241	855	37	227	807	35	56	200	9	645	2286	100
Western Residential	295	31	106	19	59	201	36	59	199	36	14	49	9	164	555	100
Total Studv Area	1995	364	183	18	817	409	39	721	361	35	169	85	8	2071	1038	100

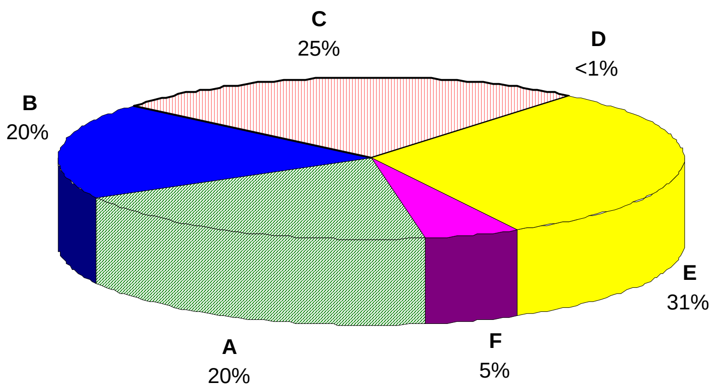
Table 4.14 CO_2 emissions produced at different times of a typical winter's day by motor vehicles across various suburb areas of Timaru.

		6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
Suburb Area	Area (ha)	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield Residential	228	4097	17970	19	7984	35016	36	7959	34907	36	2018	8853	9	22058	96746	100
Industrial	79	1017	12869	18	2399	30372	41	2102	26612	36	272	3447	5	5791	73300	100
Maori Hill	56	3141	56095	18	6310	112674	37	6112	109138	36	1574	28115	9	17137	306021	100
Northern Residential	321	6444	20075	19	13056	40671	38	12074	37614	35	3005	9361	9	34578	107720	100
Southern Residential	447	6539	14628	19	13091	29287	37	12503	27972	35	3143	7031	9	35276	78918	100
Washdyke	287	7266	25317	19	14580	50800	39	12780	44528	34	3222	11228	9	37848	131874	100
Westend and Inner City	282	10936	38779	19	22069	78260	37	20815	73811	35	5170	18332	9	58990	209183	100
Western Residential	295	4524	15335	19	8586	29106	36	8509	28843	36	2094	7099	9	23713	80383	100
Total Studv Area	1995	43963	22037	19	88075	44148	37	82853	41531	35	20499	10275	9	235391	117990	100

5. INDUSTRIAL EMISSIONS

5.1 Timaru Industry - Background

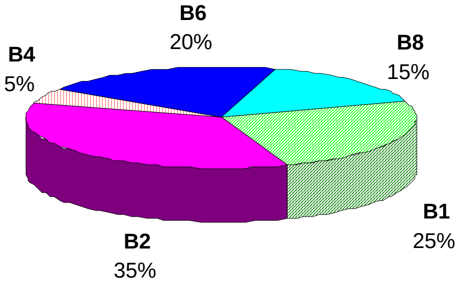
Across the total study area of Timaru it is estimated that there are approximately 102 industrial and commercial premises, many of which emit various quantities of PM_{10}, CO, NO_x, SO_x, VOC and CO_2 into the air on a typical winter's day. A quarter of the industries within Tamaru are considered commercial in nature (Figure 5.1). These industries primarily emit pollutants from the combustion of solid fuels for heating or as part of their operations. Manufacturing represents a fifth of Timaru's industries while a further fifth of industries use surface coatings or thinners (paint, varnish, lacquer or paint primer). Community services make up nearly a third (31%) while wholesale and trade represent 5%. Less than 1% of industries are services allied to transport.



A = Surface coatings and thinners **B** = Manufacturing **C** =Commercial - combustion
D = Services allied to transport **E** = Community Services **F** =Wholesale and trade

Figure 5.1 Timaru industry breakdown.

Manufacturing industries within Timaru can be further divided into eight categories (Figure 5.2). Five percent of manufacturing industries produce chemicals, rubber and plastic products while a quarter produce food and beverages. Thirteen percent produce non-metallic mineral products (i.e glass, bricks and clay products, cement, lime). Just over a third (35%) of manufacturing industry produce textiles, clothing and leather goods while another fifth manufacture basic metal (i.e foundries). Wood processing and wood product manufactures make up 15% of Timaru manufacturers.



B1	Food and beverage
B2	Textile/clothing/leather
B3	Paper and paper products, printing and publishing
B4	Chemicals, rubber and plastic products
B5	Non-metallic mineral products
B6	Basic metal
B7	Fabricated metal
B8	Wood and wood products

Figure 5.2 Timaru manufacturing industry breakdown.

Like manufacturing, community services can also be divided into four categories (Figure 5.3). Educational and medical facilities around Timaru represent 85% of the community service industries while sanitary services (including refuse burning and pathological waste) represent 3%. Laundries and cleaning facilities represent 12% of community services in Timaru.

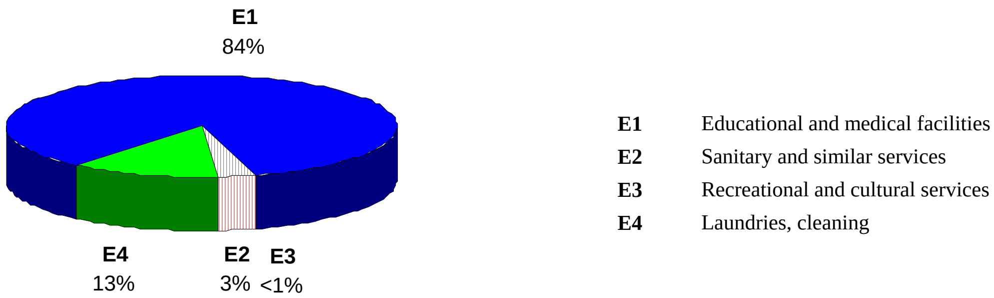


Figure 5.3 Timaru community service breakdown.

For the purpose of this inventory, emissions have been assessed on the size of industry and not industry type primarily because the scale of process, the fuel consumption, the boiler size and control technology used can directly influence pollutant emissions to the air. As a result, three categories of industry have been adopted (Part A, Part B and Part C). The classification of Part A, B and C industries within Timaru were based on definitions from the Clean Air Act 1972 (Appendix IV).

Based on this classification scheme, eight of the 102 industries across the total study area of Timaru are considered large scale, 11 medium sized, and 83 are considered small commercial and industrial operations (Table 5.1).

Table 5.1 Number and type of industry within various study areas of Timaru.

Suburb Area	Industry Type and Number			
	Total Number	A	B	C
Highfield Residential	4	0	0	4
Industrial	8	2	2	4
Maori Hill	1	0	0	1
Northern Residential	10	0	0	10
Southern Residential	18	1	2	15
Washdyke	23	4	7	12
Westend and Inner City	37	1	0	36
Western Residential	1	0	0	1
Total	102	8	11	83

5.2 Industrial Emission Factors, Calculation Techniques And Assumptions

Emissions from industrial sources were considered separately under combustion and process emissions. For the calculations, data were required on the amount / nature of the fuel consumed and the amount / nature of any raw materials used and products produced for each individual industry. Much of the information was gained from CRC resource consent files but where gaps in the information existed, Christchurch emissions from various industrial sources were used and scaled to the Timaru environment.

5.2.1 Combustion Emissions

For the calculation of combustion emissions, emission factors for various boiler sizes were developed from a literature survey of ‘utility’ (power generating) and ‘commercial’ (heat generating) boilers. (United States Environmental Protection Agency (USEPA) 1994, Economopoulos 1993, International Panel on Climate Change 1995, and Air Pollution Engineering Manual 1992).

Because of the difficulty encountered when trying to obtain information on the actual control technology used for each individual industry, emissions factors which assume average operating conditions using the various fuels were adopted for this inventory (Table 5.2). However, it should be noted that processes using older technology or, conversely, state of the art abatement equipment may have emissions rates significantly higher or lower than the numbers shown below.

Table 5.2 Boiler emission factors per unit of fuel burnt.

Fuel	Boiler Size	Typical Fuel Use 10^3m^3/yr or T/yr	PM_{10} kg/U	CO kg/U	NO_x kg/U	SO_x kg/U	VOC kg/U	CO_2 kg/U
Natural Gas	5 MW	4380	0.086	0.560	1.300	0.010	0.100	2010
10^3m^3	50 MW	43800	0.096	0.640	4.550	0.010	0.092	2010
LPG	5 MW	3430	0.060	0.710	2.600	0.007	0.120	2885
Tonne	50 MW	34300	0.060	0.710	2.600	0.007	0.120	2885
Oil	40 kW	31	0.280	0.640	2.800	4.000	0.180	3010
Tonne	10 MW	7690	0.280	0.640	2.800	4.000	0.180	3010
Coal	40 kW	50	5.000	2.300	8.200	17.500	0.060	2355
Tonne	10 MW	12600	5.000	2.500	9.000	17.500	0.060	2355
Wood	40 kW	126	1.300	2.000	0.330	0.037	0.150	1100
Tonne	10 MW	31500	1.300	13.000	1.150	0.037	0.150	1100

Overall, NO_x and CO emissions (but to a lesser extent) are influenced by boiler size whereas SO_x VOC, CO_2 and PM_{10} emissions are effectively fuel dependent and do not vary with the boiler size.

Using the typical emissions rates for each of the key contaminants (Table 5.2), and the actual fuel consumption information obtained from CRC resource consent records, the daily emissions of each contaminant from combustion processes for each industrial source were then calculated for a typical winter’s day using the following formula:

*Combustion Emissions (kg/day) = Actual Fuel Consumption (U/day) * Unit Emissions Rate (kg/U)*

where the typical emissions rate depends on the size of the process and *U* is the unit of production (t or m^3 etc.).

So, to calculate CO emissions from the burning of 5 tonne of coal per day on a 40 kW boiler, the equation would look like:

*CO Emissions (kg/day) = 5 t/day * 2.3 kg/t = 11.5 kg/day*

5.2.2 Process Emissions

For the calculation of process emissions where applicable (as not all industries produce process emissions), emissions factors were developed for each industry type from USEPA and Economopoulos. These factors are based on the amount of raw materials used, or the amount of product produced, and were scaled using the actual information from consent records to give process emissions totals for the different contaminants. Again, as in the case of the combustion emissions, the process emissions factors assume typical operation as follows:

*Process Emissions (kg/day) = Actual Product Produced or Raw Materials Consumed (U/day) * Unit Emissions Rate (kg/U)*

where the U is the unit of production (t or m^3 etc.) and the unit emissions rate depends on the nature of the process.

For example, for an industry producing 100 tonnes of resins and adhesives per day, the equation for VOC emissions would look like:

*VOC Emissions (kg/day) = 100 t/day * 3.0 kg/t = 300 kg/day*

Please note that resin / adhesive manufacture results in VOC only process emissions. Other industry processes emit other contaminants (see Appendix V).

Following calculation of both combustion and process emissions, the total industrial emissions for all industry within a suburb were then aggregated to produce daily kilogram totals. To produce a "normalised" weight per area value (e.g. grams per hectare), emissions were then divided by the number of hectares within each suburb area (1 hectare = $10000m^2$). This normalisation was done to allow fair comparison between differently-sized study areas.

To establish the fuel quantities used, the product produced or the raw materials consumed on a typical winter's day, annual figures were divided into seasonal quantities based on variation in industry operation. The winter consumption for each industry was then divided by 182.5 days. This gave a daily quantity.

5.2.3 Assumptions

The following assumptions were made for the calculation of industrial emissions.

1. The amount of energy released per unit fuel (calorific value or CV) for the different fuels:

Natural gas	36 MJ/m3
LPG	46 MJ/kg
Oil	41 MJ/kg
Coal	25 MJ/kg
Wood	10 MJ/kg

   This information is used to calculate the typical annual fuel consumption figures given in Table 5.2

2. typical coal = 1.0 wt% sulphur (range 0.4 to 2.0) (The typical sulphur content directly reflects the SO_x emission factors.)

3. ash content of coal = 4.0 wt% (range 3.0 to 5.0) (This reflects the amount of PM_{10} emitted from coal burning.)

4. density of LPG = 0.5 kg/litre (conversion factors if different units are specified)

5. density of oil = 0.845 kg/litre (conversion factors if different units are specified)

6. “oil” refers to automotive diesel, marine diesel, and blended heating oil as the physical properties of each are almost identical. (The Ministry of Commerce Energy Data File considers these fuels together but under the classification ‘diesel’.)

7. Hours of operation (unless specified). Used for the calculation of daily fuel, product and raw material quantities, and resultant pollutant emissions and times:
   Part A industries 24 hours a day, 7 days a week
   Part B industries 12 hours a day (between 6am and 6pm), 6 days a week
   Part C industries 8 hours a day (between 8am and 5pm), 5 days a week

8. Boiler size emissions factor category:
   Part A industries 10 MW - 50 MW
   Part B industries 10 MW - 50 MW
   Part C industries 40 kW - 5 MW

5.3 Industrial Emissions On A Typical Winter's Day By Industry Type

Emissions to the air from the various industry types on a typical winter's day for the total study area of Timaru are presented in Figure 5.4 and Table 5.3.

Across the study area of Timaru, Part C industrial and commercial premises are the main emitters of CO and NO_x (39% each) and SO_x (41%) while Part B industries emit larger quantities of VOC (78%) and CO_2 (48%). Part A, B and C industries emit relatively equal quantities of PM_{10} (31%, 34% and 34% respectively) (Figure 5.4 and Table 5.3).

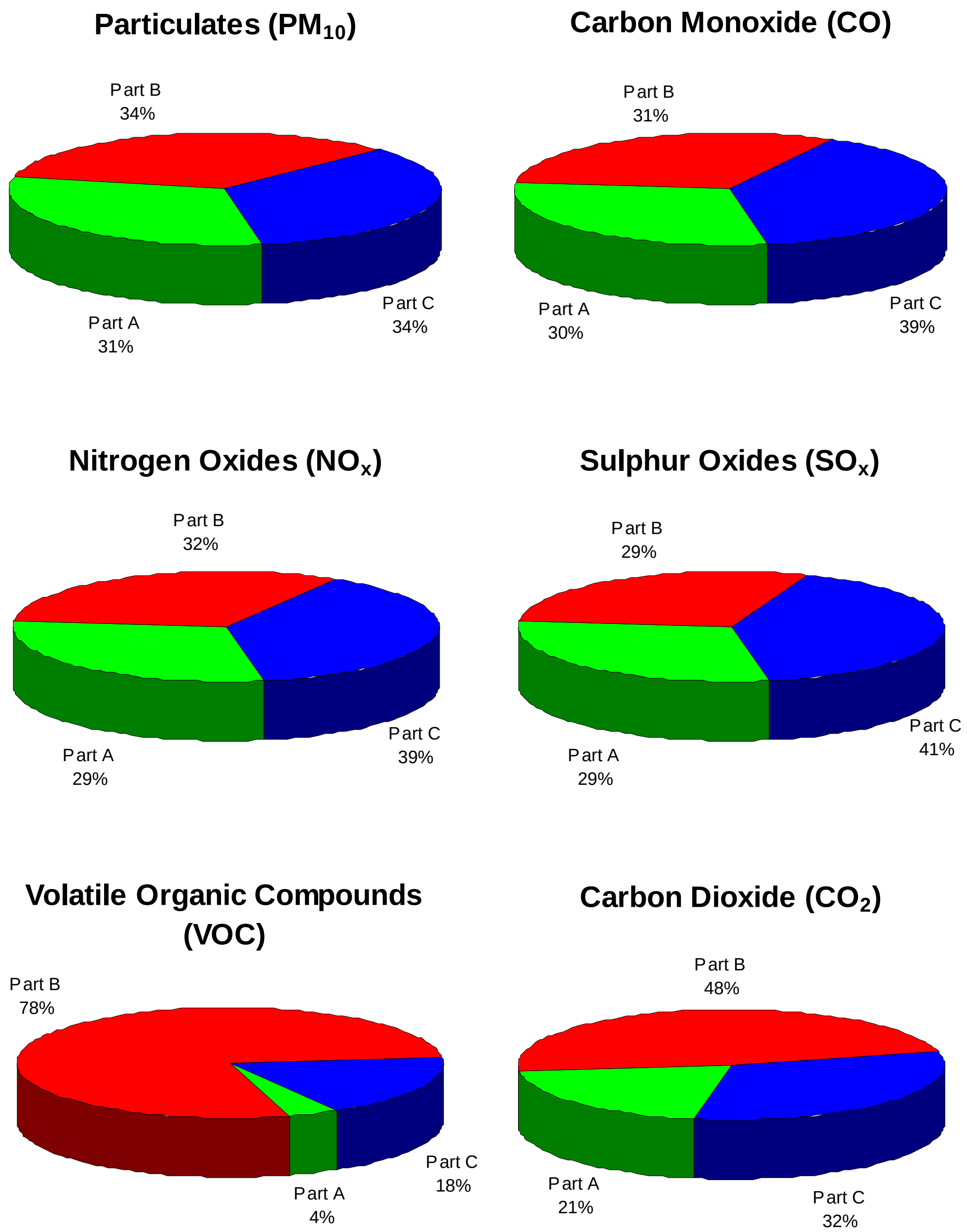


Figure 5.4 Emissions by industry type for the total study area of Timaru.

When examining combustion emissions from Part A, B and C industries more closely, the combustion of solid fuels by Part A industries across Timaru produces approximately a fifth of PM_{10} and CO_2 emissions (19% and 21% respectively), almost a third of CO, NO_x and SO_x emissions (30%, 29% and 29% respectively), and only 4% of VOC. For Part B industries, 8 of the 11 premises (73%) contribute to approximately 15% of PM_{10} and VOC emissions, nearly a third of the CO, NO_x and SO_x (31%, 32% and 29% respectively), and to almost half (48%) of CO_2 emissions from the combustion of solid fuels. Nearly 70% of Part C industries across Timaru (55 in total) emit just over a quarter (26%) of PM_{10} emissions, 39% of CO and NO_x, 41% of SO_x, 7% of VOC and 32% CO_2 emissions from the combustion of solid fuels (Table 5.3).

Process emissions are somewhat different. Actual process operation within Part A industries across Timaru emit 12% of the total industrial PM_{10} emissions. Furthermore, 73% of Part B premises (eight of the 11 in total) emit a fifth (19%) of PM_{10} emissions while approximately 2.5% of Part C industries emit 8% of PM_{10}. Nearly a quarter of the Part C industries emit around 12% of VOC emissions from other processes while 9% of Part B industries emit almost two-thirds (62%).

These results indicate that the nature and size of the industry can influence process emissions. Within Timaru, PM_{10} emissions from other processes are commonly released during the manufacture of concrete, bitumen, food and the processing of animal by-products. VOC emissions are released during the cooking of certain foods and from the application of paints, varnishes, lacquers and thinners.

Individual suburb results can be found in Appendix III.

Table 5.3 Emissions by industry type for the total study area of Timaru.

	PM_{10}			CO			NO_x			SO_x			VOC			CO_2		
	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Part A																		
Combustion	110	55	19	55	28	30	200	100	29	387	194	29	1	1	4	53728	26931	21
Other Processes	73	36	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sub-total	183	92	31	55	28	30	200	100	29	387	194	29	1	1	4	53728	26931	21
Part B																		
Combustion	87	44	15	57	29	31	218	109	32	386	193	29	6	3	16	124296	62304	48
Other Processes	114	57	19	0	0	0	0	0	0	0	0	0	22	11	62	0	0	0
Sub-total	201	101	34	57	29	31	218	109	32	386	193	29	28	14	78	124296	62304	48
Part C																		
Combustion	155	77	26	73	37	39	262	131	39	548	275	41	2	1	7	82080	41143	32
Other Processes	47	23	8	0	0	0	1	0	0	0	0	0	4	2	12	0	0	0
Sub-total	201	101	34	73	37	39	263	132	39	548	275	41	6	3	18	82080	41143	32
Total																		
Combustion	352	176	60	185	93	100	680	341	100	1321	662	100	10	5	27	260104	130378	100
Other Processes	233	117	40	0	0	0	1	0	0	0	0	0	26	13	73	0	0	0
Total	585	293	100	185	93	100	681	341	100	1321	662	100	35	18	100	260104	130378	100

5.4 Industrial Emissions On A Typical Winter's Day - Total

Industrial emissions to the air on a typical winter's day for various study areas of Timaru are presented in Table 5.4 over.

The total study area is estimated to produce approximately 585 kilograms of PM_{10} per day, 185 kilograms of CO, 681 kilograms of NO_x, 1321 kilograms of SO_x, 35 kilograms of VOC and 260104 kilograms of CO_2 per day (Table 5.4).

On a grams per hectare basis (g/ha), the total study area of Timaru is estimated to produce 293 g/ha of PM_{10}, 93 g/ha of CO, 341 g/ha of NO_x, 662 g/ha of SO_x, 18 g/ha of VOC and 130378 g/ha of CO_2 per day (Table 5.4).

On an individual suburb basis (Table 5.4), industrial emissions vary considerably from suburb to suburb. The suburb of Washdyke consistently recorded the highest emissions of all six pollutants under study whereas Maori Hill consistently recorded the lowest. When comparing industrial emissions from these two suburbs, PM_{10} emissions per hectare within Washdyke are approximately 1700 times larger than those estimated for the Maori Hill. CO can be as much as 560 times larger, NO_x over 2000 times larger, SO_x nearly 4000 times greater, VOC approximately 100 times larger and CO_2 around 800000 times larger.

Table 5.5 indicates that the number and type of industries within a study area largely determine industrial pollutant emissions. Suburb areas with few or no industries (such as Western Residential and Maori Hill) tend to exhibit lower pollutant emissions from industrial sources per day whereas suburbs with a greater number of industries (Washdyke, Industrial) displayed higher pollutant emissions.

Table 5.4 Typical winter's day emissions from industry for various study areas of Timaru.

Suburb Area	Area (ha)	PM_{10} kg	PM_{10} % Total	PM_{10} g/ha	CO kg	CO % Total	CO g/ha	NO_x kg	NO_x % Total	NO_x g/ha	SO_x kg	SO_x % Total	SO_x g/ha	VOC kg	VOC % Total	VOC g/ha	CO_2 kg	CO_2 % Total	CO_2 g/ha
Highfield Residential	228	1	0	4	1	0	2	2	0	9	4	0	18	0	0	0	1169	0	5127
Industrial	79	45	8	569	4	2	45	13	2	163	25	2	317	1	4	17	3493	1	44210
Maori Hill	56	0	0	1	0	0	0	0	0	2	0	0	4	0	0	0	29	0	510
Northern Residential	321	2	0	7	1	1	4	5	1	14	9	1	29	0	0	0	1898	1	5914
Southern Residential	447	26	5	59	13	7	29	47	7	104	92	7	206	1	1	1	14440	6	32305
Washdyke	287	497	85	1733	161	87	561	591	87	2060	1143	87	3983	30	86	106	230164	88	801964
Westend and Inner City	282	12	2	42	6	3	21	21	3	75	44	3	155	3	8	10	7805	3	27677
Western Residential	295	1	0	3	1	0	2	2	0	7	4	0	13	0	0	0	1106	0	3750
Total Study Area	1995	585	100	293	185	100	93	681	100	341	1321	100	662	35	100	18	260104	100	130378

Table 5.5 Typical winter's day emissions from industry in descending order of PM_{10} for the various suburb areas of Timaru.

	Industry Type and Number				Pollutant (g/day)					
Suburb Area	Total	A	B	C	PM_{10}	CO	NO_x	SO_x	VOC	CO_2
Washdyke	23	4	7	12	497422	160940	591267	1143081	30447	230163628
Industrial	8	2	2	4	44946	3577	12896	25026	1368	3492573
Southern Residential	18	1	1	16	26482	12741	46620	92069	508	14440460
Westend and Inner City	37	1	0	36	11908	5832	21152	43772	2908	7804942
Northern Residential	10	0	0	10	2404	1231	4515	9153	72	1898335
Highfield Residential	4	0	0	4	969	563	2126	4083	52	1168983
Western Residential	1	0	0	1	906	528	1998	3831	50	1106105
Maori Hill	1	0	0	1	60	28	98	210	1	28539
Average	13	1	1	11	73137	23180	85084	165153	4426	32512946
Median	9	1	0	7	7156	2404	8705	17089	290	2695454

5.5 Industrial Emissions By Time of Day

Across the total study area, just over a third (36%) of CO, NO_x, SO_x and CO_2, and ~40% of PM_{10} and VOC are released between the hours of 10am and 4pm on a typical winter's day. A further third (~30%) of CO, NO_x, SO_x, VOC and CO_2 are emitted between 4pm and 10pm. Just over a quarter (26%) of PM_{10} are also released during this time period. Another quarter of the PM_{10} and VOC emissions (24% each), and just over a fifth (22%) of CO, NO_x, SO_x, and CO_2 are released between 6am and 10am. All pollutants display a low period of emissions between the hours of 10pm and 6am (Figure 5.5 and Table 5.6).

On an individual suburb basis, PM_{10}, CO, NO_x, SO_x, VOC and CO_2 emissions tend to peak between the hours of 10am and 4pm in all suburbs except the Industrial area. Peak PM_{10} and CO emissions in the Industrial suburb were estimated between 10am and 4pm but for NO_x, SO_x, VOC and CO_2, emissions the peak was estimated between the hours of 10pm and 6am.

In five of the eight suburbs (Highfield Residential, Northern Residential, Southern Residential, Westend and Inner City and Western Residential), a secondary peak in PM_{10}, CO, NO_x, SO_x, VOC and CO_2 emissions was estimated between the hours of 6am and 10am. For Maori Hill and Washdyke, the secondary peak in all pollutant emissions tended to be between 4pm and 10pm. For PM_{10} emissions within Maori Hill, the secondary peak was estimated between 6am and 10am (Table 5.7 - Table 5.12).

Again the Industrial suburb displayed a differing pattern to the other suburbs. The secondary peak for PM_{10} and CO emissions occurs between the hours of 6am and 10am while for the other pollutants the secondary peak is recorded between the hours of 10am and 10pm (Table 5.7 - Table 5.12).

Low PM_{10} and CO emissions occur between 10pm and 6am in all eight suburbs. The remaining pollutants also record their lowest emissions between 10pm and 6am in all suburbs except the Industrial area. Within the Industrial area, the lowest period of NO_x, SO_x, VOC and CO_2 emissions tends to be between the hours of 6am and 10am.

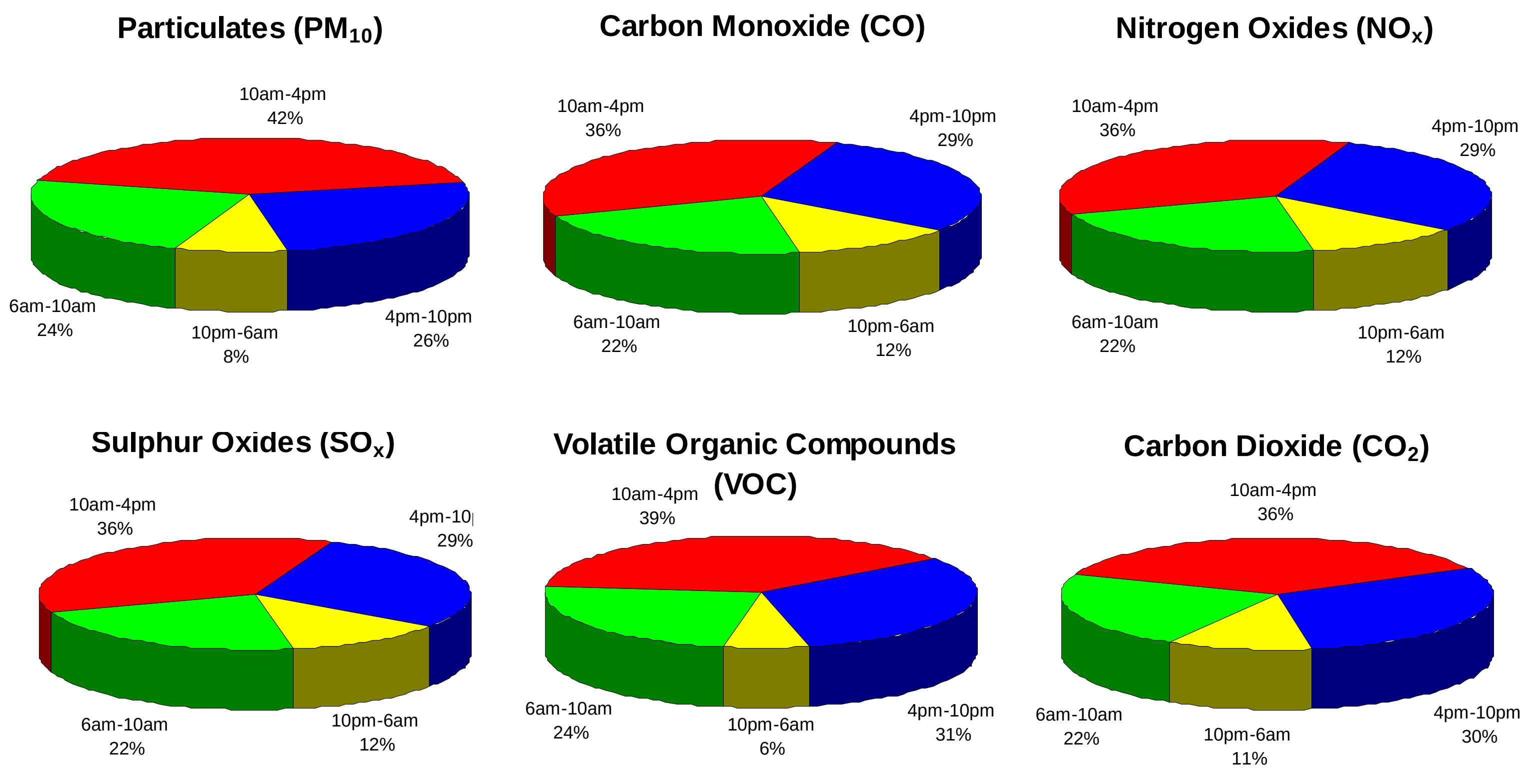


Figure 5.5 Breakdown of industrial emissions for different times of a typical winter's day for the total study area of Timaru.

Table 5.6 Estimated industry emissions for various times of a typical winter's day across the total study area of Timaru.

	PM_{10}			CO			NO_x			SO_x			VOC			CO_2		
	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
6am-10am	138	69	24	41	21	22	151	76	22	292	146	22	8	4	24	58386	29263	22
10am-4pm	248	124	42	67	34	36	247	124	36	480	241	36	14	7	39	94888	47563	36
4pm-10pm	151	76	26	55	27	29	201	101	29	388	195	29	11	6	31	78465	39331	30
10pm-6am	49	24	8	23	11	12	82	41	12	160	80	12	2	1	6	28366	14218	11
Total	585	293	100	185	93	100	681	341	100	1321	662	100	35	18	100	260104	130378	100

Table 5.7 PM_{10} emissions produced at different times of a typical winter's day by industry across various suburb areas of Timaru.

		6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
Suburb Area	Area (ha)	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield Residential	228	0	1	25	1	3	63	0	1	13	0	0	0	1	4	100
Industrial	79	10	130	23	24	300	53	7	90	16	4	50	9	45	569	100
Maori Hill	56	0	0	25	0	1	63	0	0	13	0	0	0	0	1	100
Northern Residential	321	1	2	25	2	5	63	0	1	13	0	0	0	2	7	100
Southern Residential	447	7	15	25	17	37	62	3	7	13	0	0	0	26	59	100
Washdyke	287	117	407	23	197	687	40	139	483	28	45	156	9	497	1733	100
Westend and Inner City	282	3	11	25	7	26	63	1	5	13	0	0	0	12	42	100
Western Residential	295	0	1	25	1	2	63	0	0	13	0	0	0	1	3	100
Total Study Area	1995	138	69	24	248	124	42	151	76	26	49	24	8	585	293	100

Table 5.8 CO emissions produced at different times of a typical winter's day by industry across various suburb areas of Timaru.

		6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
Suburb Area	Area (ha)	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield Residential	228	0	1	25	0	2	63	0	0	13	0	0	0	1	2	100
Industrial	79	1	8	17	1	11	25	1	11	25	1	15	33	4	45	100
Maori Hill	56	0	0	25	0	0	63	0	0	13	0	0	0	0	0	100
Northern Residential	321	0	1	25	1	2	63	0	0	13	0	0	0	1	4	100
Southern Residential	447	3	7	25	8	18	62	2	4	13	0	0	0	13	29	100
Washdyke	287	35	123	22	53	186	33	51	178	32	21	74	13	161	561	100
Westend and Inner City	282	1	5	25	4	13	63	1	3	13	0	0	0	6	21	100
Western Residential	295	0	0	25	0	1	63	0	0	13	0	0	0	1	2	100
Total Study Area	1995	41	21	22	67	34	36	55	27	29	23	11	12	185	93	100

Table 5.9 NO_x emissions produced at different times of a typical winter's day by industry across various suburb areas of Timaru.

		6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
Suburb Area	Area (ha)	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield Residential	228	1	2	25	1	6	63	0	1	13	0	0	0	2	9	100
Industrial	79	2	27	17	3	41	25	3	41	25	4	54	33	13	163	100
Maori Hill	56	0	0	25	0	1	63	0	0	13	0	0	0	0	2	100
Northern Residential	321	1	4	25	3	9	63	1	2	13	0	0	0	5	14	100
Southern Residential	447	12	26	25	29	65	62	6	13	13	0	0	0	47	104	100
Washdyke	287	129	451	22	196	683	33	188	654	32	78	271	13	591	2060	100
Westend and Inner City	282	5	19	25	13	47	63	3	9	13	0	0	0	21	75	100
Western Residential	295	0	2	25	1	4	63	0	1	13	0	0	0	2	7	100
Total Study Area	1995	151	76	22	247	124	36	201	101	29	82	41	12	681	341	100

Table 5.10 SO_x emissions produced at different times of a typical winter's day by industry across various suburb areas of Timaru.

		6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
Suburb Area	Area (ha)	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield Residential	228	1	4	25	3	11	63	1	2	13	0	0	0	4	18	100
Industrial	79	4	53	17	6	79	25	6	79	25	8	105	33	25	317	100
Maori Hill	56	0	1	25	0	2	63	0	0	13	0	0	0	0	4	100
Northern Residential	321	2	7	25	6	18	63	1	4	13	0	0	0	9	29	100
Southern Residential	447	23	51	25	57	129	62	12	26	13	0	0	0	92	206	100
Washdyke	287	250	871	22	378	1319	33	363	1265	32	152	529	13	1143	3983	100
Westend and Inner City	282	11	39	25	27	97	63	5	19	13	0	0	0	44	155	100
Western Residential	295	1	3	25	2	8	63	0	2	13	0	0	0	4	13	100
Total Study Area	1995	292	147	22	480	241	36	388	195	29	160	80	12	1321	662	100

Table 5.11 VOC emissions produced at different times of a typical winter's day by industry across various suburb areas of Timaru.

		6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
Suburb Area	Area (ha)	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield Residential	228	0	0	25	0	0	63	0	0	13	0	0	0	0	0	100
Industrial	79	0	4	24	1	10	60	0	2	13	0	0	2	1	17	100
Maori Hill	56	0	0	25	0	0	63	0	0	13	0	0	0	0	0	100
Northern Residential	321	0	0	25	0	0	63	0	0	13	0	0	0	0	0	100
Southern Residential	447	0	0	25	0	1	62	0	0	13	0	0	0	1	1	100
Washdyke	287	7	25	24	11	37	35	10	36	34	2	8	7	30	106	100
Westend and Inner City	282	1	3	25	2	6	63	0	1	13	0	0	0	3	10	100
Western Residential	295	0	0	25	0	0	63	0	0	13	0	0	0	0	0	100
Total Study Area	1995	8	4	24	14	7	39	11	6	31	2	1	6	35	18	100

Table 5.12 CO_2 emissions produced at different times of a typical winter's day by industry across various suburb areas of Timaru.

		6am-10am			10am-4pm			4pm-10pm			10pm-6am			Daily Total		
Suburb Area	Area (ha)	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Highfield Residential	228	292	1282	25	731	3204	63	146	641	13	0	0	0	1169	5127	100
Industrial	79	583	7383	17	873	11052	25	873	11052	25	1163	14722	33	3493	44210	100
Maori Hill	56	7	127	25	18	319	63	4	64	13	0	0	0	29	510	100
Northern Residential	321	475	1478	25	1186	3696	63	237	739	13	0	0	0	1898	5914	100
Southern Residential	447	3601	8056	25	8984	20098	62	1819	4069	13	37	82	0	14440	32305	100
Washdyke	287	51200	178397	22	77526	270126	34	74272	258787	32	27166	94654	12	230164	801964	100
Westend and Inner City	282	1951	6919	25	4878	17298	63	976	3460	13	0	0	0	7805	27677	100
Western Residential	295	277	937	25	691	2343	63	138	469	13	0	0	0	1106	3750	100
Total Study Area	1995	58386	29263	22	94888	47563	36	78465	39331	30	28366	14218	11	260104	130378	100

6. COMBINED EMISSIONS

6.1 How Do Industrial Emissions Compare With Motor Vehicle Emissions And Home Heating Emissions?

Across the total study area of Timaru, two thirds of PM_{10} emissions, half of CO and VOC and just over a quarter (27%) of CO_2 emissions to the air on a typical winter's day result from domestic solid fuel heating. Nearly three quarters (73%) of NO_x, nearly half of the CO and VOC (49%), and just over a third (35%) of the CO_2 emissions are derived from motor vehicles. Nearly all SO_x emissions (80%), 38% of CO_2, 29% of PM_{10} and 23% of NO_x stem from industrial sources (Table 6.1).

Three quarters of the suburbs (the results of which can be found in Appendix III), more PM_{10} emissions to the air on a typical winter's day result from domestic solid fuel heating than from motor vehicles or industry. Motor vehicles emit more NO_x and CO_2 than home heating or industry in 88% and 63% of the suburbs respectively. Highfield, Northern, Southern and Western Residential areas emit more CO and VOC from home heating than from motor vehicles or industry. In the Industrial area, Maori Hill, Washdyke and Westend and Inner City, more CO and VOC's are emitted from motor vehicles than from home heating or industry. Half of the suburbs (Highfield, Northern and Southern Residential areas, and Maori Hill) emit more SO_x from home heating, 38% of the suburbs emit more SO_x from industry (the Industrial area, Washdyke and Westend and Inner City) while Western Residential emits more SO_x from motor vehicles.

The combined emissions for the various study areas do not account for variations in local air quality that result from differing dispersion methods. Pollutants emitted from domestic home heating are expected to produce more uniform concentrations throughout the airshed because of greater regularity between sources and the height at which the pollutants are released. Motor vehicle and industrial emissions however, can result in much higher localised concentrations when compared to home heating emissions. Pollutants from motor vehicles tend to be released at exhaust height and are usually concentrated along the narrow corridors of the roading system within a suburb area. Industrial emissions tend to be released from single point sources within an area.

Another factor that also needs to be noted when considering PM_{10} emissions from motor vehicles is that the calculations used in this study only relate to emissions of primary particulate direct from the vehicle exhaust. Other pollutants emitted from motor vehicles, such as sulphur oxides and nitrogen oxides, can react later in the atmosphere to form secondary particulate. While quantifying this effect is outside the scope of this project, the contribution from this source is expected to be relatively minor compared to the contribution from domestic fires.

Table 6.1 Home heating, motor vehicle and industry emissions for the total study area.

	PM_{10}			CO			NO_x			SO_x			VOC			CO_2		
	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Home Heating	1347	675	66	8612	4317	50	126	63	4	240	120	14	2153	1079	50	188023	94247	27
Motor Vehicles	110	55	5	8438	4229	49	2161	1083	73	93	47	6	2071	1038	49	235391	117990	34
Industry	585	293	29	185	93	1	681	341	23	1321	662	80	35	18	1	260104	130378	38
Total	2042	1024	100	17235	8639	100	2968	1488	100	1654	829	100	4259	2135	100	683518	342616	100

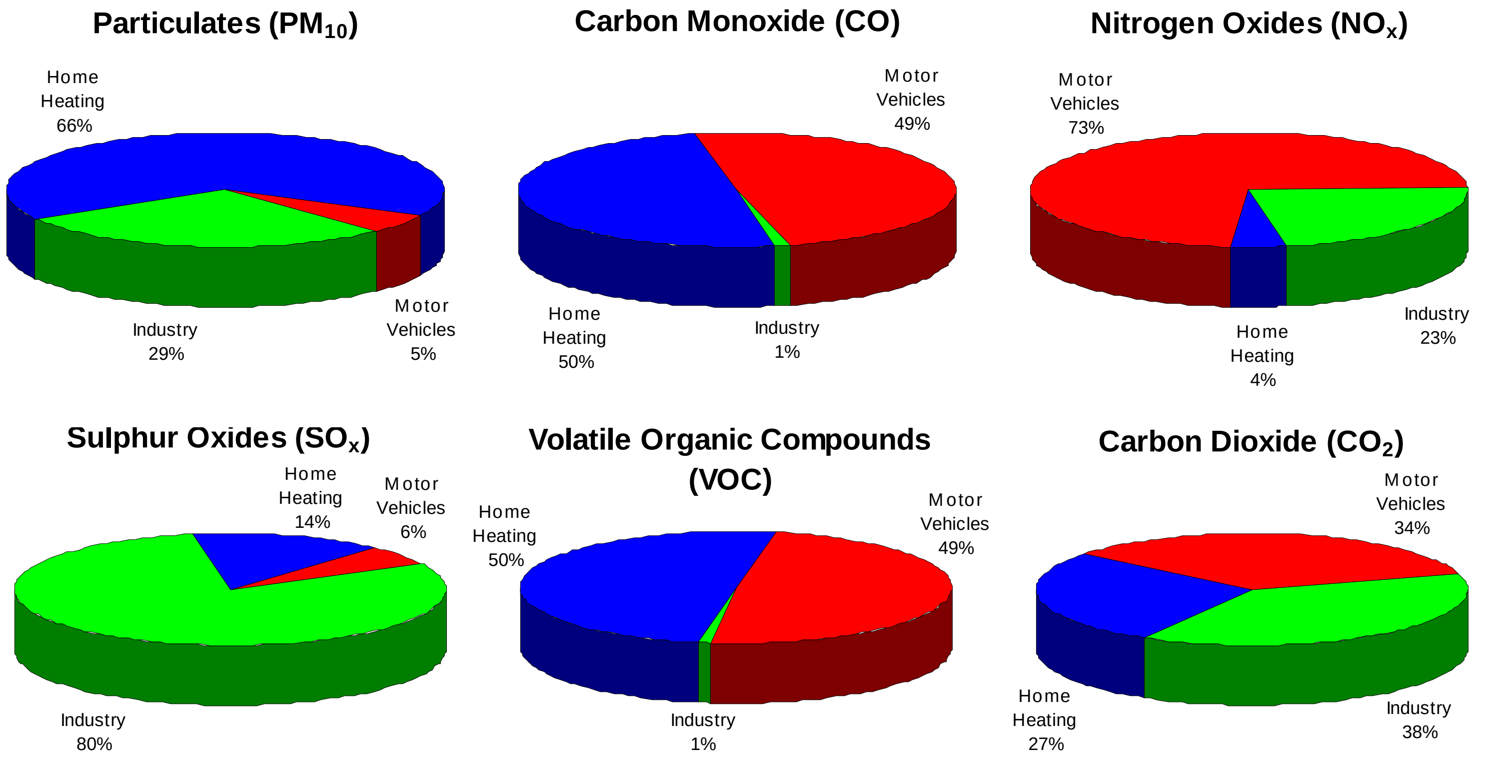


Figure 6.1 Comparison of home heating and motor vehicle emissions of PM_{10}, CO, NO_x, SO_x, VOC, and CO_2 for a typical winter's day for the total study area of Timaru.

6.2 How Do Combined Emissions Vary With The Time Of Day?

Across the total study area, combined home heating, motor vehicle and industrial PM_{10}, CO, SO_x, VOC and CO_2 emissions peak between the hours of 4pm and 10pm (which also coincides with the onset of temperature inversion conditions) (Table 6.2). Combined NO_x emissions peak between 10am and 4pm (which coincides with high VKTs from Table 4.4). Combined PM_{10}, CO, NO_x, SO_x, VOC and CO_2 emissions are at their lowest between 10pm and 6am (which also coincides with lower VKTs from Table 4.4 and reduced industry operation from Table 5.6).

This pattern for combined emissions is slightly different to that of the separate source emissions (Table 6.2). Solid fuel heating emissions of PM_{10}, CO, NO_x, SO_x, VOC and CO_2 peak between 4pm-10pm and are at their lowest between 6am-10am (except for SO_x which is lowest between 10pm and 6am). The peak period for all motor vehicle emissions and industry however, tends to occur between 10am and 4pm while the low period occurs from 10pm to 6am.

Across the individual suburbs, combined motor vehicle, solid fuel heating and industrial emissions of PM_{10}, CO, VOC and CO_2 peak between the hours of 4pm-10pm in all suburbs except Industrial and Washdyke (Appendix III). Combined NO_x and SO_x emissions from Highfield, Northern, Southern and Western Residential areas, and in Westend and Inner City and Maori Hill, peak between 10am and 10pm. Within the Industrial area and Washdyke, combined emissions peak between 10am and 4pm. The only exception to this is combined CO and VOC emissions in Washdyke (which peak between 4pm and 10pm). Combined emissions of all six pollutants tended to be lowest between the hours of 10pm and 6am across all suburbs except for PM_{10} and CO emissions in Western Residential, and SO_x emissions in Industrial (which displayed the low between 6am and 10am).

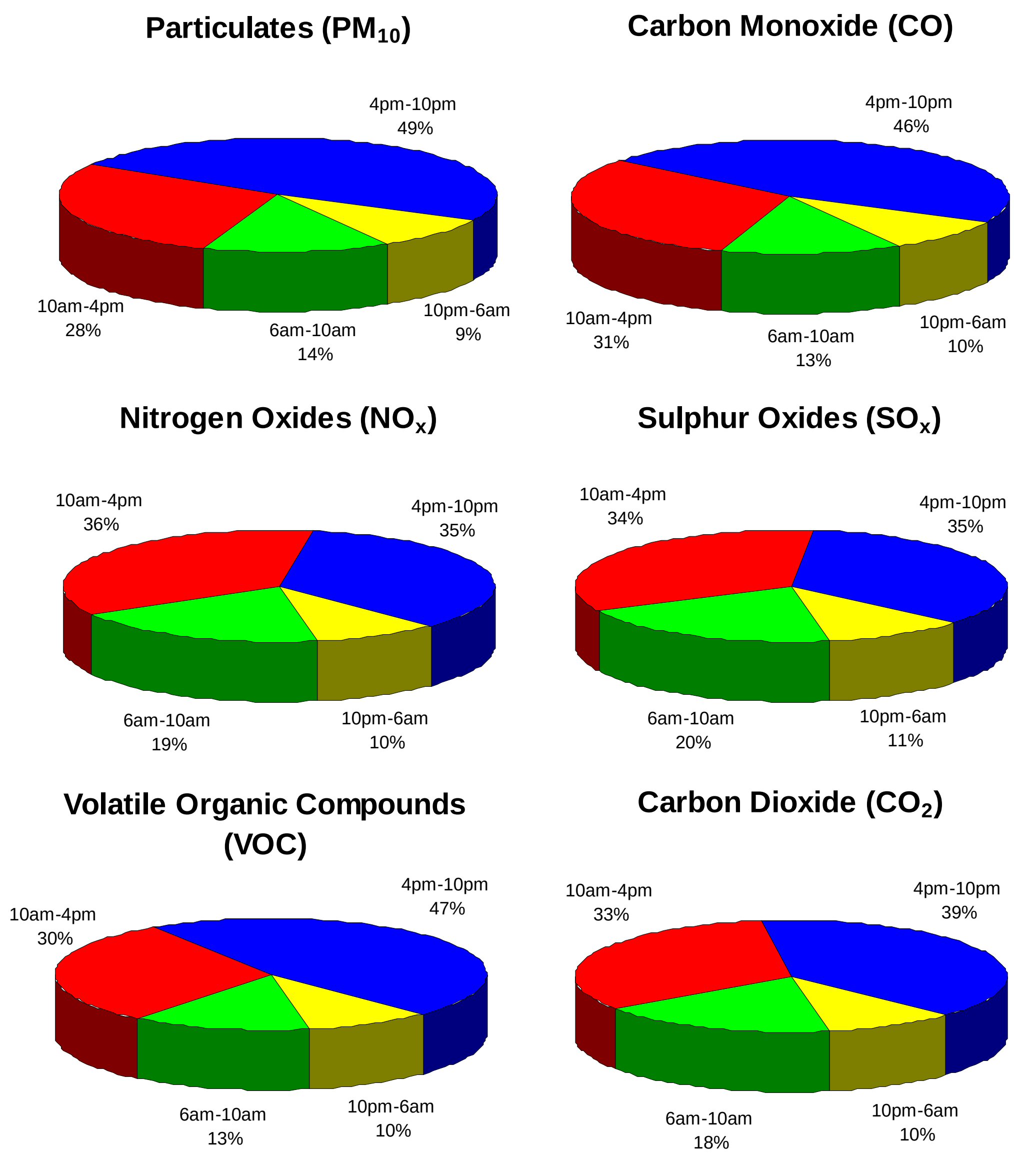


Figure 6.2 Comparison of home heating, motor vehicle and industrial PM_{10}, CO, NO_x, SO_x, VOC and CO_2 emissions for various times of a typical winter's day for the total study area of Timaru.

Table 6.2 Combined estimated pollutant emissions for various times of a typical winter's day across the total study area of Timaru.

	PM_{10}			CO			NO_x			SO_x			VOC			CO_2		
	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total	kg	g/ha	% Total
Home Heating																		
6am-10am	124	62	9	801	401	9	12	6	9	24	12	10	200	100	9	18998	9523	10
10am-4pm	288	144	21	1819	912	21	27	13	21	51	25	21	455	228	21	40419	20260	21
4pm-10pm	805	404	60	5033	2523	58	74	37	59	154	77	64	1258	631	58	108746	54509	58
10pm-6am	129	65	10	956	479	11	13	7	11	11	5	5	239	120	11	19738	9894	10
Total	1347	675	100	8612	4317	100	126	63	100	240	120	100	2153	1079	100	188023	94247	100
Motor Vehicles																		
6am-10am	20	10	18	1433	719	17	415	208	19	17	9	19	364	183	18	43963	22037	19
10am-4pm	42	20	38	3424	1716	41	786	394	36	35	18	38	817	409	39	88075	44148	37
4pm-10pm	39	19	35	2920	1463	35	765	383	35	33	16	35	721	361	35	82853	41531	35
10pm-6am	9	5	9	661	331	8	194	97	9	8	4	9	169	85	8	20499	10275	9
Total	110	55	100	8438	4229	100	2161	1083	100	93	47	100	2071	1038	100	235391	117990	100
Industry																		
6am-10am	138	69	24	41	21	22	151	76	22	292	146	22	8	4	24	58386	29263	22
10am-4pm	248	124	42	67	34	36	247	124	36	480	241	36	14	7	39	94888	47563	36
4pm-10pm	151	76	26	55	27	29	201	101	29	388	195	29	11	6	31	78465	39331	30
10pm-6am	49	24	8	23	11	12	82	41	12	160	80	12	2	1	6	28366	14218	11
Total	585	293	100	185	93	100	681	341	100	1321	662	100	35	18	100	260104	130378	100
Combined Total																		
6am-10am	282	141	14	2275	1140	13	578	290	19	333	167	20	572	287	13	121347	60826	18
10am-4pm	578	290	28	5310	2662	31	1060	531	36	566	284	34	1286	645	30	223382	111971	33
4pm-10pm	995	499	49	8008	4014	46	1040	521	35	575	288	35	1990	997	47	270064	135370	40
10pm-6am	187	94	9	1640	822	10	289	145	10	179	90	11	410	206	10	68603	34387	10
Total	2042	1024	100	17235	8639	100	2968	1488	100	1654	829	100	4259	2135	100	683518	342616	100

7. KEY FINDINGS

From this study the following key results have been identified:

Methods of Home Heating:

- Multiple methods of home heating occur within main living area of the same household on a typical winter's day.
- Electricity is used by almost two thirds (63%) of household across the total study area of Timaru to heat the main living area on a typical winter's day.
- Approximately 940 households use an open fire on a typical winter's day to heat the main living area. This equates to approximately 10% of the total number of households in the total study area, and nearly 17% of solid fuel burning appliances in use.
- Approximately 4240 households use woodburners to heat the main living area on a typical winter's day (approximately 43% of the total number of households across Timaru and just over three quarters of solid fuel burning appliances in use).

Wood and Coal Use:

- By weight, the use of wood on a typical winter's day within the total study area is approximately seven times greater that the use of coal (90 tonnes of wood compared to 12 tonnes of coal).
- Nearly half (42%) of the daily coal consumption is burnt on open fires while 41% is burnt on woodburners. Sixteen percent of the daily coal consumption is burnt on enclosed coal burners and on pot bellies (8% each). Three quarters (77%) of the daily firewood consumption is burnt on woodburners, 18% on open fires, 3% on enclosed coal burners and 2% on pot bellies.

Home Heating Emissions:

- The burning of wood and coal on open fires across the total study area is estimated to produce nearly a third (31%) of the home heating PM_{10} emissions while the burning of wood on woodburners produces half. Only a small proportion (5%) of PM_{10} emissions stem from the burning of wood and coal on enclosed coal burners.
- Open fires are responsible for just over a quarter of home heating CO, NO_x and VOC emissions (27%, 28% and 27% respectively), 40% of SO_x emissions, and 23% of CO_2 emissions. Of those emissions, wood burning on an open fire produces between a fifth and a quarter of CO, VOC and NO_x (23%, 23% and 22% respectively), 1% of SO_x emissions, and 15% of CO_2 emissions. Coal burning on an open fire makes up the difference.
- The burning of wood and coal on woodburners across Timaru produces approximately two thirds of home heating CO, NO_x, VOC and CO_2 emissions (65%, 63% 65% and 70% respectively), and 45% of SO_x emissions. Of those emissions, wood burning on a woodburner produces nearly two-thirds the CO, NO_x, VOC and CO_2 (63%, 59%, 63% and 62% respectively), and only 6% of the SO_x. Coal burning on a woodburner makes up the difference.
- Across the total study area, less that 10% of CO, NO_x, VOC and CO_2 emissions stem from other burners (pot bellies and enclosed coal burners only). In the case of SO_x, 14% of emissions stem from the burning of coal on pot bellies and enclosed coal burners.
- The total study area is estimated to produce approximately 1347 kilograms of PM_{10} per day, 8612 kilograms of CO, 126 kilograms of NO_x, 240 kilograms of SO_x, 2153 kilograms of VOC and 188023 kilograms of CO_2.
- On a grams per hectare basis (g/ha), the total study area is estimated to produce approximately 675 g/ha of PM_{10} per day, 4317 g/ha of CO, 63 g/ha of NO_x, 120 g/ha of SO_x, 1079 g/ha of VOC and 94247 g/ha of CO_2.

- On an individual suburb basis, PM_{10} emissions per hectare in Maori Hill can be as much as eight times larger than those in Washdyke. CO, VOC, CO_2 and NO_x can be as much as seven times larger and SO_x 13 times greater.
- Across the total study area, between 58% and 64% of PM_{10}, CO, NO_x, SO_x, VOC, and CO_2 are emitted between 4pm and 6am on a typical winter's night. The next highest period of emissions occurs between 10am and 4pm across all pollutants (approximately a fifth of each pollutant released during this time).
- Estimated PM_{10}, CO, NO_x, SO_x, VOC, and CO_2 emissions are lowest between the hours of 6am and 10am when around 10% of the total daily emissions are released.

Motor Vehicle Emissions:

- Suburbs with larger vehicle kilometres travelled (VKT) values and more major traffic routes display higher emissions of the six pollutants than suburbs with lower VKTs values.
- Light duty petrol vehicles are the main emitters of CO (88%), VOC (83%), and CO_2 (~70%). Heavy duty diesel vehicles tend to emit larger quantities of PM_{10} (67%) and SO_x (88%). A further fifth (21%) of CO_2 emissions stem from heavy duty diesel vehicles while just over a quarter (26%) of PM_{10} emissions are derived from light duty petrol vehicles. Both light duty petrol vehicles and heavy duty diesel vehicles release approximately half the NO_x (50% and 45% respectively).
- The total study area is estimated to produce approximately 110 kilograms of PM_{10} per day, over 8400 kilograms of CO, approximately 2100 kilograms of NO_x and VOC, 93 kilograms of SO_x, 2071 kilograms of VOC and nearly 235,000 kilograms of CO_2. On a grams per hectare basis (g/ha), the total study area emits approximately 55 g/ha of PM_{10} per day, 4230 g/ha of CO, around 1100 g/ha of NO_x, 47 g/ha of VOC, 1038 g/ha of SO_x, and nearly 118,000 g/ha of CO_2.
- On an individual suburb basis, PM_{10}, SO_x, and CO_2 emissions per hectare in Maori Hill are approximately four times larger than those in Western Residential. Carbon Monoxide can be as much as eight times larger, NO_x three times larger and VOC six times greater.
- On average, approximately 40% of all motor vehicle emissions of PM_{10}, CO, NO_x, SO_x, VOC and CO_2 are released between the hours of 10am and 4pm across the total study area. The next highest period of emissions occurs between 4pm and 10pm, during which just over a third (35%) of contaminants are emitted. A further 17%-19% of pollutants are emitted between 6am and 10am. Less than 10% of all pollutants are emitted overnight (between 10pm and 6am).

Industrial Emissions:

- Part C industrial and commercial premises are the main emitters of CO and NO_x (39% each) and SO_x (41%) while Part B industries emit larger quantities of VOC (78%) and CO_2 (48%). Part A, B and C industries emit relatively equal quantities of PM_{10} (31%, 34% and 34% respectively).
- Part A industries across Timaru emit nearly a fifth of PM_{10} and CO_2, almost a third of CO, NO_x and SO_x, and only 4% of VOC emissions from the combustion of solid fuels. For Part B industries, 8 of the 11 premises (73%) contribute to 15% of PM_{10}, 31% of CO, 32% of NO_x, 29% of SO_x, 16% of VOC and 48% of CO_2 emissions from the combustion of solid fuels. Two thirds of the Part C industries across Timaru (55 in total) emit a quarter (26%) of PM_{10} emissions, 39% of CO and NO_x, 41% of SO_x, 7% of VOC and a third (32%) CO_2 emissions from the combustion of solid fuels.
- The total study area is estimated to produce approximately 585 kilograms of PM_{10} per day, 185 kilograms of CO, 681 kilograms of NO_x, 1321 kilograms of SO_x, 35 kilograms of VOC and 260104 kilograms of CO_2 per day. On a grams per hectare basis (g/ha), the total study area of Timaru produces 293 g/ha of PM_{10}, 93 g/ha of CO, 341 g/ha of NO_x, 662 g/ha of SO_x, 18 g/ha of VOC and 130378 g/ha of CO_2 per day.

- On an individual suburb basis, industrial emissions vary considerably from suburb to suburb. The suburb of Washdyke consistently recorded the highest emissions of all six pollutants under study whereas Maori Hill consistently recorded the lowest. When comparing these two suburbs, PM_{10} emissions per hectare within Washdyke are approximately 1700 times larger than those estimated for the Maori Hill. Carbon monoxide can be as much as 560 times larger, NO_x over 2000 times larger, SO_x nearly 4000 times greater, VOC approximately 100 times larger and CO_2 around 800000 times larger.
- The number and type of industries within a study area largely determine pollutant emissions. Suburb areas with few or no industries tend to exhibit lower pollutant emissions per day whereas suburbs with a larger number of industries displayed higher pollutant emissions.
- Across the total study area, ~35% of CO, NO_x, SO_x and CO_2, and ~40% of PM_{10} and VOC are released between the hours of 10am and 4pm on a typical winter's day. A further 30% of CO, NO_x, SO_x, VOC and CO_2 are emitted between 4pm and 10pm. Just over a quarter (26%) of PM_{10} are also released during this time period. A further quarter (24%) of PM_{10} and VOC, and 22% of CO, NO_x, SO_x, and CO_2 are released between 6am and 10am. All pollutants displayed a low period of emissions between the hours of 10pm and 6am.
- On an individual suburb basis, PM_{10}, CO, NO_x, SO_x, VOC and CO_2 emissions tended to peak between the hours of 10am and 4pm in all suburbs except the Industrial area.
- Five of the eight suburbs (Highfield Residential, Northern Residential, Southern Residential, Westend and Inner City and Western Residential) recorded the next highest peak in PM_{10}, CO, NO_x, SO_x, VOC and CO_2 emissions between the hours of 6am and 10am. For Maori Hill and Washdyke, the secondary peak in all pollutant emissions tended to be between 4pm and 10pm. PM_{10} emissions in Maori Hill however, recorded the secondary peak between 6am and 10am.
- The industrial area recorded the highest PM_{10} and CO emissions between 10am and 4pm but for NO_x, SO_x, VOC and CO_2, emissions peaked between the hours of 10pm and 6am. The secondary peak for PM_{10} and CO emissions occurred between the hours of 6am and 10am while for the other pollutants the secondary peak was recorded between the hours of 10am and 10pm.
- Low PM_{10} and CO emissions were displayed between 10pm and 6am in all eight suburbs. The remaining pollutants also recorded their lowest emissions between 10pm and 6am in all suburbs except the Industrial area. Within the Industrial area, the lowest period of NO_x, SO_x, VOC and CO_2 emissions tended to occur between the hours of 6am and 10am.

Combined Emissions:

- Across the total study area of Timaru, two thirds of PM_{10} emissions, half of CO and VOC, and just over a quarter (27%) of CO_2 emissions to the air on a typical winter's day result from domestic solid fuel heating. Approximately 73% of NO_x, 49% of CO and VOC, and just over a third (35%) of CO_2 emissions are derived from motor vehicles. Nearly all SO_x emissions (80%), 38% of CO_2, 29% of PM_{10} and 23% of NO_x are derived from industrial sources.
- In three-quarters of the suburbs, more PM_{10} emissions to the air on a typical winter's day result from domestic solid fuel heating than from motor vehicles or industry. Motor vehicles emit more NO_x and CO_2 than home heating or industry in 88% and 63% of the suburbs respectively. Highfield, Northern, Southern and Western Residential areas emit more CO and VOC from home heating than from motor vehicles or industry. In the Industrial area, Maori Hill, Washdyke and Westend and Inner City, more CO and VOC's are emitted from motor vehicles than from home heating or industry. Half of the suburbs (Highfield, Northern and Southern Residential areas, and Maori Hill) emit more SO_x from home heating, just over a third (38%) of the suburbs emit more SO_x from industry (the Industrial area, Washdyke and Westend and Inner City) while Western Residential emits more SO_x from motor vehicles.

- Combined home heating, motor vehicle and industrial PM_{10}, CO, SO_x, VOC and CO_2 emissions peak between the hours of 4pm-10pm (which also coincides with the onset of temperature inversion conditions). Combined NO_x emissions peak between 10am and 4pm (which coincides with high VKTs). Combined PM_{10}, CO, NO_x, SO_x, VOC and CO_2 emissions are at their lowest between 10pm-6am (which also coincides with lower VKTs and reduced industry operation).
- Across the individual suburbs, combined motor vehicle, solid fuel heating and industrial emissions of PM_{10}, CO, VOC and CO_2 peak between the hours of 4pm-10pm in all suburbs except Industrial and Washdyke (Appendix III). Combined NO_x and SO_x emissions from Highfield, Northern, Southern and Western Residential areas, and in Westend and Inner City and Maori Hill, peak between 10am and 10pm. Within the Industrial area and Washdyke, combined emissions peak between 10am and 4pm. The only exception to this is combined CO and VOC emissions in Washdyke (which peak between 4pm and 10pm). Combined emissions of all six pollutants tended to be lowest between the hours of 10pm and 6am across all suburbs except for PM_{10} and CO emissions in Western Residential, and SOx emissions in Industrial (which displayed the low between 6am and 10am).

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APPENDICES

I Suburb Boundaries
II Home Heating Survey Questionnaire
III Individual Suburb Results
IV Industry Definitions
V Process Emission Factors