Air Quality Trends in the Illawarra

Current knowledge based on emission, monitoring and modelling studies, and areas of ongoing research

September 2015

Acknowledgements:

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Cover: View of the Illawarra from Sublime Point. Photo: Jen Byrne/EPA

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ISBN: 978-1-76039-108-9
OEH 2015/0587
September 2015

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Air Quality Trends in the Illawarra provides an overview of how air quality has varied in the Illawarra region over the 1992 to 2014 period, based primarily on data from the Office of Environment and Heritage (OEH) air quality monitoring network. Reference is also made to information from emission inventories, particle speciation studies and modelling research, while the environmental factors affecting air quality and its impacts are also discussed. This report is intended to inform air policies and programs implemented by NSW Environment Protection Authority (EPA) to improve air quality in the region.

Regional context and air quality

The Illawarra region on the NSW east coast includes Wollongong, Shellharbour and Kiama local government areas (LGAs) with a combined population of about 300,000 people. The proximity to the coast and topography influences the local meteorology and therefore the air quality of the region, with the escarpment and land–sea breeze circulation affecting wind patterns and the height to which air pollutants can mix.

Air quality monitoring has been undertaken by OEH in the Illawarra since 1992, with carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), particulate matter (PM_{10}, $PM_{2.5}$) and ozone (O_3) measured at several sites to assess regional air quality affecting the general population. Air quality in the Illawarra has been observed to be comparable with cities in New South Wales and other Australian jurisdictions, and good by world standards. CO, NO_2 and SO_2 concentrations have generally decreased since the 1990s, with recent measured levels within national air quality standards.

Particle levels (PM_{10} and $PM_{2.5}$) and ozone concentrations in the Illawarra are comparable with the levels measured in Australian cities and below levels measured in several countries abroad. However, these pollutants do exceed national standards from time to time, posing pollution-related health risks to local communities. Health effects due to exposures to ambient particle and ozone concentrations are also known to occur at levels which are below national standards.

Ground-level ozone is a secondary photochemical pollutant formed in the air when precursor pollutants, oxides of nitrogen (NOx) and volatile organic compounds (VOCs), react in the presence of sunlight. Particle pollution incudes primary particles released directly from sources, and secondary particles produced by chemical reactions between gases or between gases and other particles in the air. The composition of $PM_{2.5}$ has been found to typically include ammonium sulfate, sea salt, black carbon, organic matter and soil. This indicates that particle and gaseous emissions from natural and human-made sources contribute to ambient $PM_{2.5}$ concentrations.

Exceedances of particle standards often coincide with regional dust storms or bushfire events. High ozone levels can occur as a result of photochemical smog produced from local emissions, smog or precursors transported down the coast from Sydney, or emissions from inland bushfires. Exceedances of the ozone standards generally occur during the warmer months of the year, with peaks coinciding with periods of high temperatures and with regional bushfire events.

Air emission sources in the Illawarra

Whereas the importance of interregional transport of air pollutants is recognised, an overview of air pollution sources situated in the Illawarra is provided in the report. Major sources contributing to total regional and LGA emissions were identified based on the most recent NSW Greater Metropolitan Region (GMR) Air Emissions Inventory, undertaken for the 2008 calendar year. Trends in source emissions were evaluated by comparing information from the 2003 and 2008 GMR emission inventories, with reference also made to industry-reported emissions data from the National Pollutant Inventory (NPI) for the 2008 to 2013 period.

Major sources of particle emissions in the Illawarra are industrial (70% of $PM_{2.5}$ and 81% of PM_{10} emissions) and domestic–commercial sources (12% of $PM_{2.5}$ and 20% of PM_{10} emissions). Iron and steel production, and mining and extractive activities account for the bulk of industrial emissions. Residential wood heating accounts for over 90% of particle emissions from domestic–commercial sources. Other sources of particle emissions include on-road and non-road mobile sources.

Significant sources of VOC emissions are natural (45%), domestic–commercial (30%) and on-road mobile (10%). In the natural source category, biogenic emissions from vegetation is the largest source. The use of solvents, aerosols and surface coatings by households and commercial businesses accounts for about half of the VOC emissions from domestic–commercial sources.

Notable sources of NOx emissions are industrial (60%), on-road mobile (26%), and non-road mobile (11%). Iron and steel production is the greatest industrial source. Industrial sources account for about 98% of the SO_2 emissions in the Illawarra in 2008, with iron and steel production contributing the bulk of these emissions. The highest levels of particle, SO_2 and ground-level ozone precursor emissions in the Illawarra occur in the industrial areas at Port Kembla.

Total on-road mobile emissions reduced over the 2003 to 2008 period due to advances in vehicle technology, more stringent national vehicle emission standards and the introduction of cleaner fuels, despite increases in vehicle activity. Reductions in vehicle emissions are projected to continue over the next 10 to 20 years in spite of the continued increase in vehicle activity. However, some transport routes may experience an increase in vehicle emissions due to more substantial growth in activity rates. Residential development along major transport corridors can also increase the potential for greater exposure to air pollutants being released from transport corridors.

No emission standards are in place for non-road mobile sources, which include diesel-powered construction and mining equipment, rail locomotives, equipment at ports and ships. This sector is the largest source of fine particles that remains largely unregulated. Increases in particle, NOx and VOC emissions from non-road mobile sources between 2003 and 2008 occurred mainly because of increased activity levels. The lower SO_2 emissions from non-road mobile sources was largely due to refinements in the data and methods used for estimating shipping emissions. Due to reductions in the sulfur content of diesel fuel prescribed by national fuel quality standards, lower SO_2 emissions were estimated for industrial non-road vehicles.

Particle, SO_2, NOx and VOC emissions from industrial and commercial sources decreased over the 2003 to 2008 period. Regulation of EPA-licensed premises including the application of increasingly stringent emission standards under the Protection of the Environment Operations (POEO) Clean Air Regulation and the implementation of pollution reduction programs is expected to have contributed to the reduction in emissions. Based on NPI-reported facility data, emissions have increased in 2009–10 and 2010–11 but decreased in more recent years. Changes in emissions at the Port Kembla steelworks have contributed to the increase and subsequent reduction in recent years. Advances in emission estimation techniques accounted in part for lower commercial source emissions in 2008.

Emissions from biogenic (i.e. natural and living) and geogenic (i.e. natural non-living) sources include wind erosion of exposed areas, agricultural burning, bushfires and prescribed burning. These emissions typically vary from year to year, with higher emissions occurring during hotter, dryer years. Higher biogenic and geogenic emissions were estimated to occur in 2003 due to greater bushfire activity.

A 24% increase in fine particle emissions from domestic–commercial sources occurred over the 2003 to 2008 period, due to equivalent increases in residential wood heater emissions.

Future air quality

Factors affecting future air quality in the Illawarra include regional growth, changes in transport and industrial activity levels, and changes in climate and air quality management practices. Potential reductions in on-road and industrial emissions in the region due to progressively more stringent regulation and the general decline in industrial activity may be offset by increased non-road mobile emissions and residential emissions (wood heaters; aerosols, solvent and surface coatings use).

Changes in climate are also projected to affect future air quality in the region. Based on modelling by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), climate change is projected to increase the number of days exceeding the ozone standard in the Illawarra and the geographical extent of ozone impacts, as a result of increased temperatures. Changes to rainfall, temperature and weather patterns may also increase the frequency of dust storms and bushfire-related pollution events, leading to higher particle emissions.

Research to further extend the evidence base

Future research will contribute to a better understanding of air pollution sources and impacts in the region. Major research efforts by OEH, EPA and leading science partners include the following:

- **Emissions inventory –** EPA is updating the NSW GMR Air Emissions Inventory for the 2013 calendar year to improve the evidence on source contributions to total emissions. The inventory update will include improvements, such as the inclusion of additional sources and particle components to support regional particle modelling.
- **Regional airshed modelling –** OEH's Regional Airshed Modelling Program is being implemented to progressively advance photochemical and secondary particle modelling capabilities to enhance the evidence base for NSW air policy and support development planning.
- **Air quality forecasting –** The OEH Air Quality Forecasting Program is progressively expanding the scope and enhancing the accuracy of air quality forecasting capabilities in New South Wales. The intention is to design and develop a scalable, cost-effective and fit-for-purpose forecasting capability, with a focus on forecasting ozone and particle pollution within the GMR and key regional areas of New South Wales.

- **Particle characterisation –** OEH, EPA and NSW Health continue to collaborate with Australian Nuclear Science and Technology Organisation (ANSTO) and CSIRO to undertake particle speciation and source apportionment studies in New South Wales. To date, particle speciation studies have been undertaken for Sydney (OEH 2014a) and the Upper Hunter (Hibberd et al. 2013) and a further study is underway in the Lower Hunter (OEH 2015a). $PM_{2.5}$ sampling and characterisation at Warrawong in the Illawarra, conducted as part of ANSTO's east coast Aerosol Sampling Program (ASP), is ongoing and allows changes in particle composition over time to be tracked and compared to particle composition measured at other sites.
- **Emerging monitoring techniques for rapid response** – OEH recently established rapid response air quality monitoring capabilities for deployment within New South Wales, with OEH and EPA devising procedures to guide the implementation of such incidence monitoring and the assessment and communication of measurement results. OEH's monitoring includes two portable stations able to hold up to seven air quality monitors that comply with Australian Standards and the National Environment Protection Measure (NEPM) for Ambient Air Quality (the 'AAQ NEPM'), non-compliance monitors for rapid deployment and 'indicative' measurement to support immediate decision-making, meteorological monitors, telemetry and communications systems and web reporting capabilities for incident monitoring. To further extend these capabilities OEH is investigating air toxics sampling methods and emerging technologies.
- **Black carbon monitoring** – Black carbon is a major component of airborne fine particulate matter in urban areas and has received increasing attention internationally due to its effects on urban air quality, public health and global climate. Although the monitoring of black carbon is not required by Australian legislation, OEH is trialling the measurement of Equivalent Black Carbon (EBC) using AE33 aethalometers at two sites located in the Lower Hunter region. Research into the application of aethalometers to support source apportionment is ongoing.
- **Health effects of air pollution –** EPA, OEH and NSW Health collaborate with the independent Centre for Air Quality and Health Research and Evaluation[1] to initiate new research to increase understanding of the health impacts, risks and costs of air pollution in New South Wales. An evaluation of the health impacts of difference sources, types and levels of airborne particles in New South Wales is due for completion in 2015. EPA, NSW Health, the Centre for Air Pollution and Health Research and Evaluation and CSIRO are collaborating on a study to estimate the health impacts of $PM_{2.5}$ -related shipping emissions in the Greater Metropolitan Region, including Port Kembla. This research is expected to be completed in 2015. EPA is supporting the University of Tasmania in an interstate study on the relative health effects of smoke pollution from bushfire events and planned hazard reduction burns. This is a multi-year study initiated in 2014.
- **Air quality management** – EPA leads a range of projects assessing the technical feasibility and benefits and costs of a range of air pollution mitigation measures. These include the assessment of measures implementable by the industrial and commercial sector, and measures to address emissions from residential wood burning and the non-road mobile sector (industrial vehicles, locomotives, shipping). The EPA-commissioned assessment of the technical feasibility, ship-owner/operator costs and emission impacts of

[1] www.car-cre.org.au

adopting emission reduction measures for shipping in the Greater Metropolitan Region is due for completion during the first half of 2015.

- **Climate change impacts on air quality** – Projections of climate change and related impacts on regional air quality are being undertaken as part of the NSW and ACT Regional Climate Modelling (NARCliM) project, a multi-agency research partnership between the NSW and ACT governments and the Climate Change Research Centre at The University of New South Wales. This research will address future trends in both ozone and particle pollution.

1 Introduction

Community research undertaken by the NSW Government has consistently found that air quality is a key environmental issue for NSW residents (OEH 2012). Providing information to local communities on air quality is listed as a high priority in *NSW 2021 – A plan to make NSW number one* (NSW Government 2014).

The Office of Environment and Heritage (OEH) supports industry and communities in understanding air pollution and their role in making our air cleaner. OEH also gathers and analyses information on air quality in our towns and cities to keep local communities informed about the air they breathe, and works with the NSW Environment Protection Authority (EPA) and NSW Health to provide a scientific basis for measures to reduce air pollution and protect the community's health.

Air Quality Trends in the Illawarra, prepared by OEH, provides an overview of how air quality has varied in this region over the 1992 to 2014 period, based primarily on data from the OEH Illawarra air quality monitoring network. Reference is also made to information from emission inventories, particle speciation studies and modelling research, while a description is also provided about the environmental factors such as topography, population, climate, meteorology and sources of atmospheric emissions which affect air quality and contribute to its impacts.

An overview of the region and available information sources to inform the assessment of air quality trends is provided in Sections 2 and 3 respectively. Air quality trends measured in the Illawarra are discussed in Section 4, with information on sources and emissions of atmospheric emissions provided in Section 5 and air quality modelling studies discussed in Section 6. An overview of research underway to improve our understanding of past, present and future air quality in the Illawarra region is presented in Section 7.

This report is intended to inform air policies and programs implemented by EPA to improve air quality in the region.

2 Overview of the region

The Illawarra region on the NSW east coast, south of Sydney, includes Wollongong, Shellharbour and Kiama local government areas (LGAs) (Figure 1)[2]. An overview of information relevant to regional ambient air quality in the region is provided in this section, including a description of the topography, population, climate and meteorology.

2.1 Population and topography

The combined population of the three LGAs is approximately 300,000 with about 70% of people residing in the Wollongong LGA.

The region has over 100 kilometres of coastline, characterised by long sandy beaches, rivers, large protected estuaries and small coastal bays protected by large sandstone headlands.

The coastal plain is clearly delineated from the rolling hills of the Southern Highlands in the west, by the sharp rise of the Illawarra escarpment which stretches 120 kilometres from the sea cliffs of Royal National Park in the north to the junction of the Shoalhaven and Kangaroo rivers in the south. The escarpment rises from 300 metres above sea level in the north to 700 metres in the south around Albion Park.

Land use in the region includes national parks, agricultural and mineral extractive lands, fisheries and urban areas comprising residential, commercial and industrial areas.

2.2 Regional climate and meteorology

The proximity of the Illawarra region to the coast and its topography significantly influences the local meteorology and hence the air quality of the region. The meteorology influences the generation, dispersion, transportation and eventual removal of pollutants from the atmosphere. The behavior of air pollutants is dependent on the prevailing winds, the stability of the atmosphere, the depth to which pollutants are able to disperse and the amount of rainfall.

2.2.1 Rainfall and temperature

The Illawarra region has a mostly cool temperate climate, with an average annual rainfall slightly under 1100 millimetres. Precipitation is nearly uniformly distributed throughout the year with slight summer–autumn dominance. The highest precipitation occurs to the east of the steep escarpment, south of Wollongong, with an average annual precipitation of over 1600 millimetres. Summers are mild throughout most of the region, with winters cool closer to the Southern Highlands (OEH 2014b).

2.2.2 Regional wind and mixing height

Annual average wind roses (Figure 2) indicate the prevailing winds are largely aligned with the orientation of the coast at coastal meteorological monitoring sites. South-westerly winds are

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[2] This geographical definition of the Illawarra was selected to align with the Illawarra region delineation used in the EPA's air policies and programs.

prevalent at Wollongong, with north-easterly airflow representing the next most prominent flow quadrant. At Bellambi and Kiama, northerly and southerly airflows occur frequently, as do offshore airflows with a westerly component. Inland, airflow patterns are strongly influenced by the local terrain. Southerly to south-easterly flow occurs more frequently at Albion Park South, with westerly winds prevalent at Kembla Grange.

Seasonal wind roses, given in Appendix A, illustrate intra-annual variations in airflow patterns occurring due to seasonal changes in synoptic-scale circulation. During winter, offshore westerly flow occurs frequently over much of the region. During summer, onshore airflow becomes more frequent, with such flow occurring as northerly, north-easterly, southerly and south-easterly winds depending on the configuration of the coastline in relation to monitoring station locations. More varied airflow patterns are characteristic of autumn and spring.

The surface wind field is strongly influenced by topography and local land–sea breezes (Hyde et al. 1997). The escarpment can result in the deflection of surface winds and the decoupling of winds above and below the escarpment. Inversions may form at the top of the escarpment, limiting the dispersion of pollutants in the region. The vertical structure of the atmosphere is also influenced by the land–sea breeze circulation, and the interface between land and marine air masses. Onshore sea breezes occur during the daytime, with return flow observed above the sea breeze in the region. At night, westerly drainage flows from the escarpment have been observed over much of the region (Hyde & Prescott 1984). Diurnal variations in airflow patterns for Wollongong are illustrated in Appendix B. Stronger north-easterly (onshore) wind occurs during the daytime in summer, with the sea breeze strengthened by synoptic circulation patterns. Whereas during the night time in autumn and winter, strong south-westerly (offshore) winds occur as a result of the combined influence of synoptic and land breeze circulations.

The height to which air pollutants are able to mix is termed the ‘mixing depth’. Mixing depth is not routinely measured at meteorological sites and needs to be estimated. Diurnal variations in the mixing depth for Port Kembla, projected using CSIRO’s The Air Pollution Model (TAPM) prognostic meteorological model for 2013, are shown in Figure 3. The mixing depth and extent to which pollution will accumulate or disperse in the atmosphere is dependent on the degree of thermal (convective) and mechanical turbulence. Mixing depth typically increases during the day as the heat from the sun promotes convective mixing, with maximum depths occurring in the mid to late afternoon periods at the time of peak solar energy. High wind speeds in combination with surface roughness generate mechanical turbulence which enhances the extent of the mixing zone.

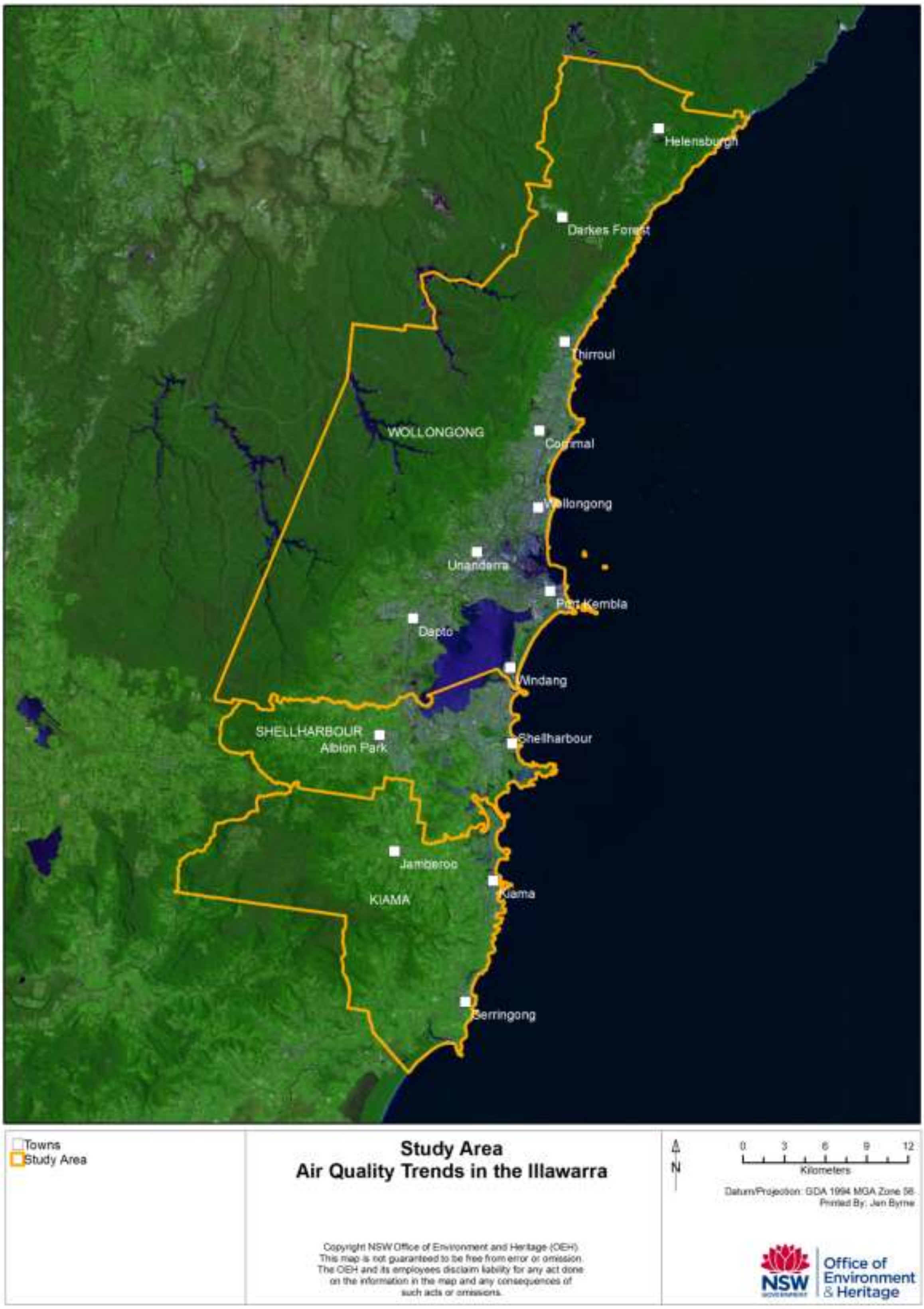


Figure 1: Study area for *Air Quality Trends in the Illawarra*

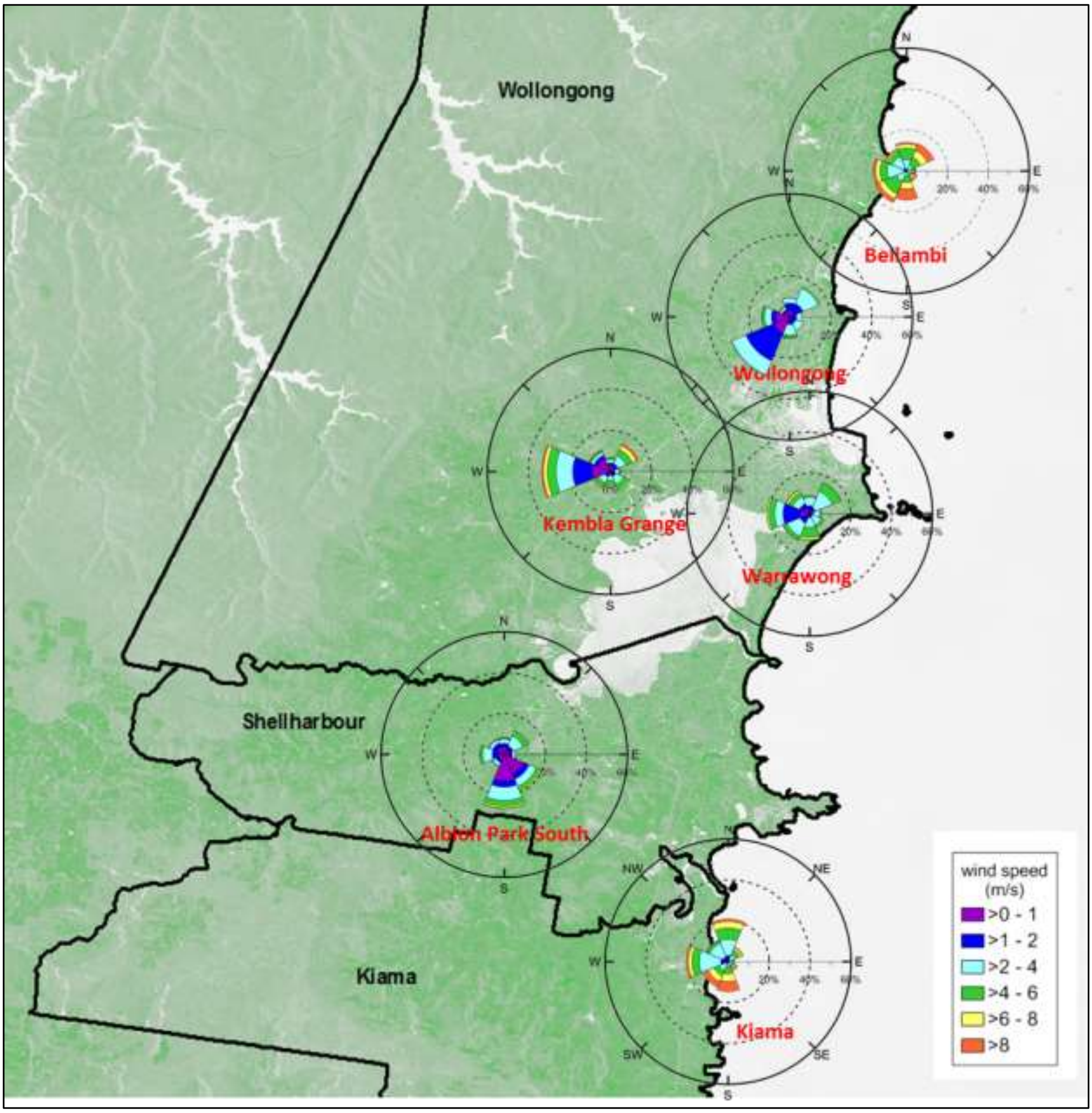


Figure 2: Annual average wind roses for the Illawarra[3]

[3] Wind roses for Wollongong, Kembla Grange, Albion Park South are generated from OEH air quality monitoring data for 2013 and Warrawong for 2005; wind roses for Bellambi, Kiama are generated from Bureau of Meteorology (BOM) weather stations for 2013.

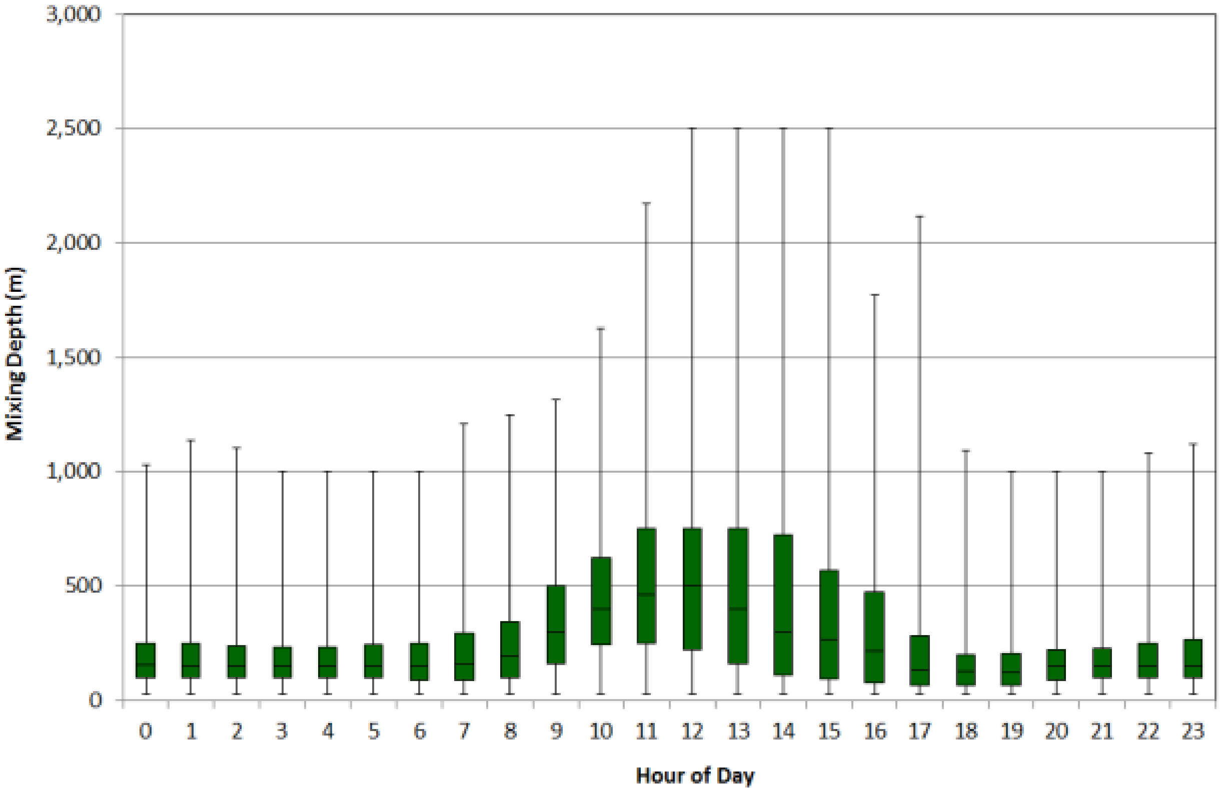


Figure 3: Estimated mixing height by time of day for Port Kembla

Boxes indicate the 25th, mean and 75th percentile of the TAPM-estimated mixing depth for 2013, with maximum and minimum values shown by the upper and lower whiskers.

3 Sources of information on emissions and air pollution

To understand how air pollution varies over time and across regions, and what sources contribute to it, we draw on a range of information sources and methods. Emission inventories, ambient air quality monitoring, particle characterisation studies and air quality modelling are important methods for air quality assessment and management, as shown in Figure 4.

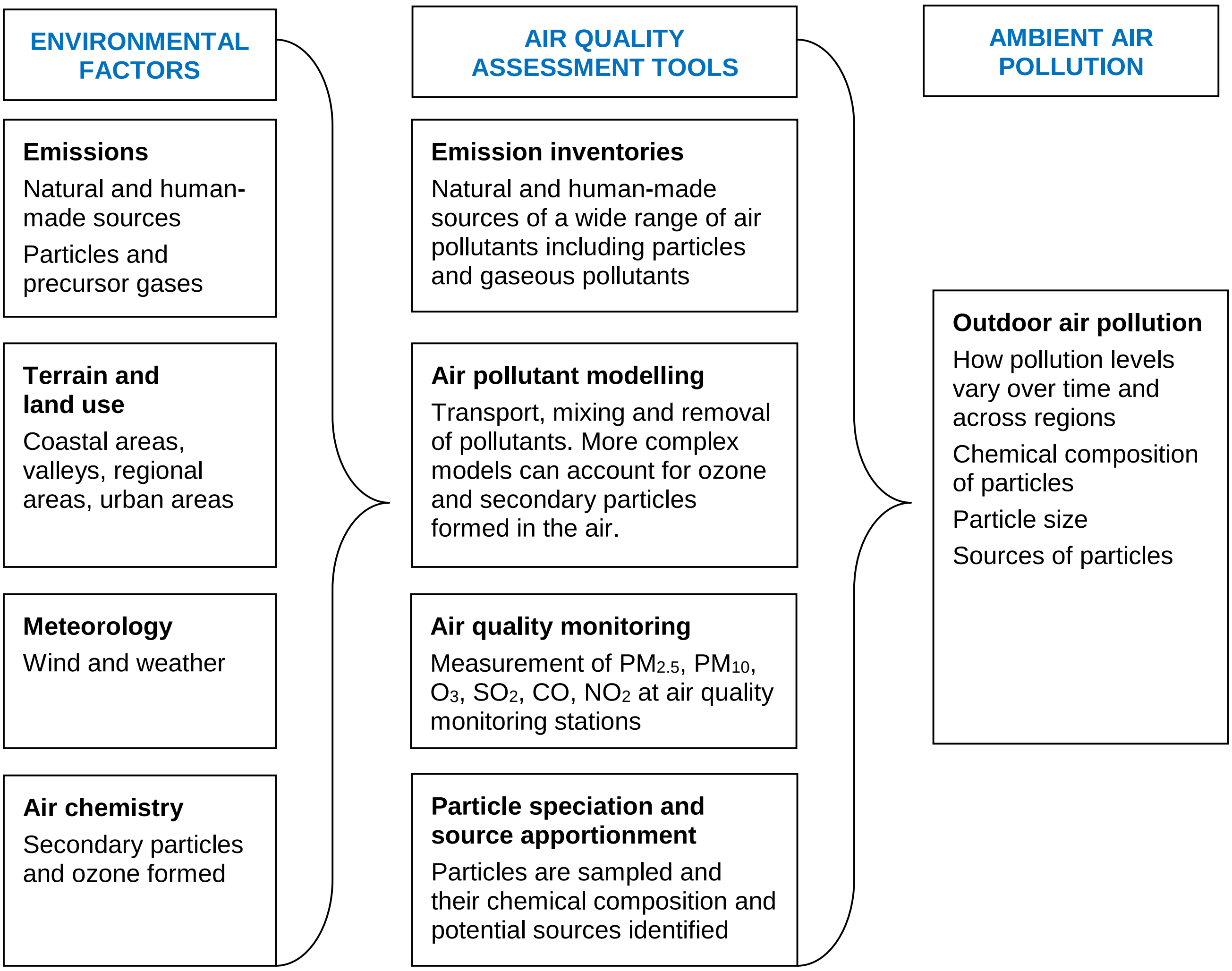


Figure 4: Methods used to characterise outdoor air pollution

These methods are used to characterise air pollution in the region, with further analysis then undertaken to assess the effects of pollution on human health and the environment. Increasingly, these methods are improving our understanding of pollutants emitted directly into the air and pollutants formed in the atmosphere such as ozone and secondary particle pollution.

The **NSW Greater Metropolitan Region Air Emissions Inventory** provides information on natural and human-made sources of air emissions including primary particle emissions and precursor gas releases which lead to ground-level ozone and secondary particle formation. Information from the emissions inventory is used, together with meteorological and terrain data within air quality models, to predict air pollutant concentrations. Other sources of emissions information relevant to the Illawarra include the National Pollutant Inventory (NPI) and a national shipping air emissions inventory compiled by the Australian Maritime College, University of Tasmania.

The **NSW air quality monitoring network** provides continuous, high quality measurements of air pollutant concentrations at a number of sites and makes this information available to government and communities in near real-time (i.e. within an hour of the measurement being made). This network is intended to monitor regional air quality relevant for assessing more widespread general population exposures and compliance with national air quality standards. Air pollutants which are typically measured include particles (including PM_{10}: particulate matter with a diameter of less than 10 micrometres, and $PM_{2.5}$: particulate matter less than 2.5 micrometres in diameter), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3) and nitrogen dioxide (NO_2). Further information on the Illawarra air quality monitoring network is given in Section 3.1.

Protection of the Environment Operations Act 1997 (POEO Act) scheduled activities, for example coal mines and power stations, may be required to monitor the concentration of air pollutants as a result of a condition of an environment protection licence. This monitoring is generally intended to measure source-related peak air pollutant concentrations under specific conditions, and is usually not acceptable for assessing compliance with national air quality standards.

Since it is not possible to measure pollution everywhere, **air quality models** are used to provide additional information on how air pollution levels vary over a region. Models are also useful for assessing the extent to which air emissions affect pollutant concentrations and allow us to project future changes in air pollutant levels and evaluate the benefits of emission reduction measures.

Particles can be made up of a range of chemical species depending on the source of the particle or the precursor gases from which they form. So the chemical composition of particles in the air can, in some cases, indicate the source of the particles. In **particle speciation studies**, airborne particles are sampled and the chemical composition of the particles determined. Mathematical models, known as 'receptor models', are then used to estimate source contributions to the particles occurring at the measurement site.

3.1 Illawarra air quality monitoring network

In the Illawarra, OEH currently operates air quality monitoring stations at Wollongong, Albion Park South and Kembla Grange to characterise regional air quality. Ozone (O_3), nitrogen oxides (NOx, NO, NO_2), PM_{10}, $PM_{2.5}$, sulfur dioxide (SO_2), carbon monoxide (CO), visibility and meteorology (wind speed, wind direction, air temperature and relative humidity) are continuously monitored at these stations. Lead monitoring was discontinued in 2004 due to reductions in ambient lead levels to well below the national standard. Air quality monitoring was previously conducted at Albion Park, Albion Park Rail and Warrawong (Table 1). Locations of current and decommissioned monitoring stations are shown in Figure 5.

The Wollongong and Kembla Grange stations were established in 1992 and 1994 respectively. The station at Albion Park South was established in 2005 and was a replacement for the Albion Park station. Each air quality monitoring station conforms to the National Environment Protection Measure (NEPM) for Ambient Air Quality (the 'AAQ NEPM') requirements of providing a representative measure of regional air quality across the Illawarra region. The monitoring sites are also designed to conform, as far as practical, to the Australian Standard *AS/NZS 3580.1.1:2007 Methods for sampling and analysis of ambient air – Part 1.1: Guide to siting air monitoring equipment.* The Illawarra air quality monitoring network was upgraded in 2014–15; see Box 1 for further details.

Table 1: Air quality monitoring stations in the Illawarra region operated by OEH

Station	**Year established**	**Ozone (O_3)**	**Nitrogen oxides (NOx)**	**Particles (PM_{10})**	**Particles ($PM_{2.5}$)**	**Carbon monoxide (CO)**	**Sulfur dioxide (SO_2)**	**Visibility (nephelometry)**	**Meteorology**
Wollongong (a)	1992	✓	✓	✓(1994)	✓(1998)	✓	✓	✓	✓
Albion Park South (b)	2005	✓	✓	✓			✓	✓	✓
Kembla Grange (b)	1994	✓	✓	✓(2004)	✓(2015)			✓	✓
Albion Park	1998 (operated till 2005)	✓	✓	✓			✓	✓	✓
Albion Park Rail	1992 (operated till 1997)	✓	✓			✓	✓	✓	✓
Warrawong	1993 (operated till 2006)	✓	✓	✓(1993)	✓(1996)		✓	✓	✓

(a) Wollongong monitoring station is a classified as a 'trend' air quality monitoring station under the AAQ NEPM and therefore measures a more complete suite of air pollutants.

(b) Albion Park South and Kembla Grange monitoring stations are classified as 'performance' monitoring stations under the AAQ NEPM, comprising permanent upper bound stations where selected pollutants are measured to ensure that major pollutant events are captured and reported.

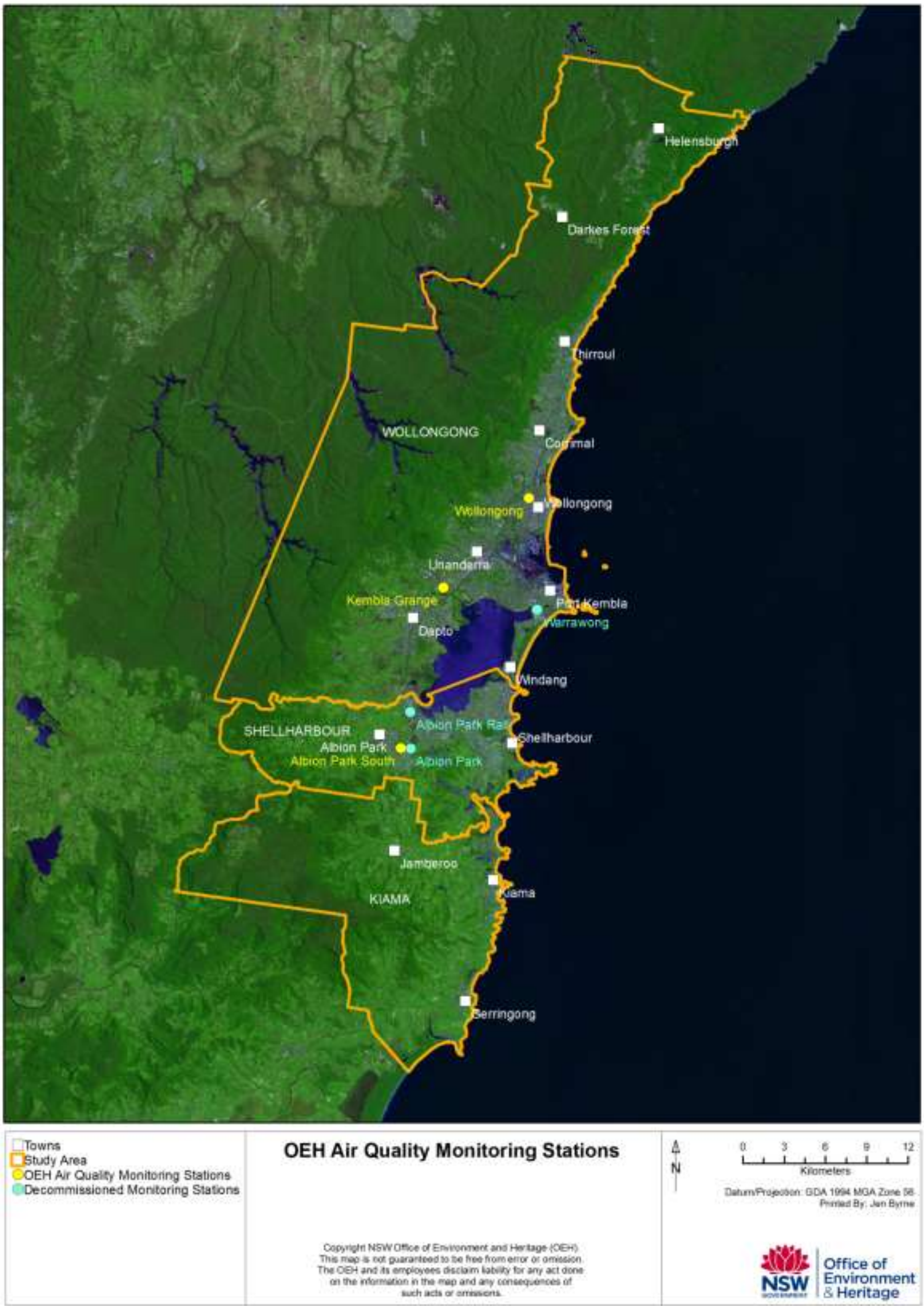


Figure 5: Current and decommissioned air quality monitoring stations in the Illawarra region

Box 1 – Upgrades to Illawarra air quality monitoring stations

The Illawarra air quality monitoring network was upgraded during the September 2014 to March 2015 period to replace assets past their useable life, modernise with the latest technology, standardise station configuration across the statewide air quality monitoring network, improve data acquisition validity and instrument online time and improve work health and safety. The following specific improvements were made to the Illawarra network:

- An entirely new monitoring site was established at Kembla Grange, located just 50 metres away from the original site, with provision made for a new concrete footing, fencing and a new shed.
- PM_{10} is measured using a tapered element oscillating microbalance (TEOM) analyser in line with Australian Standards (AS/NZS 3580.9.8:2008). New 1405 TEOMs were installed at the Wollongong, Albion Park South and Kembla Grange sites to replace PM_{10} monitoring using the more dated 1400ab TEOMs.
- $PM_{2.5}$ monitoring was initiated at Kembla Grange with the installation of a Beta Attenuation Monitor (BAM) Thermo 5014i instrument. BAM monitoring of $PM_{2.5}$ is in line with Australian Standards (AS/NZS 3580.9.12:2013).
- Existing monitoring sheds were replaced at all three sites with new sheds comprising modernised configurations, reduced carbon footprint due to better insulation, improved work health and safety by using a work platform instead of fall restraint systems and improved aesthetics.
- New data loggers were installed at all three sites comprising a new industrial type with a completely solid-state design to eliminate malfunctions related to moving parts such as hard disk drives and cooling fans.
- Relative humidity and temperature sensors were replaced with sensors allowing digital output due to the data logger requiring digital inputs.
- Uninterruptable power supply (UPS) units were installed at all three sites to keep the data logger powered during power outages.
- Permanently mounted staircases and access platforms were installed to replace the ladders being used to gain access to the roof of the monitoring sheds to perform maintenance on the instrument inlets and meteorological instrumentation. This represents a significant work health and safety improvement.


Figure 6: OEH air quality monitoring stations at Albion Park (left) and Wollongong (right)

3.2 NSW Greater Metropolitan Region Air Emission Inventory

The NSW Greater Metropolitan Region (GMR) Air Emissions Inventory developed by the EPA is the most comprehensive study of air emissions in Australia. It is used for:

- evaluating the effectiveness of existing air quality programs, such as the Protection of the Environment Operations (Clean Air Regulation) 2010 for EPA-licensed industry, service stations and residential wood heaters
- identifying new cost-effective approaches for improving air quality, like the Dust Stop program for EPA-licensed coal mines
- fulfilling NSW state of the environment reporting obligations.

The EPA updates the emissions inventory every five years, gathering data from various household, commercial business and EPA-licensed industry surveys, as well as a wide range of government and non-government service providers. The most recent inventory, for the 2008 calendar year, was published in 2012 and is available on the EPA website (EPA 2012). The next update, for the 2013 calendar year, is due to be finalised in 2016.

The inventory covers Sydney, Newcastle and Wollongong and surrounding regions, known collectively as the Greater Metropolitan Region (GMR). It presents emissions and their sources for over 1000 pollutants in the GMR, where about 75% of the NSW population resides. In the Illawarra, the inventory covers the entire Wollongong and Shellharbour LGAs and 66% of the Kiama LGA (169 square kilometres of the total 258 square kilometres).

The inventory includes emissions from biogenic (i.e. natural and living), geogenic (i.e. natural non-living) and anthropogenic (i.e. human-made) sources, as follows:

- natural (e.g. bushfires, marine aerosols and vegetation)
- commercial businesses (e.g. non-EPA-licensed printers, quarries and service stations)
- domestic activities (e.g. residential lawn mowing, portable fuel containers and wood heaters)
- industrial premises (e.g. EPA-licensed coal mines, oil refineries and power stations)
- non-road vehicles and equipment (e.g. dump trucks, bulldozers and marine vessels)
- on-road transport (e.g. registered buses, cars and trucks).

The pollutants detailed in the inventory include primary emissions of total suspended particles (TSP), PM_{10} and $PM_{2.5}$, and emissions of precursors of ground-level ozone and secondary particles, as well as other common pollutants, organic compounds, metals and greenhouse gases.

A web-based tool *Air Emissions in My Community* (EPA 2014a) provides an accessible way for the community to learn about air emissions. It presents data at a glance from the air emissions inventory in a variety of interactive chart views. The data can be displayed for different geographical areas, ranging from the entire NSW Greater Metropolitan Region down to postcode level.

3.3 National Pollutant Inventory

In addition to the NSW GMR Air Emissions Inventory, annually updated emissions data for industrial facilities are available from the National Pollutant Inventory (NPI) program. The NPI contains information on emissions reported annually by industrial facilities, with the collated information made available to the public on the NPI website at www.npi.gov.au. Only industries which exceed NPI thresholds are required to report their emissions, which are calculated and submitted by industry and validated by state or territory environmental regulators.

Due to the scope and scientific rigour of the NSW GMR Air Emissions Inventory, this data set is considered the primary source of information on sources of atmospheric emissions for the Greater Metropolitan Region, including the Illawarra. However, given that the NSW GMR Air Emissions Inventory is updated every five years, with 2008 being the most current inventory year available, the NPI provides a useful indication of trends in emissions from industrial facilities over more recent years.

3.4 National shipping air emissions inventory

The Australian Maritime College, University of Tasmania, has compiled a 2010–11 national emissions inventory, which includes ship engine exhaust emissions and fuel consumption in Australian waters and ports (Goldsworthy & Goldsworthy 2014, 2015). Emissions are estimated by vessel type for regions within 300 kilometres of major capital cities, including bulk carriers, containers, crude oil tankers, general cargo carriers and passenger ships etc. The emissions inventory includes PM_{10}, $PM_{2.5}$, VOC, CO, SO_2 and NO_x emission estimates, in addition to estimates for various air toxics and greenhouse gases.

3.5 Particle speciation and source apportionment

Particle speciation and source apportionment studies have been commissioned by the NSW Government for Sydney and the Upper and Lower Hunter to determine the characteristics of $PM_{2.5}$ particles and identify the relative contribution of emission sources to airborne fine particles. Similar studies have been undertaken by the Australian Nuclear Science and Technology Organisation (ANSTO) for a number of Australian east coast sites including a site in the Illawarra at Warrawong.

4 Air quality in the Illawarra

Past trends and the current state of ambient air quality in the Illawarra region is described in this section. Reference is mainly made to air pollution measurements from the OEH-operated Illawarra air quality monitoring network, with the levels measured compared to national air quality standards. Since particle and ozone pollution levels do exceed national standards from time to time, a more detailed discussion of these pollutants is given. The chemical composition of airborne fine particles is described using information from the ANSTO Aerosol Sampling Program. Particles (PM_{10} and $PM_{2.5}$) and ozone concentrations in the Illawarra are also compared with levels measured in various cities in Australia and overseas, and generally found to be good by national and world standards.

Air quality information is available in near real-time from the OEH website: www.environment.nsw.gov.au/AQMS/hourlydata.htm

Air quality information for the Illawarra is also routinely reported within NSW annual air quality statements and NSW annual NEPM compliance reports: www.environment.nsw.gov.au/aqms/datareports.htm

4.1 National ambient air quality standards

To help protect the health of the Australian population, the National Environment Protection Measure for Ambient Air Quality ('AAQ NEPM') sets national ambient air quality standards for six criteria pollutants: carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), lead (Pb) and particles as PM_{10} as well as an advisory reporting standard for $PM_{2.5}$ (Table 2). AAQ NEPM standards for $PM_{2.5}$, PM_{10}, SO_2, NO_2 and O_3 are currently under review. Australian Environment Ministers have agreed to revise the AAQ NEPM particle standards by end-2015.

Table 2: AAQ NEPM air quality standards

Pollutant	Averaging period	Standard	Maximum allowable exceedences
Carbon monoxide (CO)	8 hours	9.0 ppm	1 day a year
Nitrogen dioxide (NO_2)	1 hour 1 year	0.12 ppm 0.03 ppm	1 day a year None
Sulfur dioxide (SO_2)	1 hour 1 day 1 year	0.20 ppm 0.08 ppm 0.02 ppm	1 day a year 1 day a year None
Photochemical oxidants (as ozone O_3)	1 hour 4 hours	0.10 ppm 0.08 ppm	1 day a year 1 day a year
Lead (Pb)	1 year	0.5 µg/m³	None
Particles as PM_{10} (a)	1 day	50 µg/m³	5 days a year
Particles as $PM_{2.5}$ (a)	1 day Annual	25 µg/m³ (b) 8 µg/m³ (b)	1 day a year Not applicable

(a) Particles smaller than 10 micrometres in diameter (PM_{10}) and smaller than 2.5 micrometres in diameter ($PM_{2.5}$).

(b) AAQ NEPM advisory reporting standard – the NEPM aims to collect sufficient $PM_{2.5}$ data to develop national standards.

4.2 Overview of air quality in the Illawarra

Air quality monitoring has been undertaken in the Illawarra since 1992, which has included CO, NO_2, SO_2, PM_{10}, $PM_{2.5}$ and O_3 at several sites (i.e. Albion Park, Albion Park Rail, Albion Park South, Kembla Grange, Warrawong and Wollongong). The OEH air quality monitoring network in the Illawarra is intended to characterise the regional air quality, i.e. the air quality the region's population is exposed to.

Concentrations of CO, NO_2 and SO_2 recorded at OEH air quality monitoring stations have generally decreased since the 1990s, with recent levels recorded to be within national air quality standards. No exceedance of the national air quality standard for CO has been recorded during the 1992 to 2014 period (Figure 7 and Table 3). Over this entire period, the maximum 8-hour average CO concentration measured was 4.9 ppm (in 1995), which is 55% of the national standard. In 2013, the maximum CO concentration was 2.7 ppm which is 30% of the national standard.

Similarly, no exceedances of the 1-hour and annual average NO_2 standards were recorded during the 1992 to 2014 period (Figure 7, Table 3). The maximum 1-hour average NO_2 concentration recorded (0.09 ppm at Wollongong in 1993), is 75% of the national standard. The maximum annual NO_2 concentration measured (0.012 ppm at Wollongong in 1994) is 40% of the national standard. In 2014 the maximum 1-hour and annual average NO_2 concentrations were 32% and 27% of the relevant national standards respectively.

Historically, maximum 1-hourly SO_2 levels exceeded the national standard on only three occasions: once at Wollongong (1993) and twice at Albion Park (1992 and 1993) (Figure 8, Table 3). One of the major point-source emitters of SO_2 in the region ceased operation in 2002, which has resulted in a significant drop in SO_2 concentrations. In 2014, the maximum 1-hour average SO_2 concentration measured in the region (0.02 ppm) was 10% of the national standard. No exceedances of either the maximum 24-hour or annual average SO_2 standards have been recorded at OEH air quality monitoring stations.

Although, in general, particles (PM_{10} and $PM_{2.5}$) and ozone concentrations in the Illawarra are comparable with other Australia cities and good by world standards, these pollutants do exceed national standards from time to time, posing air-pollution-related health risks to local communities (Table 3). Further discussion of ambient particulate matter and ozone levels and emission sources contributing to ambient concentrations of these sources is provided in subsequent sections.

Table 3: AAQ NEPM air quality standards and maximum ambient air pollutant concentrations measured at OEH monitoring stations in the Illawarra region 1992–2014 (total exceedences of the standard are shown, not accounting for maximum allowable exceedences)

Pollutant	Averaging period	Standard	Exceedences (1992–2013)	Maximum concentration (same units as the standard), (% of the standard)	
				1992–2013	2014
Carbon monoxide (CO)	8 hours	9.0 ppm	None	4.9 (55 %) Wollongong 1995	0.9 (10%) Wollongong

Pollutant	Averaging period	Standard	Exceedences (1992–2013)	Maximum concentration (same units as the standard), (% of the standard)	
				1992–2013	2014
Nitrogen dioxide (NO_2)	1 hour	0.12 ppm	None	0.09 (75%) Wollongong 1993	0.04 (33%) Wollongong
	1 year	0.03 ppm	None	0.012 (40%) Wollongong 1994	0.008 (27%) Wollongong
Sulfur dioxide (SO_2)	1 hour	0.20 ppm	3 in Wollongong (1993) 2 in Warrawong (1993) 2 in Albion Park (1992, 1993)	0.287 (144%) Wollongong 1993	0.02 (10%) Wollongong
	1 day	0.08 ppm	None	0.034 (43%) Wollongong 1994	0.019 (23%) Albion Park South
	1 year	0.02 ppm	None	0.002 (10%) Wollongong 1999, 2001 Warrawong 2001	0.001 (5%) Wollongong, Albion Park South
Photochemical oxidants (as ozone O_3)	1 hour	0.10 ppm	Total of 64[(a)]	0.144 (144%) Albion Park 1997	0.094 (94%) Kembla Grange, Albion Park South
	4 hours	0.08 ppm	Total of 94[(b)]	0.124 (155%) Albion Park 1997	0.08 (100%) Kembla Grange
Particles as PM_{10}	1 day	50 µg/m³	Total of 177[(c)]	1360 (2720%) Albion Park South 2009[(e)]	99.2 (198%) Kembla Grange
Particles as $PM_{2.5}$	1 day	25 µg/m³	19 in Warrawong 28 in Wollongong[(d)]	241 (964%) Wollongong 2009[(e)]	17.3 (69%) Wollongong
	Annual	8 µg/m³	3 in Warrawong (2002, 2003, 2004) 1 in Wollongong (2002)	9.4 (118%) Warrawong 2002	7.1 (89%) Wollongong

(a) Detailed information is given in Table 6
(b) Detailed information is given in Table 7
(c) Detailed information is given in Table 4
(d) Detailed information is given in Figure 13
(e) The high particle concentrations measured in 2009 coincided with the large regional dust storm event in September 2009 which affected air quality across much of New South Wales.

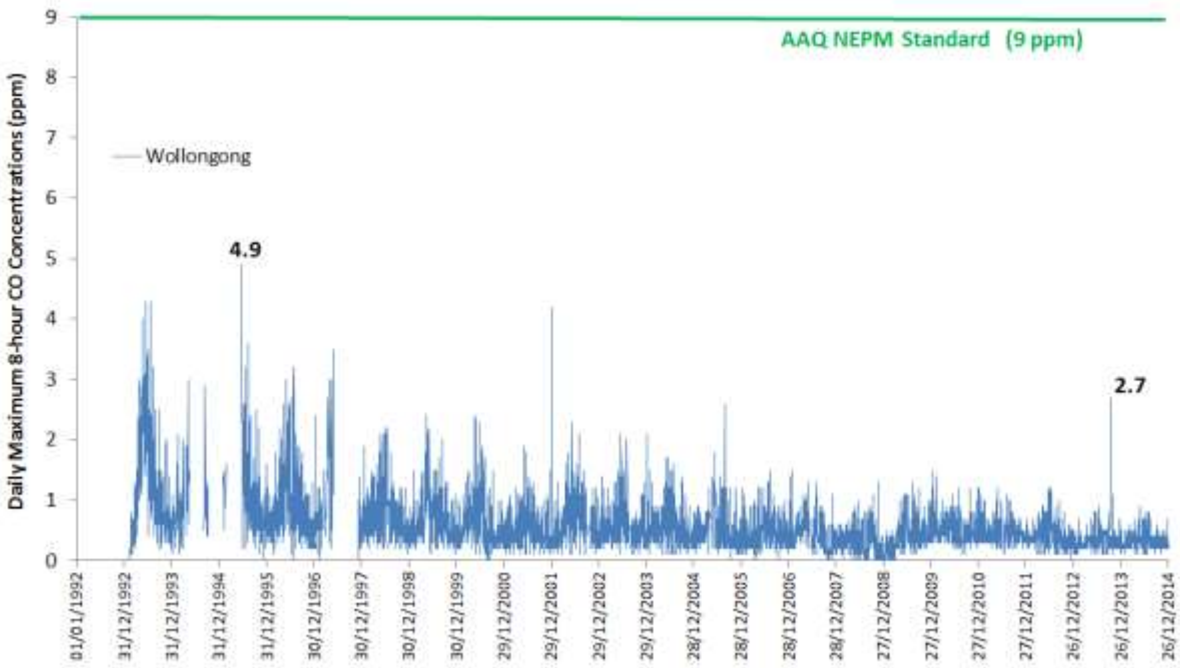


Figure 7: Daily maximum 8-hour average CO recorded at Wollongong monitoring stations 1992–2014

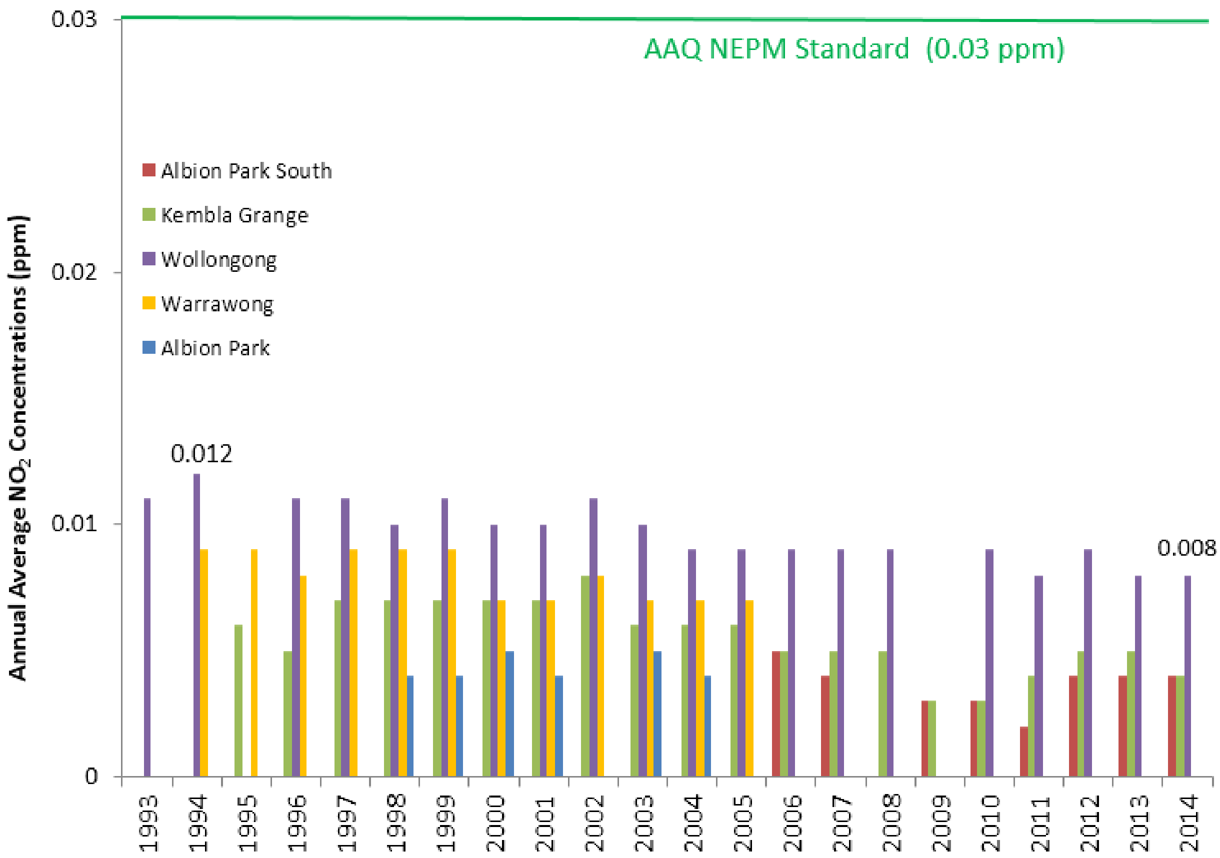


Figure 8: Annual average NO_2 recorded at Illawarra regional monitoring stations 1992–2014

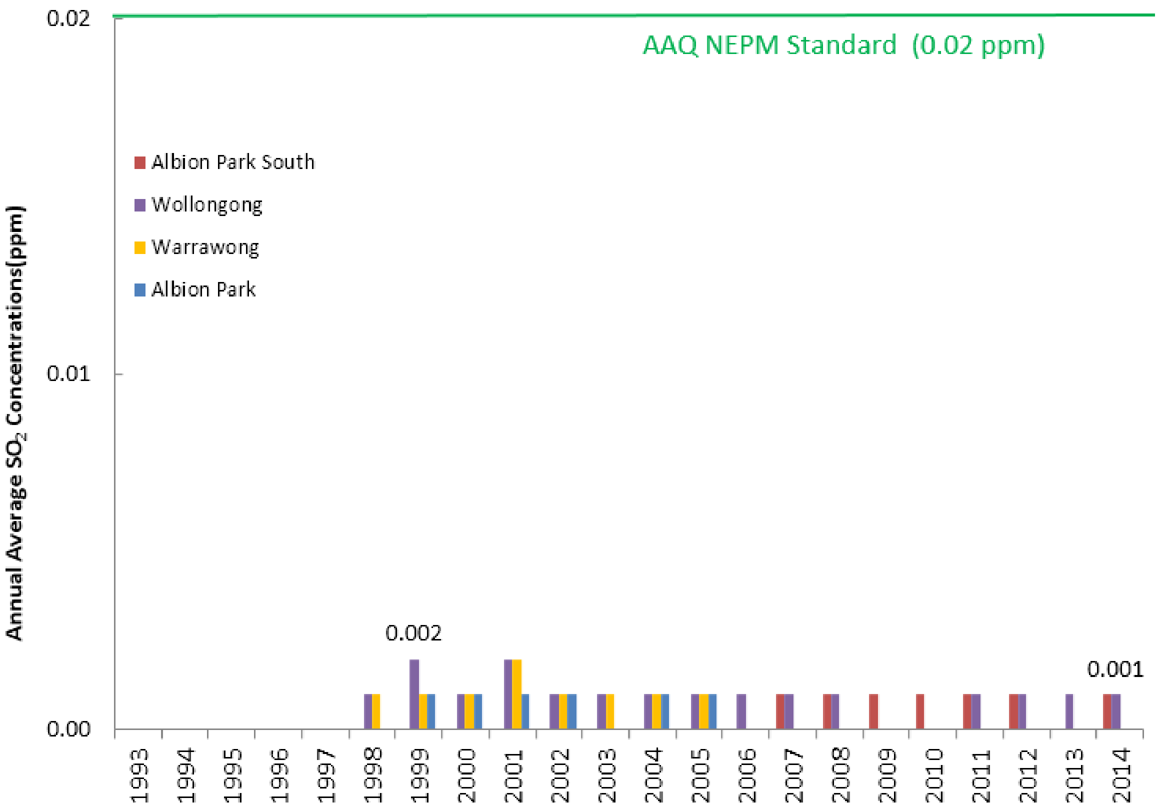


Figure 9: Annual average SO_2 recorded at Illawarra regional monitoring stations 1992–2014

4.3 Particle levels in the Illawarra

4.3.1 PM_{10} concentrations

PM_{10} levels vary significantly from year to year, as shown by annual average concentrations recorded in the Illawarra over the 1992 to 2014 period (Figure 10). Annual average PM_{10} levels are generally in the range of 10 micrograms per cubic metre (µg/m^3) to 25 µg/m^3 and below the NSW EPA Impact Assessment Criterion of 30 µg/m^3. Reference was made to the NSW EPA Impact Assessment Criterion since there is currently no national air quality standard for annual average PM_{10}. The addition of an annual national air quality standard for PM_{10} is, however, being considered as part of the AAQ NEPM revision process with an annual maximum concentration of 20 µg/m^3 proposed for consideration during the consultation period (Australian Government 2014). The potential exists for this proposed standard to be exceeded during years significantly affected by dust storms or bushfires and at sites close to Port Kembla industrial areas (e.g. Warrawong).

Exceedances of the maximum 24-hour PM_{10} national standard (50 µg/m^3 with greater than 5 exceedence days per year) were recorded to occur in 2002, 2003, 2006, 2009 and 2013 (Figure 11 and Table 4). High PM_{10} concentrations are typically recorded during years affected by large bushfires and dust storm events. Bushfires were the major contributor to high PM_{10} concentrations recorded in the Illawarra during 2002–03. Major statewide dust storms in September 2009 accounted for the extremely high 24-hour averaged PM_{10} concentration of 1360 µg/m^3 recorded in Albion Park South and the 14 exceedence days measured at Kembla Grange. In 2013 the 24-hour PM_{10} standard was exceeded on six days of the year; three of these exceedances occurred during the October–November bushfire emergency.

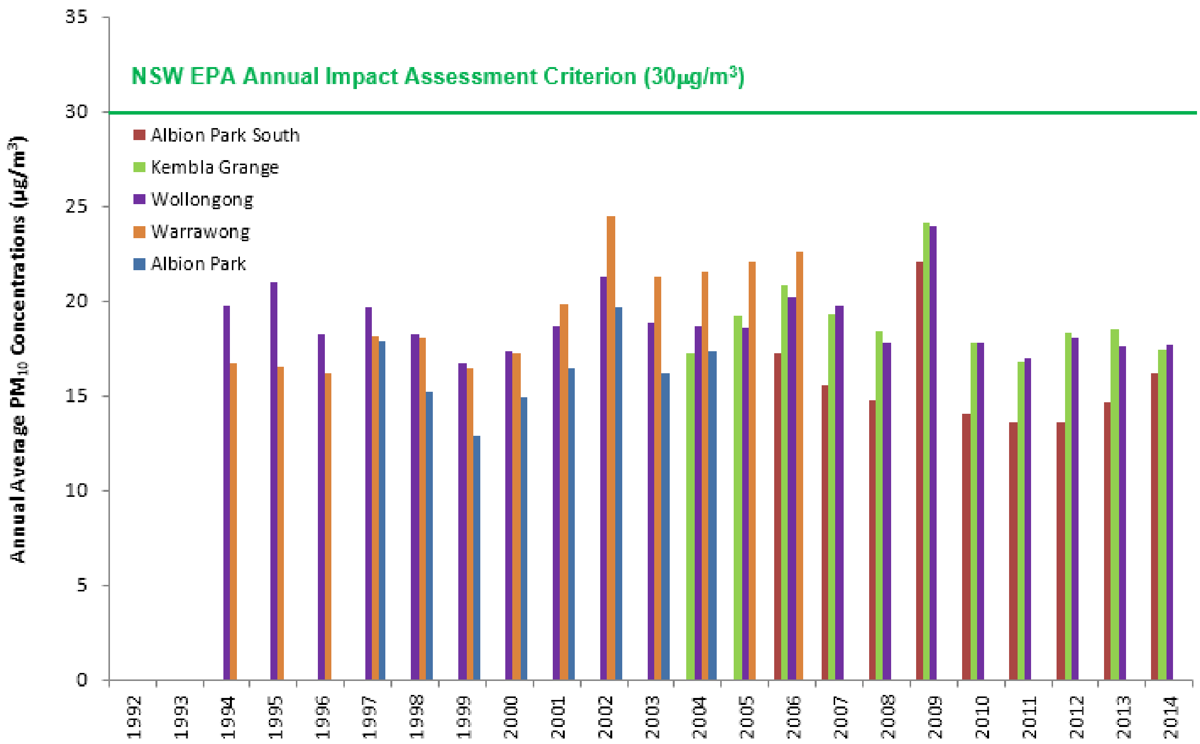


Figure 10: Annual average PM_{10} recorded at Illawarra regional monitoring stations 1992–2014

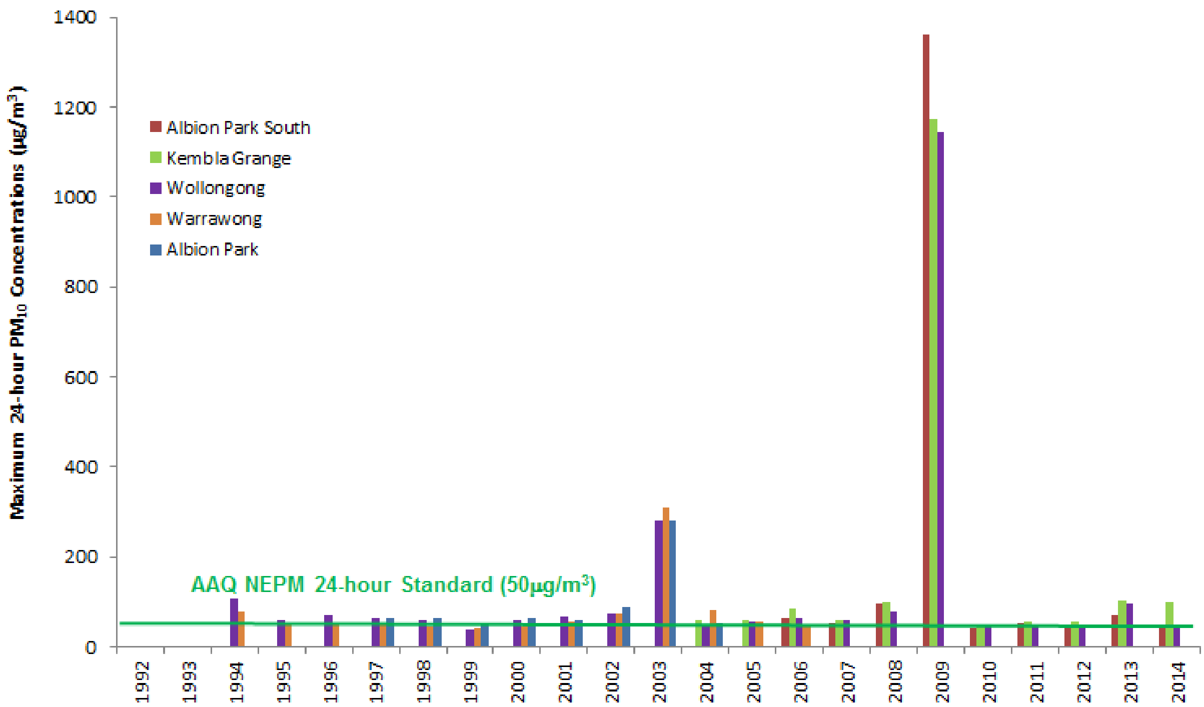


Figure 11: Maximum 24-hour average PM_{10} recorded at Illawarra regional monitoring stations 1992–2014

Table 4: Number of days exceeding the national 24-hour PM_{10} standard of 50 µg/m³ at Illawarra monitoring stations 1992–2014 (maximum allowable exceedances 5 days a year)

Year	Number of days exceeding the national PM_{10} standard				
	Albion Park	**Albion Park South**	**Kembla Grange**	**Warrawong**	**Wollongong**
1992	-	-	-	-	-
1993	-	-	-	0	0
1994	-	-	-	3	5
1995	-	-	-	0	4
1996	-	-	-	1	3
1997	2	-	-	2	2
1998	5	-	-	0	1
1999	0	-	-	0	0
2000	2	-	-	0	3
2001	1	-	-	1	5
2002	**7**	-	-	**12**	**11**
2003	4	-	-	5	**8**
2004	1	-	1	2	0
2005	0	-	4	5	1
2006	-	2	**9**	-	4
2007	-	1	5	-	3
2008	-	1	4	-	1
2009	-	**9**	**14**	-	**6**
2010	-	0	0	-	0
2011	-	1	1	-	0
2012	-	0	3	-	0
2013	-	2	4	-	**6**
2014	-	0	1	-	0

Note: '-' indicates data was not available because the air quality monitoring station was not in operation.

4.3.2 $PM_{2.5}$ concentrations

Annual average $PM_{2.5}$ concentrations measured in the Illawarra over the 1992 to 2014 period were below the national advisory reporting standard of 8 µg/m³ with the exception of 2002, 2003 and 2004 (Figure 12). Exceedances of the maximum 24-hour $PM_{2.5}$ national advisory reporting standard of 25 µg/m³ were recorded in 1996, 1997, 1998, 2000, 2001, 2002, 2003, 2006, 2009 and 2013 (Figure 12 and Figure 13, Table 5). This standard is typically exceeded 0–2 days for most years, with more frequent exceedances occurring in bushfire and dust storm affected years such as 2002–03, 2006, 2009 and 2013.

Major statewide dust storms in September 2009 accounted for the extremely high 24-hour averaged $PM_{2.5}$ concentration of 241 µg/m^3 recorded at Wollongong. Bushfires are believed to account for the 24-hour $PM_{2.5}$ concentration of 152 µg/m^3 recorded at Warrawong in 2003 and the 11 (10) exceedence days measured at Wollongong (Warrawong) in 2002. The exceedances recorded at the Wollongong station in 2013 coincided with the October–November 2013 bushfires (see Box 2). The maximum daily average $PM_{2.5}$ of 88.4 µg/m^3 measured at Wollongong on 19 October 2013 occurred during the bushfire emergency period.

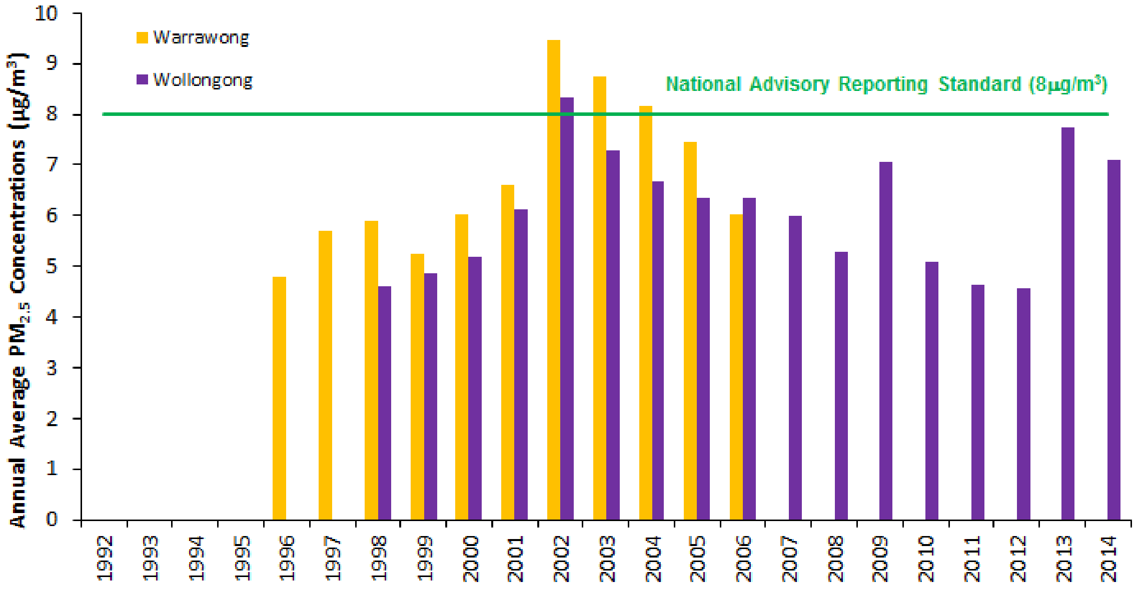


Figure 12: Annual average $PM_{2.5}$ recorded at Illawarra regional monitoring stations 1992–2014

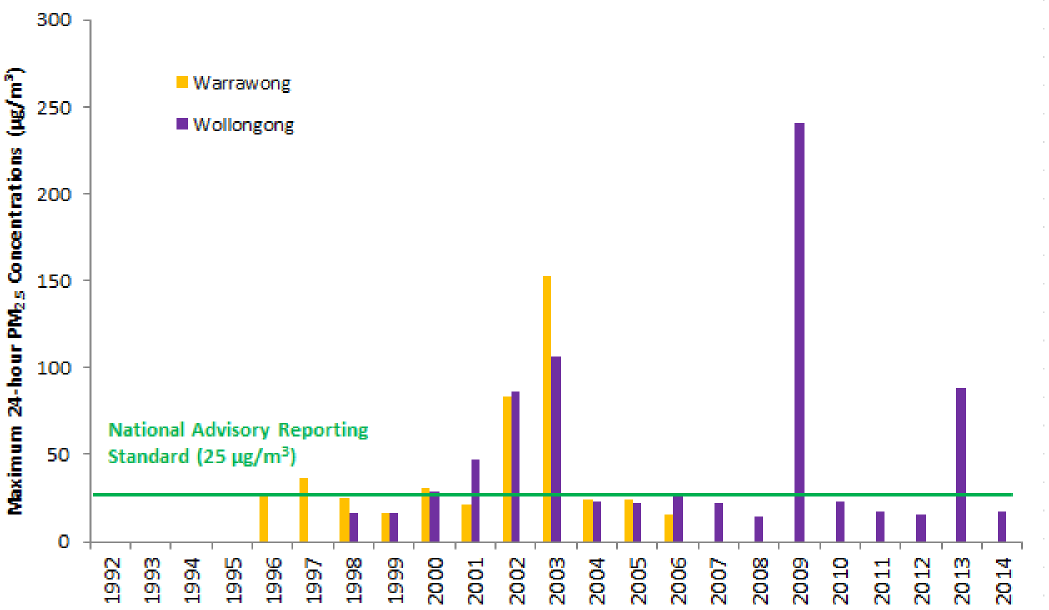


Figure 13: Maximum 24-hour average $PM_{2.5}$ recorded at Illawarra regional monitoring stations 1992–2014

Table 5: Number of days exceeding the national 24-hour $PM_{2.5}$ advisory reporting standard recorded at Illawarra regional monitoring stations 1992–2014

Year	Number of days exceeding the $PM_{2.5}$ advisory reporting standard	
	Warrawong	Wollongong
1992	-	-
1993	-	-
1994	-	-
1995	-	-
1996	1	-
1997	1	-
1998	1	0
1999	0	0
2000	2	1
2001	0	2
2002	10	11
2003	4	5
2004	0	0
2005	0	0
2006	-	2
2007	-	0
2008	-	0
2009	-	3
2010	-	0
2011	-	0
2012	-	0
2013	-	4
2014	-	0

Note: '-' indicates data was not available because the air quality monitoring station was not in operation.

Box 2 – 2013 air quality affected by bushfires and high temperatures (OEH 2014c)

After several years of very good air quality across much of the State, air quality in New South Wales in 2013 was generally poorer due mainly to warmer and drier conditions and severe bushfires. The year began with above-average temperatures and increased bushfire activity. January 2013 saw one of the warmest maximum temperatures on record in Sydney and across the State, followed by above-average temperatures during July–October and long periods of little or no rain. Warm, dry and windy conditions in September and October led to severe early-season bushfire activity in western Sydney, the Blue Mountains, Wollondilly and the Hunter Valley.

During the bushfire emergency, NSW Health issued a number of air pollution health alerts. This saw a significant increase in visits to the Air Quality Index webpage and subscriptions to the automated air pollution alert system.

4.3.3 Long-term trends in PM_{10} and $PM_{2.5}$

In New South Wales particle pollution levels can vary significantly as a result of large-scale climate variations. The El Niño–La Niña climate cycle, which typically occurs between three to five years but can vary from two to seven years, affects the prevailing weather conditions. Dry El Niño years are associated with a greater frequency of bushfires and dust storms and therefore higher particle pollution levels. Lower particle pollution levels tend to occur during wetter La Niña years.

Statistical analysis of PM_{10} and $PM_{2.5}$ concentration measurements was undertaken for the Wollongong trend monitoring station to remove seasonal variations in pollution levels so longer-term trends could be considered. This was done by expressing each daily PM_{10} and $PM_{2.5}$ concentration as a deviation from the mean for that day of the year based on the long-term record. The long-term trend of daily average PM_{10} and $PM_{2.5}$ for Wollongong are shown in Figure 14. Over the two decades of measurement, it appears there are higher PM_{10} and $PM_{2.5}$ levels during dry El Niño years (2002–07) when compared to the wetter La Niña years (2010–12).

PM_{10} levels have remained below long-term average levels in recent years (2011–14). The increase in $PM_{2.5}$ levels measured in recent years is expected to be mainly due to $PM_{2.5}$ measurement method being changed from Tapered Element Oscillating Microbalance (TEOM) instruments to Beta Attenuation Monitors (BAMs) in 2012, although bushfires impacting on airborne fine particles in the Illawarra during the October–November 2013 bushfire emergency period may also have contributed to the increase (see Box 2). Research is underway to remove the effect of the change in measurement method from the trend and to issue a final revised long-term $PM_{2.5}$ trend. The 2013 and 2014 years were equally the warmest years on record for maximum temperatures, with 2014 also being the warmest year on record for mean temperatures and the fourth-warmest year for minimum temperatures (Bureau of Meteorology 2014, 2015). Although above-average rainfall was experienced along the coast in 2013, inland regions were generally drier and more prone to dust generation and bushfires. The 2014 year was characterised by below-average rainfall across much of New South Wales and significant heatwaves in January, May, October and November.

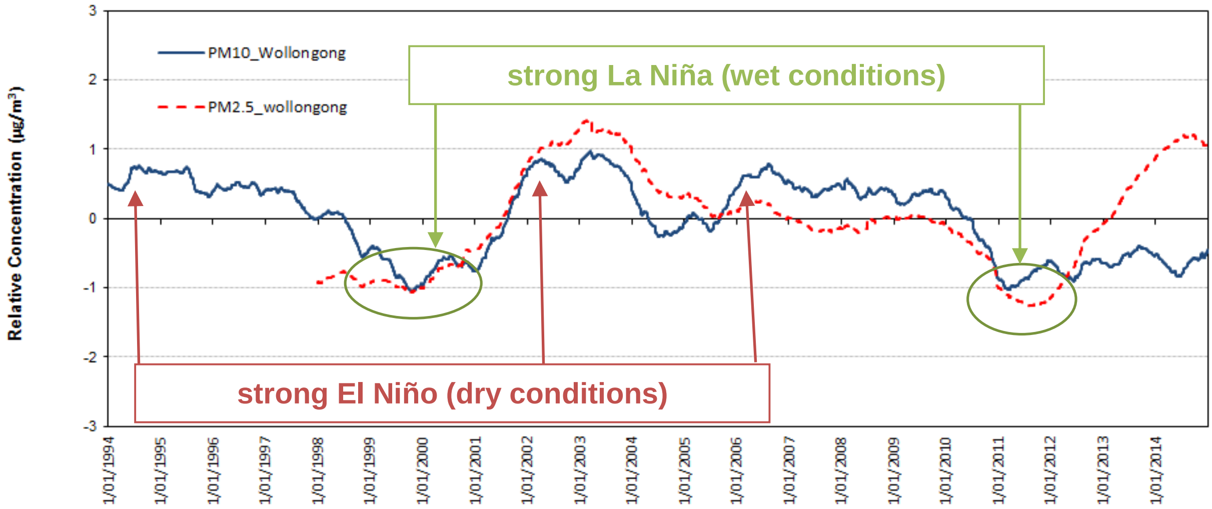


Figure 14: Long-term trend of daily average PM_{10} and $PM_{2.5}$ recorded at Wollongong monitoring station 1994–2014

Extremely high 24-hour averaged PM_{10} concentrations associated with major statewide dust storms on 23 September 2009 were excluded from long-term trend analyses.

4.4 Illawarra air quality compared with cities nationally and internationally

Air quality in the Illawarra is generally comparable with cities in other Australian jurisdictions and good by world standards. This is shown in

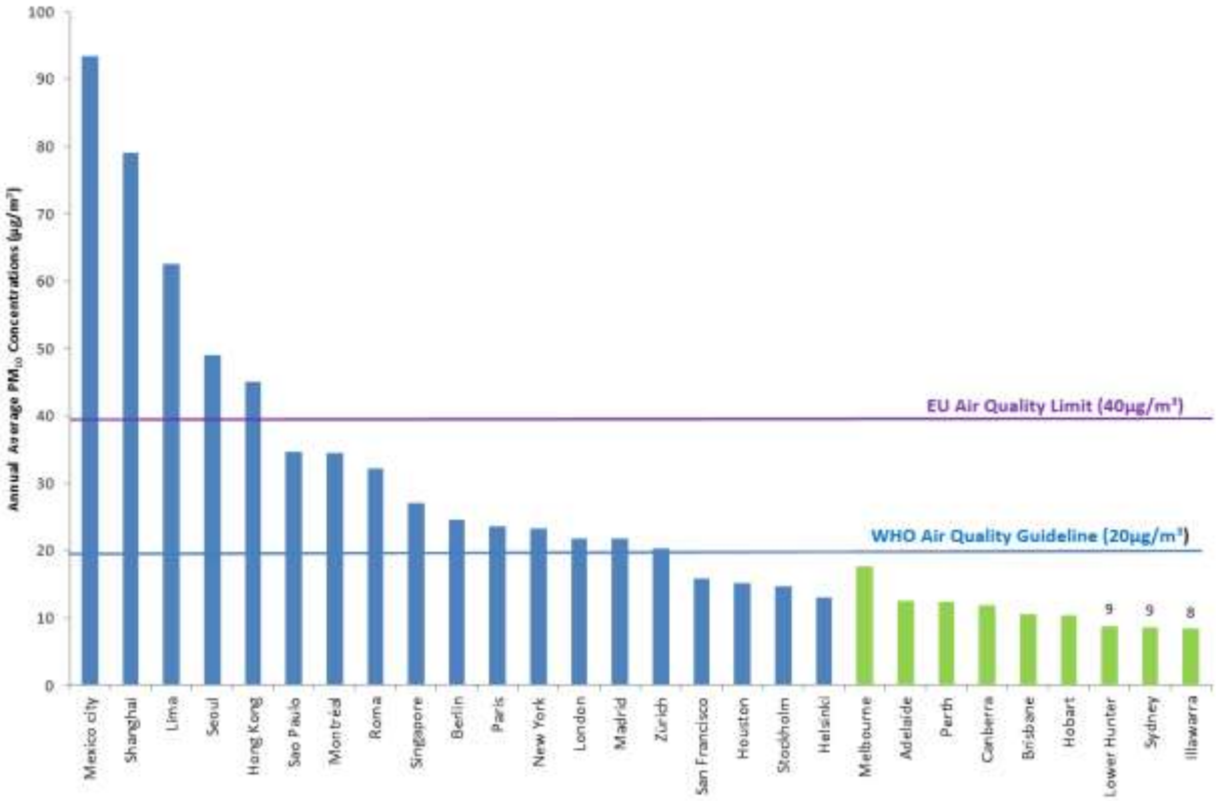


Figure 15 and Figure 16 based on annual average PM_{10} and $PM_{2.5}$ concentrations, and in Figure 17 for annual average 8-hour daily maximum ozone concentrations.

For the PM_{10} and $PM_{2.5}$ comparison, reference is made to the global comparison of air pollution levels undertaken by the World Health Organisation (WHO). The annual average PM_{10} concentration in the Illawarra shown for 2010–11 (8 µg/m³) is comparable to levels in other regions of New South Wales including Sydney and the Lower Hunter, and generally much lower than is measured in cities internationally (

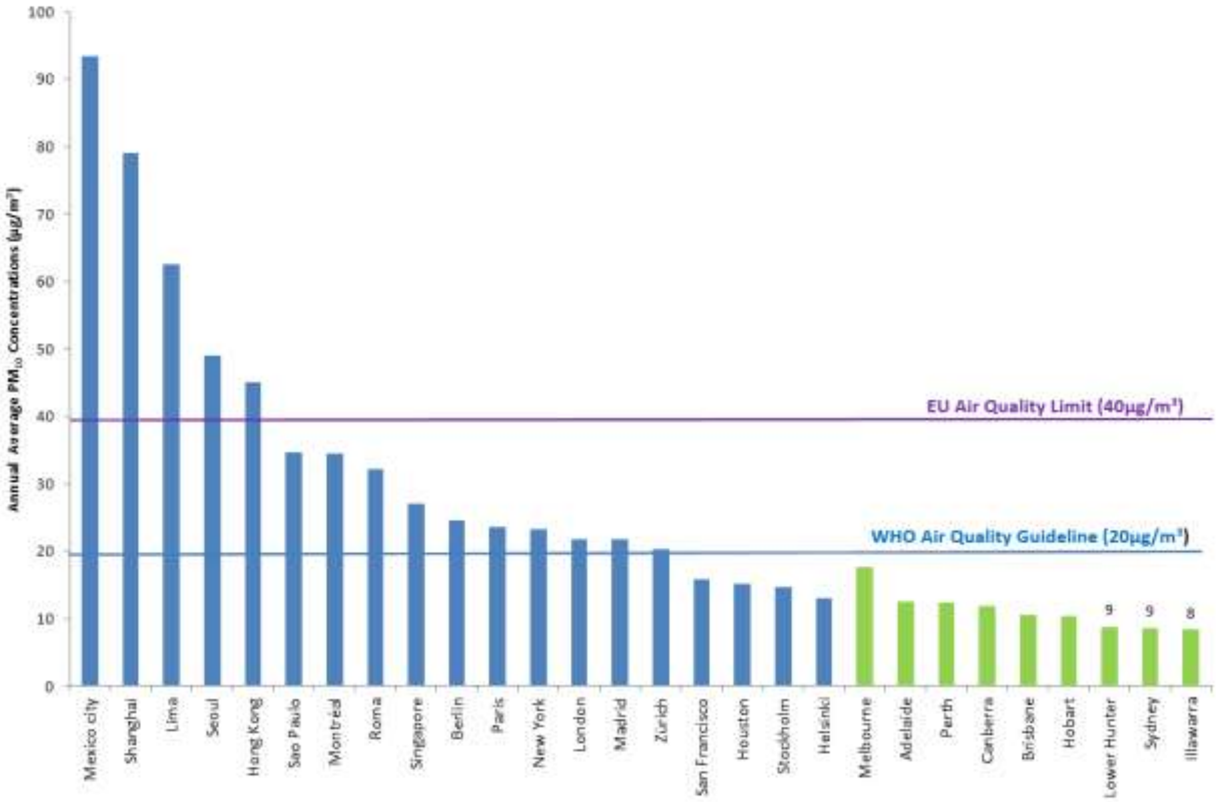


Figure 15). PM_{10} concentrations in the Illawarra are lower than the NSW EPA Impact Assessment Criterion (30 µg/m³), and international air quality standards (European Union: 40 µg/m³, World Health Organization: 20 µg/m³). No air quality standards are set nationally in Australia or the United States for annual average PM_{10}. However, an annual standard of 20 µg/m³ has been proposed for consideration as part of the AAQ NEPM review process in Australia (Australian Government 2014).

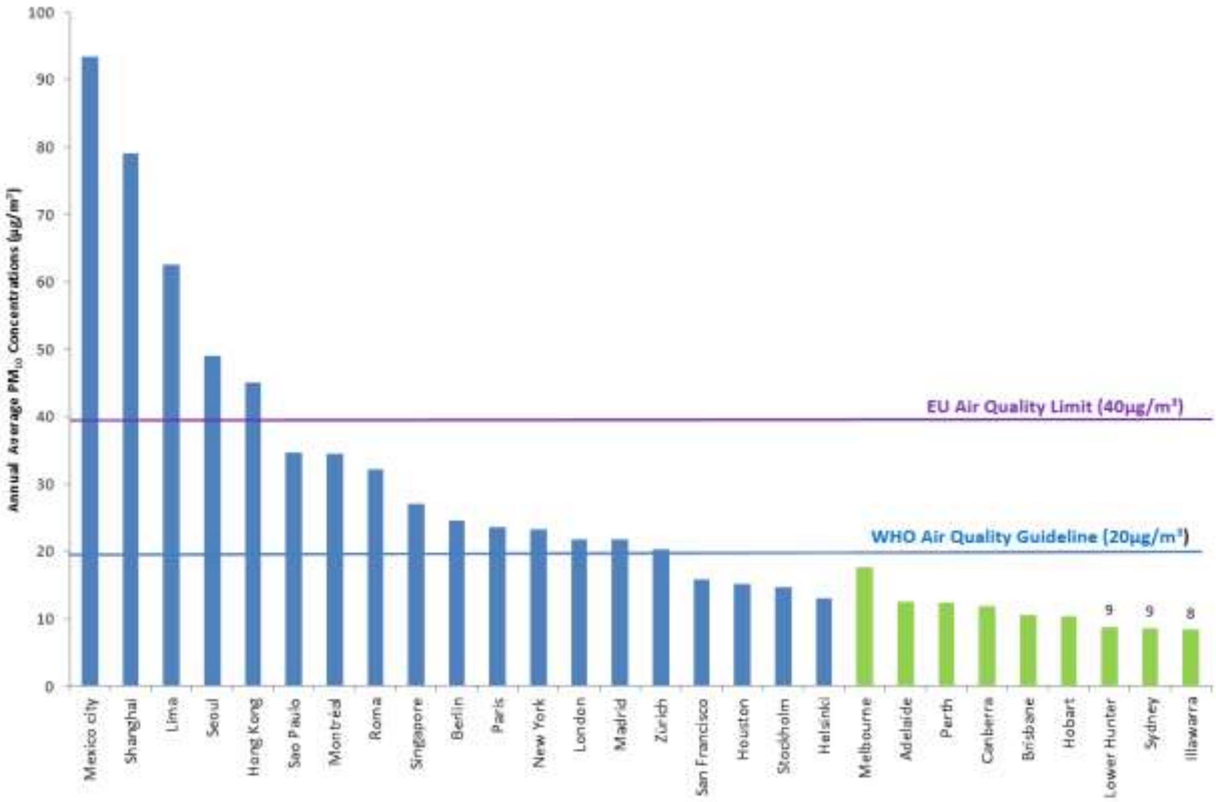


Figure 15: Comparison of annual average PM_{10} concentrations for Illawarra with several Australian and international cities 2010–11 (WHO 2014)

The annual average $PM_{2.5}$ concentration in the Illawarra (5 µg/m³) is also comparable to concentrations in other NSW regions and Australian cities, and is generally low by world standards as illustrated in Figure 16. The Australian annual average advisory reporting standard of 8 µg/m³ for $PM_{2.5}$ is more stringent than the air quality standards set internationally (European Union: 25 µg/m³, United States EPA: 12 µg/m³, World Health Organization: 10 µg/m³).

Figure 16: Comparison of annual average $PM_{2.5}$ concentrations for Illawarra with several Australian and international cities 2010–11 (WHO 2014)

Environment Canada recently did an international comparison of ozone levels using as an indicator the annual average of the 8-hour daily maximum ozone concentration measured in major cities in 2011. Ozone concentrations measured in the Illawarra and other NSW cities and regions in 2013 were calculated on the same basis for comparison as shown in Figure 17. The ozone concentration in the Illawarra (19 ppb) was measured to be 46% and 33% lower than ozone levels recorded in Sydney and the Lower Hunter respectively, and in general is considered to be low by world standards.

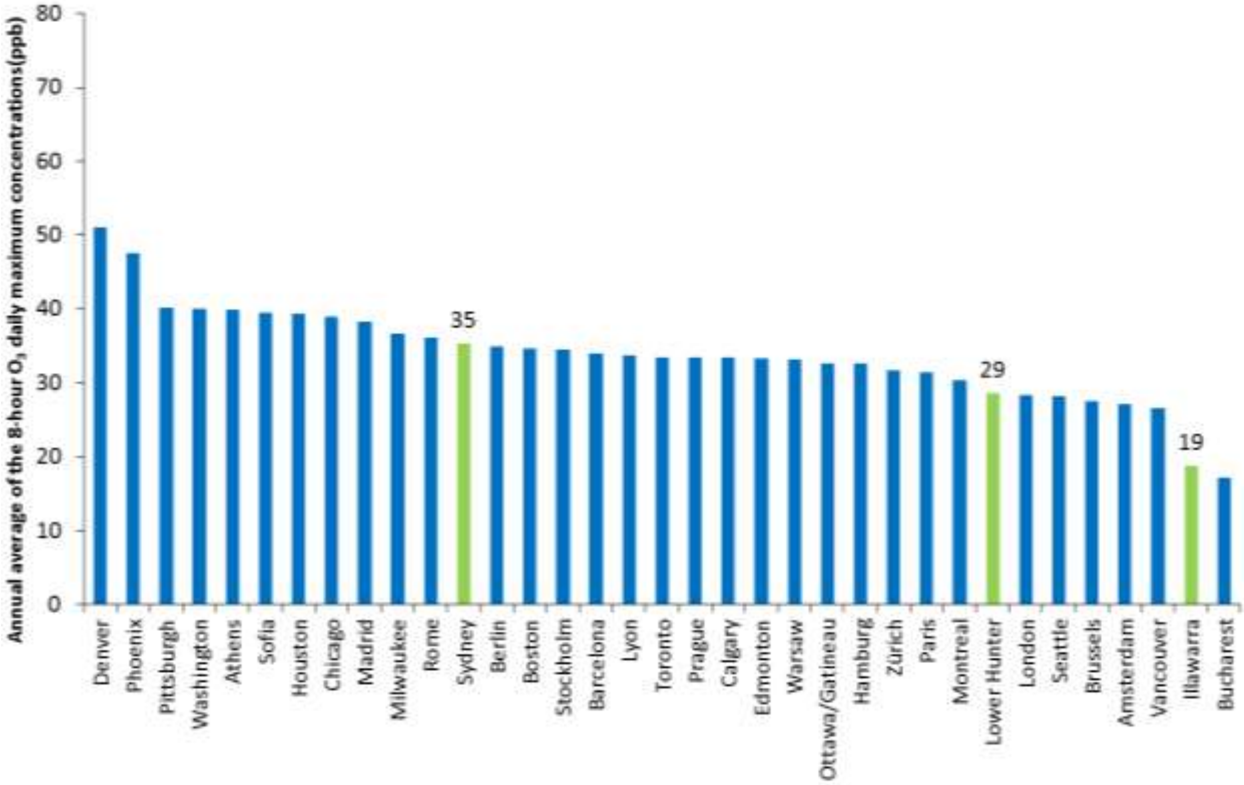


Figure 17: Comparison of annual average of the 8-hour O_3 daily maximum concentrations for Illawarra, Sydney and the Illawarra (2013) with levels measured in international cities for 2011 (Environment Canada 2014)

OEH uses the Air Quality Index (AQI) to provide a simple comparison of pollutants affecting air quality. AQI values for the Illawarra are illustrated for the past five years (2010–14) in Box 3, and compared to air quality reported for other regions of New South Wales.

Box 3 – Air quality using the OEH Air Quality Index (OEH 2015b)

The OEH AQI standardises measurements of ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, air particles and visibility into one easy-to-understand index. Using the AQI, air quality is classified as ‘very good’, ‘good’, ‘fair’, ‘poor’, ‘very poor’ and ‘hazardous’. More information on the AQI is available on the OEH website (www.environment.nsw.gov.au/AQMS/aboutaqi.htm). AQI levels for the Illawarra are given for the 2010 to 2014 period and compared to other regions of New South Wales in Figure 18.

Over the past five years air quality in the Illawarra was in the ‘very good’ or ‘good’ category for 78% to 85% of the time, in the ‘fair’ category for 13% to 20% of the time, and classified as ‘poor’ or worse for 1% to 7% of the time. The poor air quality days coincided with periods of high airborne particles or ozone pollution, with years significantly affected by regional events such as bushfires, dust storms or high temperatures experiencing the greatest frequency of poor or worse air quality days (e.g. 7% poor or worse air quality days in 2013 due to bushfires and high temperatures, see Box 2).

Based on OEH monitoring station measurements during the 2010 to 2014 period, the Illawarra is reported to typically experience fewer fair and poor or worse air quality days compared to Sydney and the Hunter, and more of such days compared to the Central Coast and rural New South Wales. (Note that $PM_{2.5}$ levels are not recorded in rural New South Wales, and that air quality monitoring was initiated more recently for the Central Coast with the establishment of the Wyong station.)

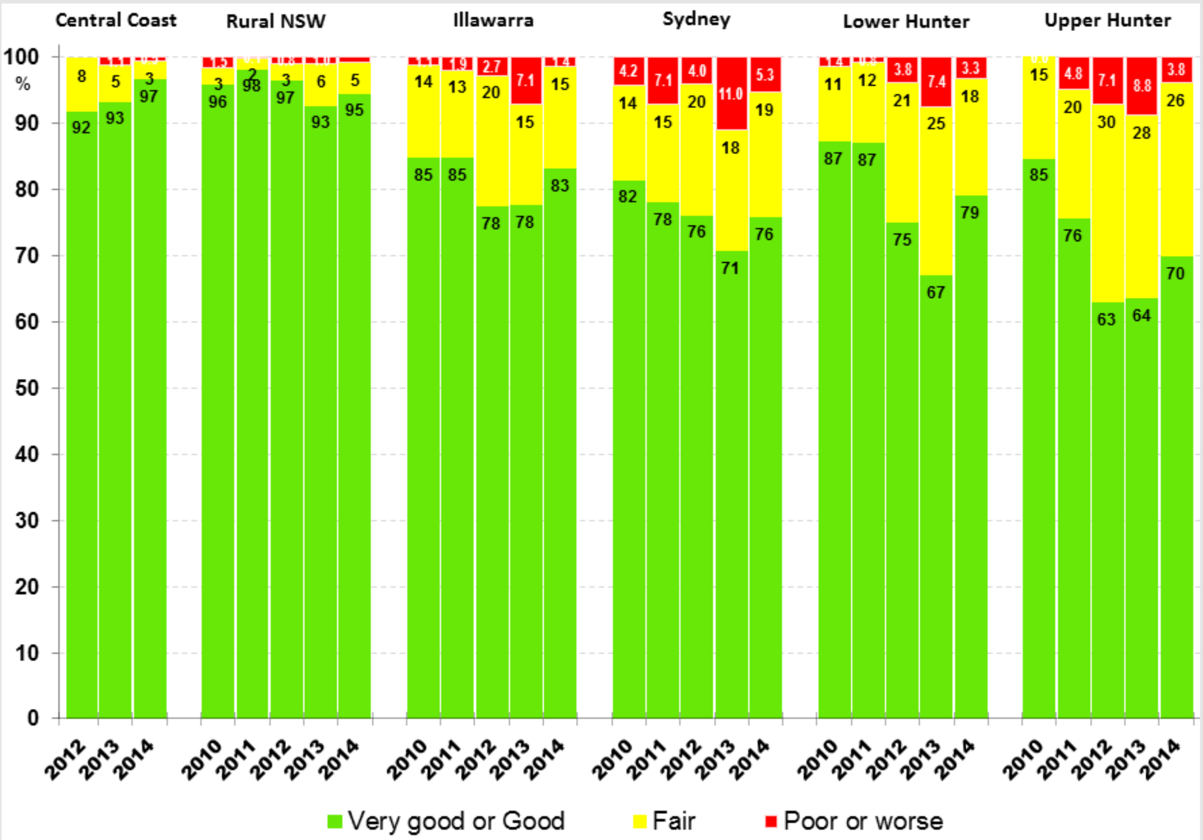


Figure 18: AQI categories as a percentage of time in each region of NSW 2010–14 (OEH 2015b)

4.5 Airborne particles composition and characterisation

As part of its Aerosol Sampling Program, the Australian Nuclear Science and Technology Organisation (ANSTO) has been conducting $PM_{2.5}$ sampling and characterisation at several Australian east coast sites since 1990, including several sites within New South Wales and a background (pristine environment) site at Cape Grim in Tasmania (ANSTO 2015a). The $PM_{2.5}$ sampling is conducted on two days each week (Wednesday and Sunday). Within the Illawarra, sampling is conducted at Warrawong. The long-term average (1998–2008) $PM_{2.5}$ concentration and the composition of fine particles measured at these sites is shown in Figure 19. Particle composition was generally found to include ammonium sulfate, black carbon, organic matter, salt, soil and 'other' components.

At the Warrawong site, the long-term average $PM_{2.5}$ concentration was measured to be 6.9 µg/m³. At this site, ammonium sulfate (29%) comprised the largest component of the long-term average $PM_{2.5}$ composition, followed by salt (16%), black carbon (15%), organic matter (14%), and soil (10%), with about 16% of the $PM_{2.5}$ mass being classified as 'other'.

Ammonium sulfate is a secondary pollutant, formed in the atmosphere when sulfur dioxide (SO_2) emissions react with ammonia. SO_2 is emitted in the Illawarra region by industrial sources, non-road sources such as industrial vehicles and shipping, on-road vehicles and residential fuel burning (see Section 5.4). The 'salt' component of fine particles is associated with sea salt aerosols emitted by waves breaking in the open ocean and from coastal surf breaks. Black carbon is emitted directly into the air during incomplete combustion of fossil fuels used for transport, heating and industrial activities, and from biomass burning due to vegetation fires (see 5.3).

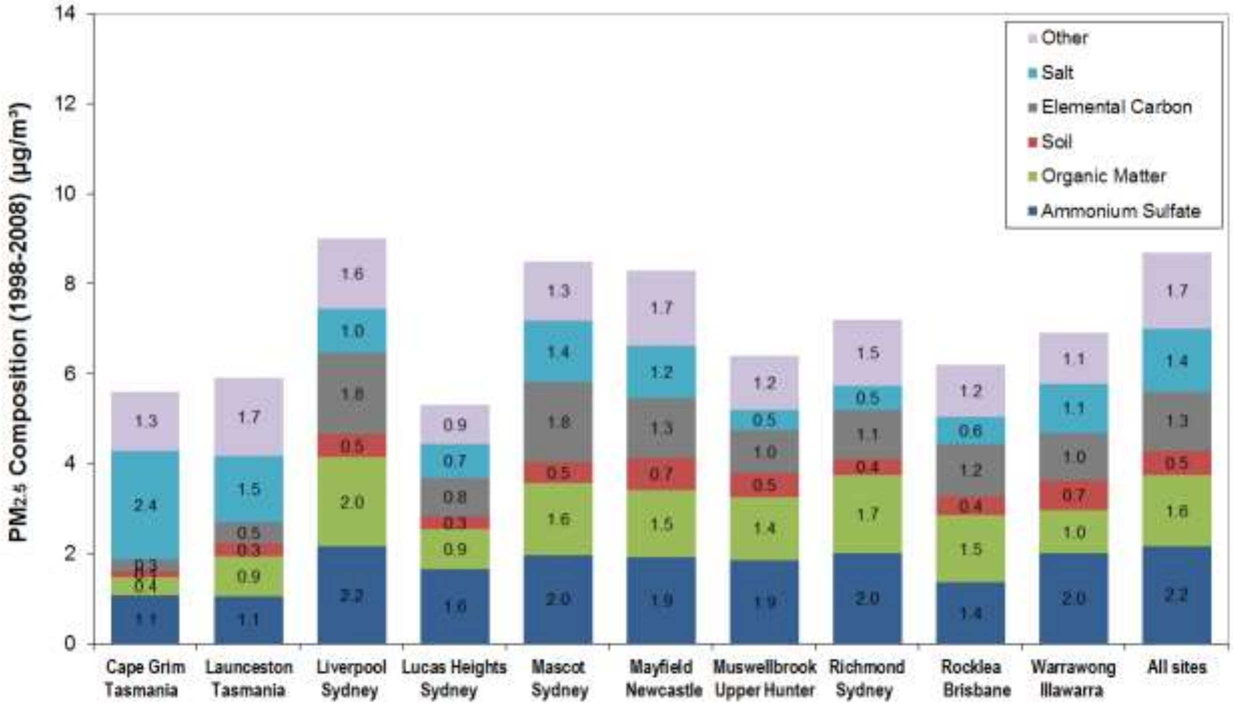


Figure 19: Average $PM_{2.5}$ mass and composition for Australian east coast sites, July 1998 to May 2008 (ANSTO 2008)

The organic matter component of $PM_{2.5}$ is likely to include primary particles released from sources such as car exhaust and industries, in addition to secondary organic particles formed in the air from volatile organic compounds emitted from natural and human-made sources (see Sections 5.3 and 5.4). The soil component is derived by adding the different oxides found in soil such as silicon oxide (SiO_2), aluminium oxide (Al_2O_3), iron oxides (FeO, Fe_2O_3), calcium oxide (CaO), and titanium oxide (TiO^2). Suspended soil particles in the atmosphere mainly originate from natural wind-blown dust, agriculture and industries such as mining and quarrying. The 'other', unclassified component of the $PM_{2.5}$ mass is likely to comprise nitrates (that are not measured by the analysis) and water vapour (Cohen et al. 1996).

Annual average $PM_{2.5}$ concentrations measured at Warrawong (based on twice weekly sampling) are shown for the 2000 to 2009 period in Figure 20 (ANSTO 2014). Annual concentrations were measured to range between 6 µg/m³ and 7 µg/m³ for most years, which are below the Australian advisory reporting standard (8 µg/m³). $PM_{2.5}$ concentrations approaching or exceeding this standard were noted to occur in years significantly affected by dust storms (2009) and bushfires (2002). Organic matter was measured to comprise 1.7 µg/m³, representing 19% of the annual average $PM_{2.5}$ concentration in the 2002 bushfire-affected year, whereas organic matter contributed 5–16% of the total $PM_{2.5}$ mass in other years (Figure 20, Figure 21).

The higher annual average $PM_{2.5}$ concentration in 2009 is associated with the major statewide dust storm that occurred in September 2009. The soil component contributed 17% of total $PM_{2.5}$ mass in 2009, whereas the soil component contributed less than 12% in other years (Figure 20, Figure 21).

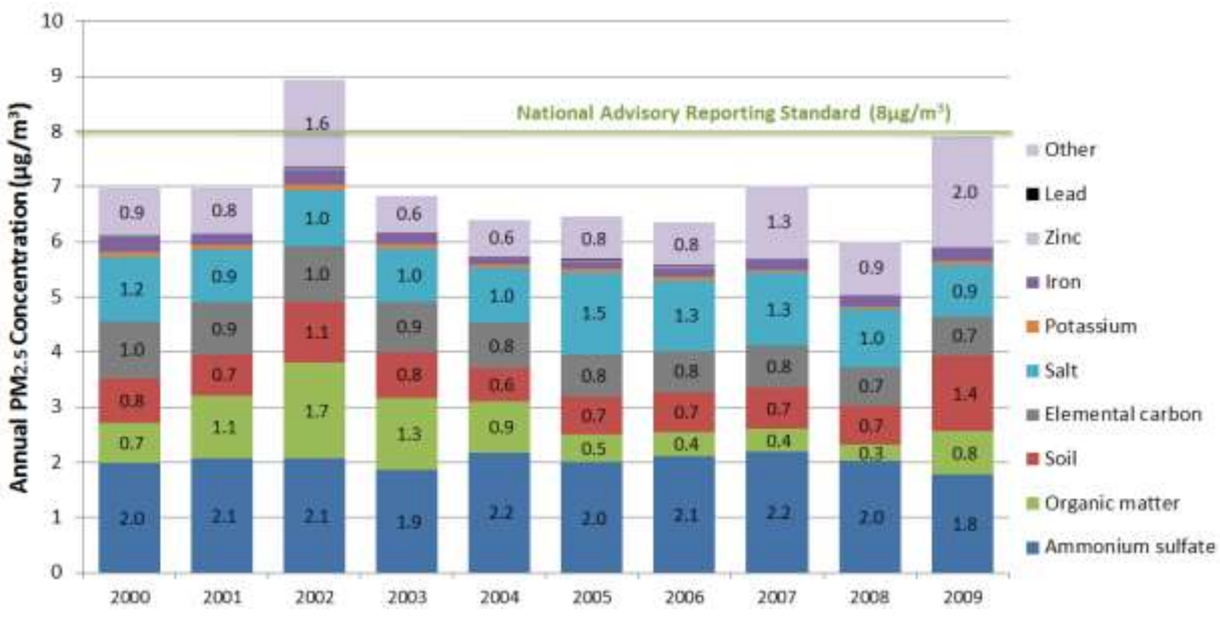


Figure 20: Annual average $PM_{2.5}$ composition for Warrawong 2000–09 (ANSTO 2014)

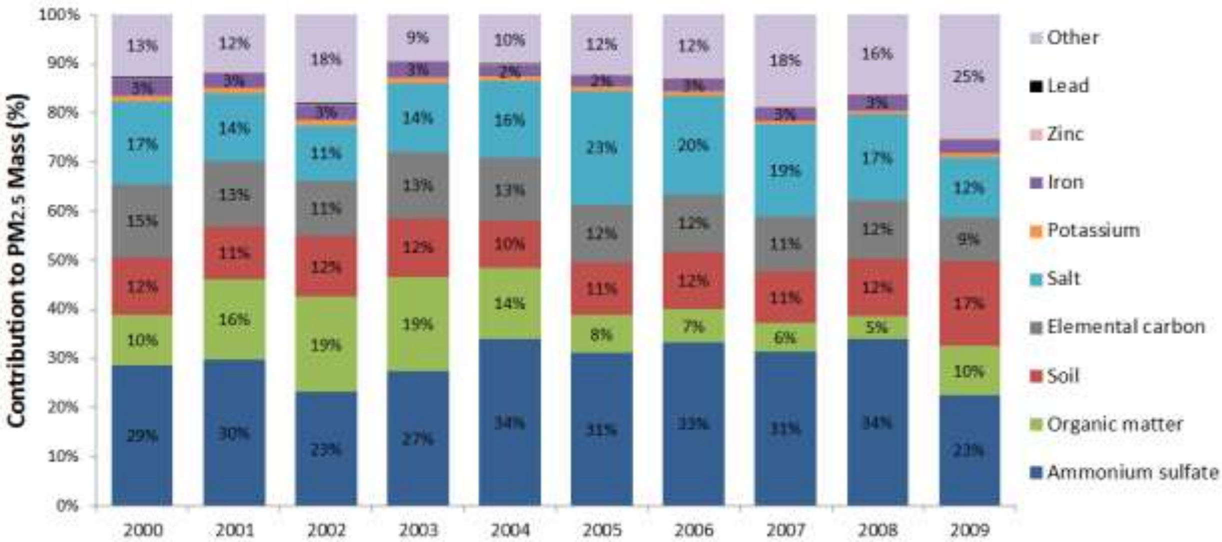


Figure 21: Percentage contribution of chemical species to annual average $PM_{2.5}$ concentration at Warrawong 2000–09

4.6 Ozone levels in the Illawarra

Maximum 1-hour ozone (O_3) concentrations recorded at Illawarra regional monitoring stations from 1992–2014 are illustrated in Figure 22. In some years the AAQ NEPM standard is approached or exceeded. However the exceedences are typically infrequent and of low magnitude. The national standard, given as 10 parts per hundred million (pphm) with no more than 1 exceedence day per year, was not met in 1993, 1994 and for most years between 1997 and 2004, with exceedances occurring again in 2013 (Table 6).

Maximum 4-hour O_3 concentrations recorded at Illawarra regional monitoring stations similarly exceed the national standard in some years (Figure 23). The national standard, given as 8 pphm with no more than 1 exceedence day per year, was not met for most years between 1995 and 2004 and again exceeded in 2009, 2011 and 2013 (Table 7).

High ozone levels in the Illawarra region can occur as a result of photochemical smog produced from local emissions, from smog or precursors transported down the coast from the Sydney region (Nelson et al. 2002), or from emissions transported to the region from remote bushfires. The number of exceedences and the magnitude of the peak are influenced by the frequency and duration of high-temperature periods, and the location of precursor pollutant emissions including regional bushfires.

The effect of bushfires on ozone levels in the Illawarra region was illustrated by the ozone pollution events occurring during the October 2013 bushfire emergency. Ozone levels were recorded above national standards at 12 air quality stations across Sydney and the Illawarra. Ozone formation on high-temperature days was evident by the widespread ozone event which occurred on 20 December 2013 during hot and calm summer conditions. The maximum 1-hour average on this day was 12.6 pphm at Kembla Grange where the maximum 4-hour average of 10.3 pphm was also recorded.

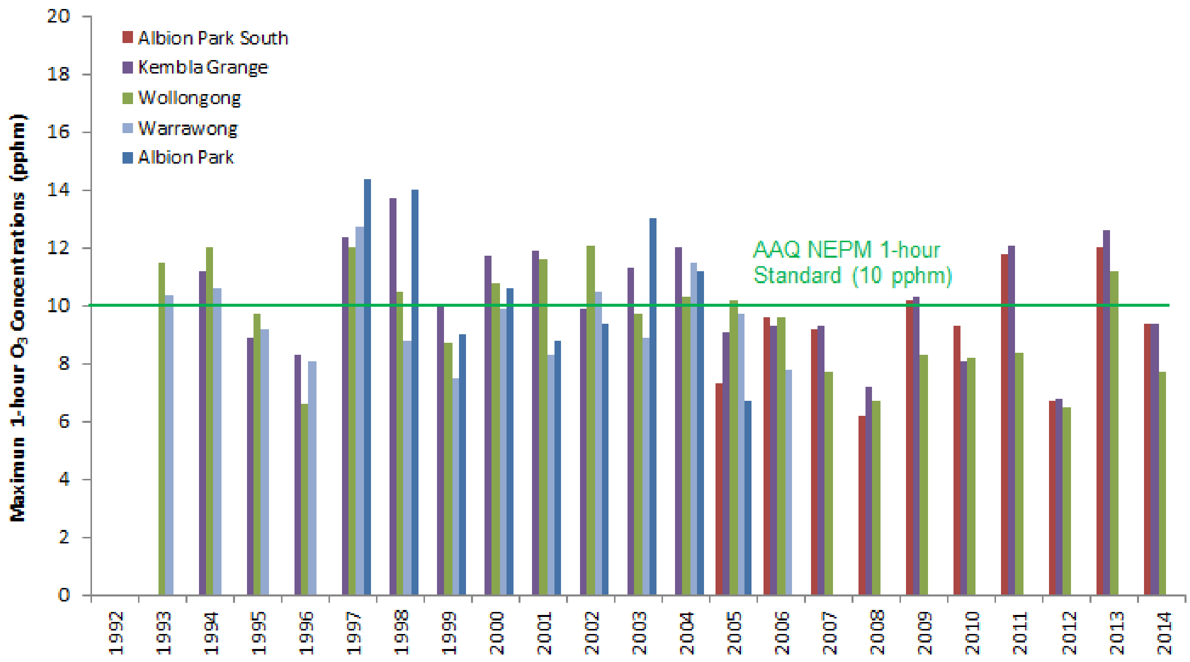


Figure 22: Maximum 1-hour O_3 measured at Illawarra regional monitoring stations 1992–2014

Table 6. Number of days exceeding the national 1-hour O_3 standard recorded at Illawarra regional monitoring stations 1992–2014

Year	Number of days exceeding the national 1-hour average O_3 standard				
	Albion Park	Albion Park South	Kembla Grange	Warrawong	Wollongong
1992	-	-	-	-	-
1993	-	-	-	1	2
1994	-	-	1	1	2
1995	-	-	0	0	0
1996	-	-	0	0	0
1997	5	-	4	2	4
1998	2	-	2	0	1
1999	0	-	1	0	0
2000	1	-	3	0	1
2001	0	-	2	0	1
2002	0	-	0	2	2
2003	4	-	2	0	0
2004	1	-	3	1	1
2005	0	-	0	0	1
2006	-	0	0	-	0
2007	-	0	0	-	0
2008	-	0	0	-	0
2009	-	1	1	-	0

Year	Number of days exceeding the national 1-hour average O_3 standard				
	Albion Park	Albion Park South	Kembla Grange	Warrawong	Wollongong
2010	-	0	0	-	0
2011	-	1	1	-	0
2012	-	0	0	-	0
2013	-	3	2	-	2
2014	-	0	0	-	0

Note: '-' indicates data was not available because the air quality monitoring station was not in operation.

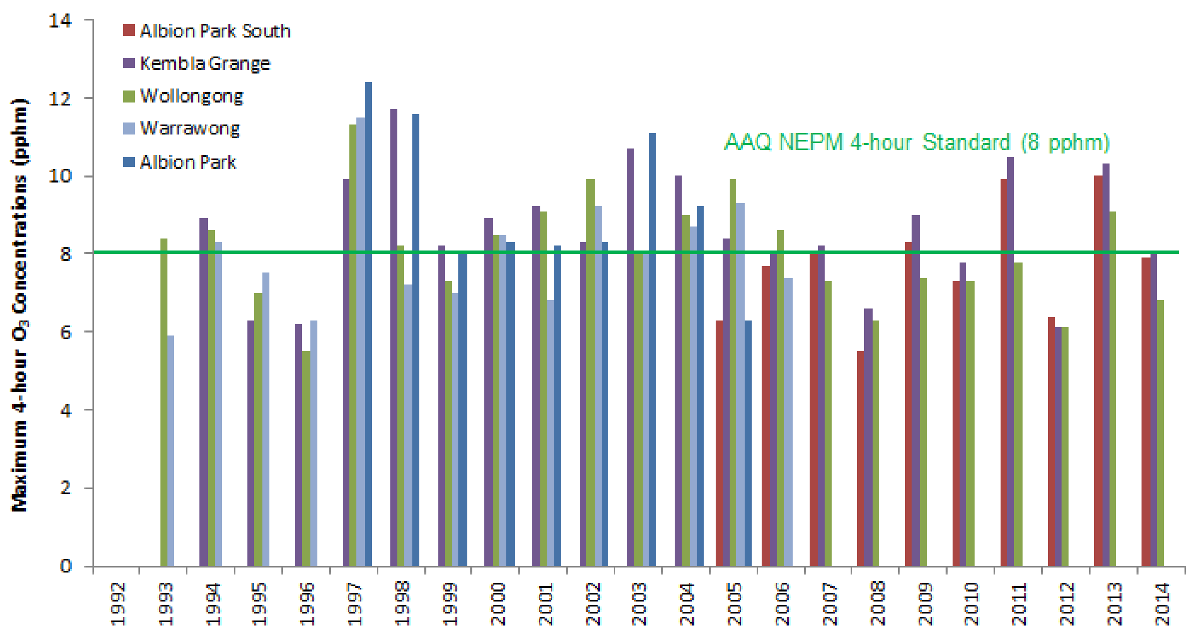


Figure 23: Maximum 4-hour O_3 recorded at Illawarra regional monitoring stations 1992–2014

Table 7: Number of days exceeding the national 4-hour O_3 standard at Illawarra regional monitoring stations 1992–2014

Year	Number of days exceeding the national 4-hour average O_3 standard				
	Albion Park	Albion Park South	Kembla Grange	Warrawong	Wollongong
1992	-	-	-	-	-
1993	-	-	-	0	1
1994	-	-	1	1	3
1995	-	-	0	0	0
1996	-	-	0	0	0
1997	5	-	5	3	4
1998	5	-	5	0	1

Year	Number of days exceeding the national 4-hour average O_3 standard				
	Albion Park	Albion Park South	Kembla Grange	Warrawong	Wollongong
1999	1	-	1	0	0
2000	3	-	4	3	2
2001	1	-	2	0	1
2002	1	-	1	2	2
2003	4	-	3	1	0
2004	1	-	3	1	2
2005	0	-	1	1	1
2006	-	0	1	-	1
2007	-	0	1	-	0
2008	-	0	0	-	0
2009	-	1	2	-	0
2010	-	0	0	-	0
2011	-	3	2	-	0
2012	-	0	0	-	0
2013	-	3	2	-	2
2014	-	0	0	-	0

Note: '-' indicates data was not available because the air quality monitoring station was not in operation.

Statistical analysis of the daily 1-hour and 4-hour maximum ozone concentrations measured at Wollongong, Kembla Grange and Albion Park South were undertaken to remove seasonal variations in pollution levels so that longer term trends could be considered. This was done by expressing the daily maximum of each 1-hour and 4-hour ozone concentration as a deviation from the mean for that day of the year based on the long-term record. Trends were found to be similar for the three stations, with the trend for Wollongong shown in Figure 24. Based on the two decades of monitoring, higher ozone levels were recorded during dry and typically hot El Niño years (2002–07), as compared to the wetter and generally cooler La Niña years (2010–12).

Increasing ozone levels were recorded in 2013 and 2014. In New South Wales these years were equally the warmest years on record for maximum temperatures, with 2014 also being the warmest year on record for mean temperatures and the fourth-warmest year for minimum temperatures (Bureau of Meteorology 2014, 2015). Although above-average rainfall was experienced along the coast in 2013, inland regions were generally drier and more prone to dust generation and bushfires. Bushfire emissions contributed significantly to ozone levels in the Illawarra during the October–November 2013 bushfire emergency period. The 2014 year was characterised by below-average rainfall across much of New South Wales and significant heatwaves in January, May, October and November.

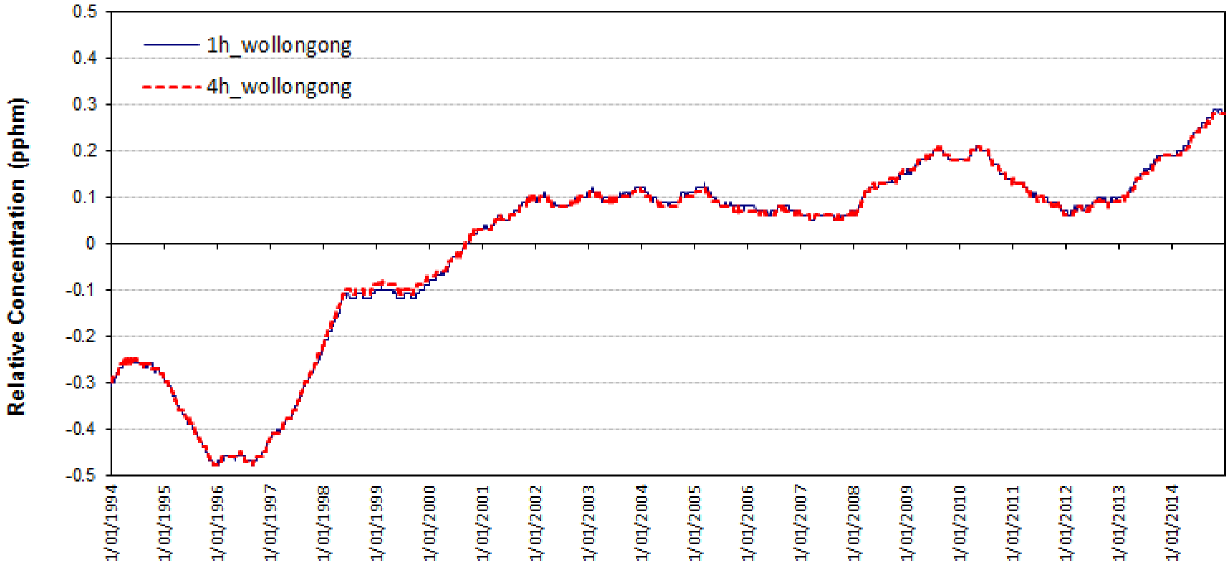


Figure 24: Long-term trend of daily 1-hour and 4-hour maximum O_3 levels recorded at Illawarra regional monitoring stations 1994–2014

4.7 Summary of findings

Air quality monitoring has been undertaken by OEH in the Illawarra since 1992, with monitoring having been undertaken for CO, NO_2, SO_2, PM_{10}, $PM_{2.5}$ and O_3 at several sites. Monitoring sites have included Albion Park, Albion Park Rail, Albion Park South, Kembla Grange, Warrawong and Wollongong, with stations located to track regional air quality affecting the general population.

Air quality in the Illawarra is generally comparable with cities in other Australian jurisdictions and good by world standards. Concentrations of CO, NO_2 and SO_2 recorded at OEH air quality monitoring stations have generally decreased since the 1990s, with recent levels recorded to be within national air quality standards. Ambient lead levels decreased significantly to well within national standards after the introduction of unleaded fuel, resulting in ambient lead monitoring being discontinued in 2004.

Particle levels (PM_{10} and $PM_{2.5}$) and ozone concentrations in the Illawarra are comparable with the levels recorded in Australian cities and below levels measured in several countries abroad. However, these pollutants do exceed national standards from time to time, posing air pollution-related health risks to local communities. It is also of note that health effects due to exposures to ambient particle and ozone concentrations have been observed to occur at levels which are within national standards (NEPC 2010).

Exceedances of the national 24-hour standard for PM_{10} and the national 24-hour advisory reporting standard for $PM_{2.5}$ in the Illawarra region usually coincides with regional dust storms or bushfire events. Annual average PM_{10} levels are observed to be within the EPA Impact Assessment Criterion of 30 µg/m³ at OEH monitoring stations. The addition of an annual national air quality standard for PM_{10} is being considered as part of the AAQ NEPM revision process with an annual maximum concentration of 20 µg/m³ proposed for consideration (Australian Government 2014). The potential exists for this proposed standard to be exceeded during years significantly affected by dust storms or bushfires (or both) and at sites close to Port Kembla industrial areas (e.g. Warrawong). Annual average $PM_{2.5}$ concentrations have been observed to exceed the national advisory reporting standard of 8 µg/m³ in some years, generally coinciding with dry, bushfire-affected years.

The composition of airborne fine particles typically includes ammonium sulfate, sea salt, black carbon, organic matter and soil. This indicates that primary particles emitted directly from sources and secondary particles formed in the air as a result of chemical reactions between gaseous pollutants (precursor pollutants) or gases and existing particles contribute to airborne $PM_{2.5}$ levels. The chemical composition also indicates that $PM_{2.5}$ concentrations in the region are associated with both natural and human-made sources of particle and gaseous emissions.

Elevated ozone levels in the Illawarra region can occur as a result of photochemical smog produced from local emissions, smog or precursors transported down the coast from the Sydney region, or emissions from regional bushfires. Exceedances of the 1-hour and 4-hour ozone national standards generally occur during the warmer months of the year, with peaks coinciding with periods of high temperature and with regional bushfire events.

5 Sources of air pollution

The relationship between ambient air quality (presented in the previous section) and air emissions (presented in this section) is quite complex and influenced by a range of factors, including meteorology, topography, chemical reactions of pollutants in the air and source type (see Box 4). For this reason, source contributions to total emissions in a region do not compare well with source contributions to air pollution levels at a particular location. This should be kept in mind when interpreting the emissions data presented.

Air quality in the Illawarra is affected by sources located in the region in addition to sources situated further afield, with interregional transport contributing to local air pollution levels (Nelson et al. 2002). Similarly, atmospheric emissions within the Illawarra region can affect air quality within neighbouring areas. While recognising the importance of interregional transport, this section focuses on sources of air pollution situated within the Illawarra region.

In this section, sources of air emissions in the Illawarra region are identified and described based on the EPA's NSW Greater Metropolitan Region (GMR) Air Emissions Inventory which provides detailed information on emissions for the 2003 and 2008 calendar years (EPA 2012). Whereas the NSW GMR Air Emissions Inventory covers the entire Wollongong and Shellharbour LGAs, it should be noted the inventory (and hence the emissions information presented) covers only 66% of the Kiama LGA (169 square kilometres of the total 258 square kilometres) (EPA 2013a). Reference is also made to industry-reported emissions from the National Pollutant Inventory (NPI) to assess recent trends in industrial emissions, and to shipping related emissions data for Port Kembla from the national shipping air emissions inventory (Goldsworthy & Goldsworthy 2014).

Attention is specifically paid to primary particle emissions, ground-level ozone precursor pollutants (volatile organic compounds [VOC] and oxides of nitrogen [NOx]), and to sulfur dioxide (SO_2). Gaseous pollutants such as SO_2, VOC and NOx contribute to the formation of secondary particles in the air.

Box 4 – Emissions inventory information compared to air quality information

When interpreting emission inventory information, it is important to understand the relationship between emissions and ambient air quality is quite complex and influenced by a number of factors. How emissions are dispersed, transported and transformed depends on:

- Meteorology (wind speed and direction, temperature, sunlight and rainfall) – high wind speeds tend to dilute emissions, while wind direction determines where they are transported. Medium- and long-range transport of emissions may impact on local air quality when emissions from a large distant source are transported by wind. Temperature and sunlight play a key role in atmospheric reactions.
- Topography (surrounding terrain) – this can either trap emissions, influence how they disperse or determine the direction they are transported.
- Atmospheric reactions – in addition to primary emissions released directly from sources, secondary pollutants, such as photochemical smog (ground-level ozone is an indicator) or secondary particulate matter (inorganic sulfates, nitrates and secondary organic aerosols) can be formed.
- Source location and type – the influence of a particular emission source on local air quality tends to decrease with distance from the source. Sources range from elevated point sources, like a boiler chimney, to ground-level, area sources such as motor vehicle emissions in an urban road network or wind-blown dust from an exposed area.

5.1 Wollongong regional emissions compared to Sydney and Newcastle

Annual PM_{10}, $PM_{2.5}$ and NOx emissions for the 'Wollongong region' (as defined within the GMR Emissions Inventory) during 2008 were equivalent to about 15% to 17% of the annual emissions for the Sydney region (Figure 25) (EPA 2013a). SO_2 emissions in the Wollongong region are estimated to be about 84% of SO_2 emissions for Sydney, with VOC releases in Wollongong being less than 10% of total VOC emissions for Sydney. When compared to emissions in the Newcastle region, Wollongong emits about half as much PM_{10}, about 10% less $PM_{2.5}$, about 20% less SO_2, 25% less VOC and about 20% more NOx emissions.

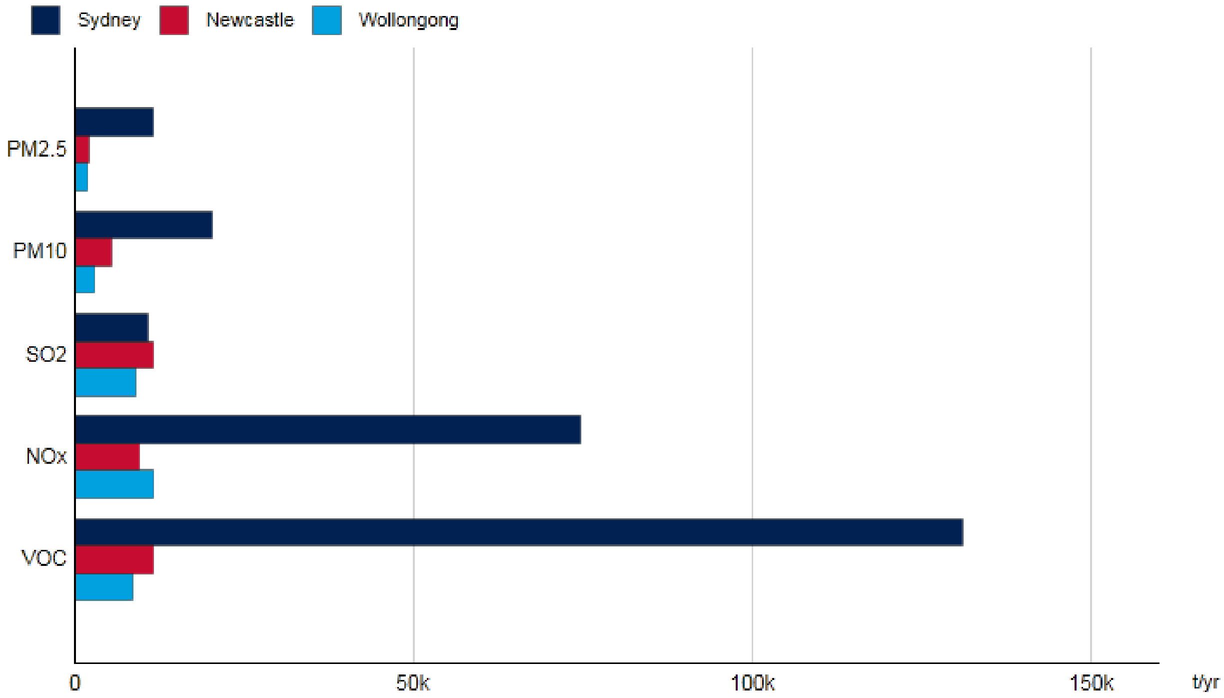


Figure 25: Summary of total annual emissions for the Wollongong, Newcastle and Sydney regions 2008 (kilotonnes per year)

5.2 Contribution of human activities to total emissions in the Illawarra

Human sources contribute significantly to overall emissions of particles, SO_2, NOx and VOC in the Illawarra (Figure 26). Natural sources, and notably biogenic emissions from forested areas, also contribute significantly to VOC emissions in the region. An overview of emissions by Illawarra LGA is provided in subsequent sections.

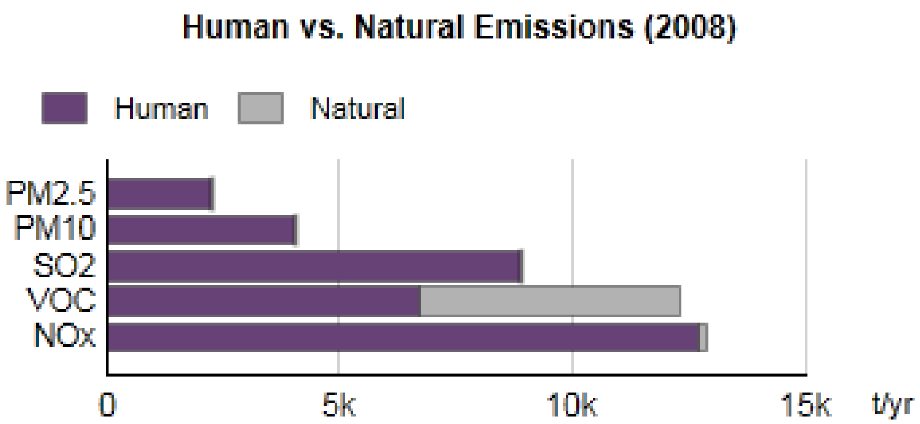
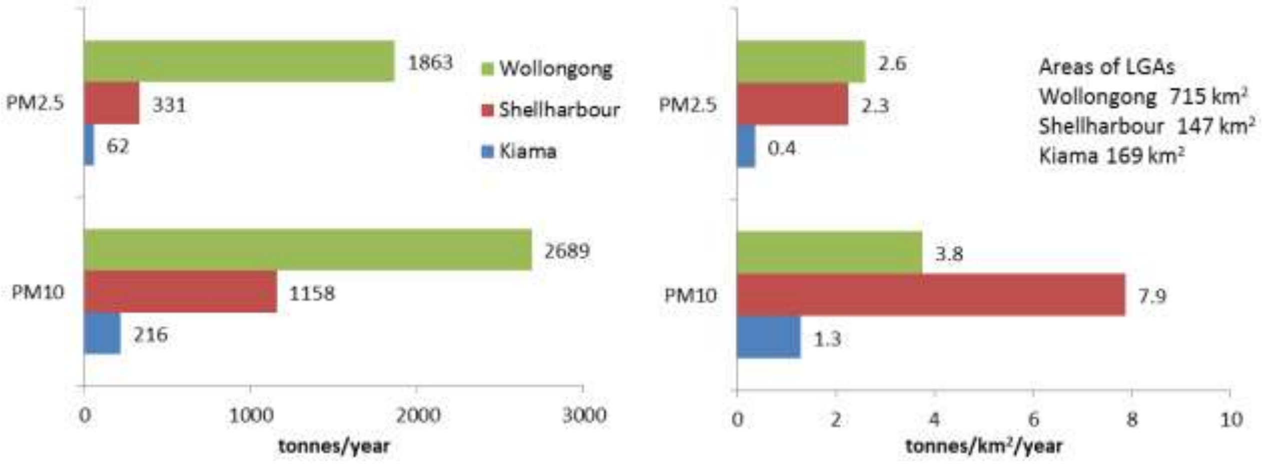


Figure 26: Contribution of human and natural sources to total emissions in the Wollongong, Shellharbour and Kiama LGAs 2008 (kilotonnes per year)

5.3 Particle emission sources in the Illawarra

Total annual PM_{10} and $PM_{2.5}$ emissions and emission intensities are illustrated for Kiama, Shellharbour and Wollongong for 2008 in Figure 27. The highest total annual PM_{10} and $PM_{2.5}$ emissions are estimated for the Wollongong LGA, followed by Shellharbour and Kiama LGAs. This indicates that sources in the Wollongong LGA contribute the most to total emissions in the Illawarra region. The highest PM_{10} emission intensity is estimated for Shellharbour LGA, with similar $PM_{2.5}$ emission intensities for Shellharbour and Wollongong LGAs.



(a) (b)

Figure 27: Geographic comparisons for PM_{10} and $PM_{2.5}$ (a) total annual emissions (tonnes/year) and (b) emission intensities (tonnes/year/km^2) in Kiama, Shellharbour & Wollongong LGAs 2008

5.3.1 Major sources of particle emissions

Major source groups contributing to PM_{10} and $PM_{2.5}$ emissions in Kiama, Shellharbour and Wollongong LGAs are shown in Figure 28, Figure 29 and Figure 30 respectively. The source groups are: industrial sources (i.e. EPA-licensed industry), on-road mobile sources (e.g. cars and trucks), non-road mobile sources (e.g. bulldozers, haul trucks, ships and locomotives), domestic–commercial sources (e.g. residential heating), commercial activities (e.g. service stations) and natural sources (e.g. vegetation, bushfires and sea salt).

Industrial emissions are the most significant source of PM_{10} emissions, accounting for 75% to 86% of total PM_{10} emissions in the three LGAs, followed by domestic–commercial emissions, accounting for 10% to 13% of total emissions.

Industrial emissions are also the dominant source of $PM_{2.5}$ emissions in Wollongong and Shellharbour LGAs, followed by domestic–commercial emissions (notably residential wood heating). Industrial and domestic–commercial sources contribute similar amounts of $PM_{2.5}$ emissions in Kiama LGA.

The top ten source types of PM_{10} and $PM_{2.5}$ emissions are given in Appendix C. The top individual source types contributing to PM_{10} and $PM_{2.5}$ emissions by LGA are:

- Kiama – non-metallic mineral mining and quarrying, and residential wood heating
- Shellharbour – non-metallic mineral mining and quarrying, and residential wood heating
- Wollongong – basic ferrous metal manufacturing and residential wood heating.

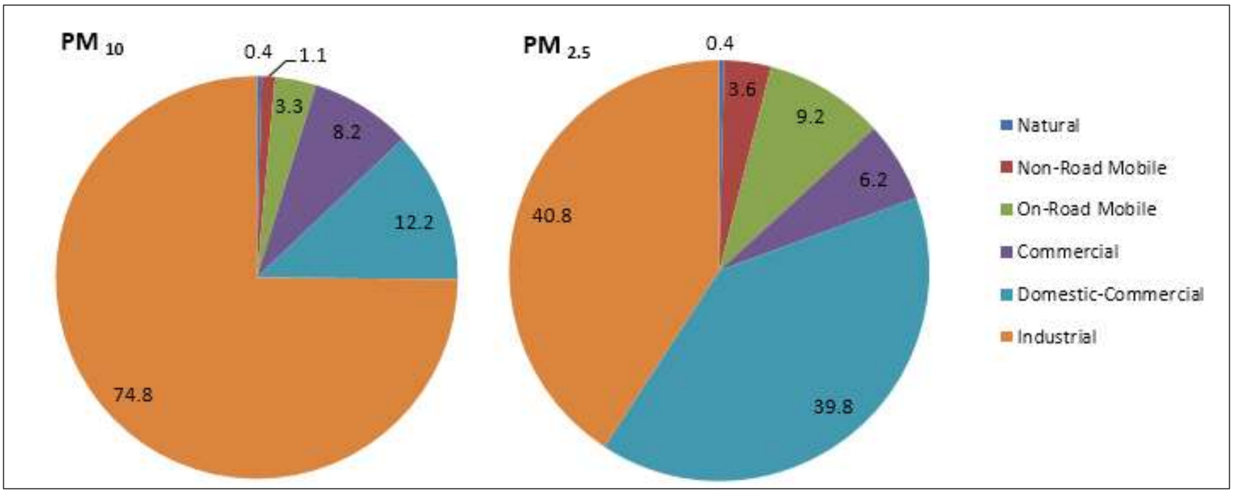


Figure 28: Major source group contributions to PM_{10} and $PM_{2.5}$ emissions in Kiama LGA (%)

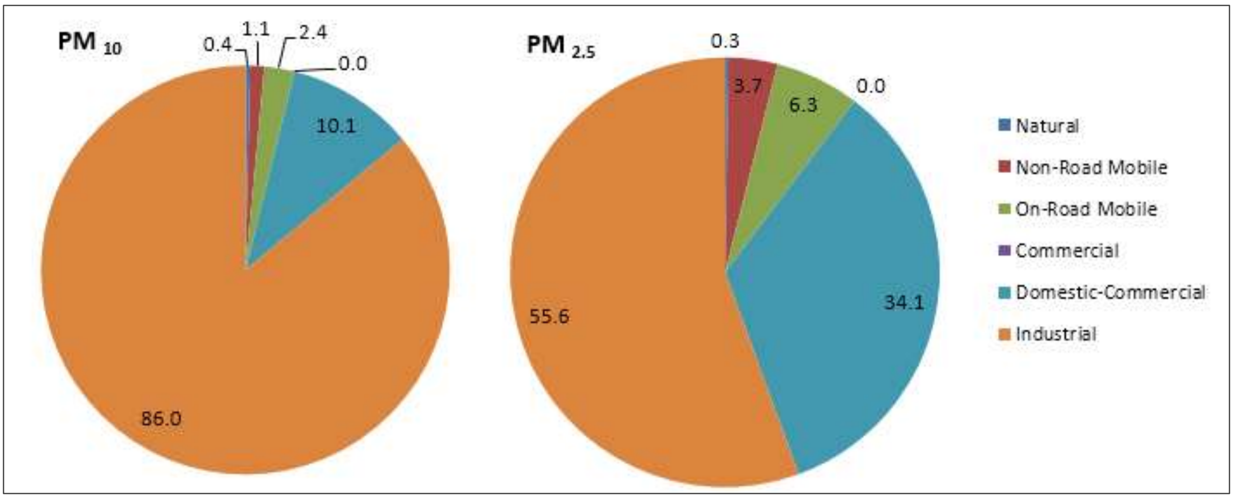


Figure 29: Major source group contributions to PM_{10} and $PM_{2.5}$ emissions in Shellharbour LGA(%)

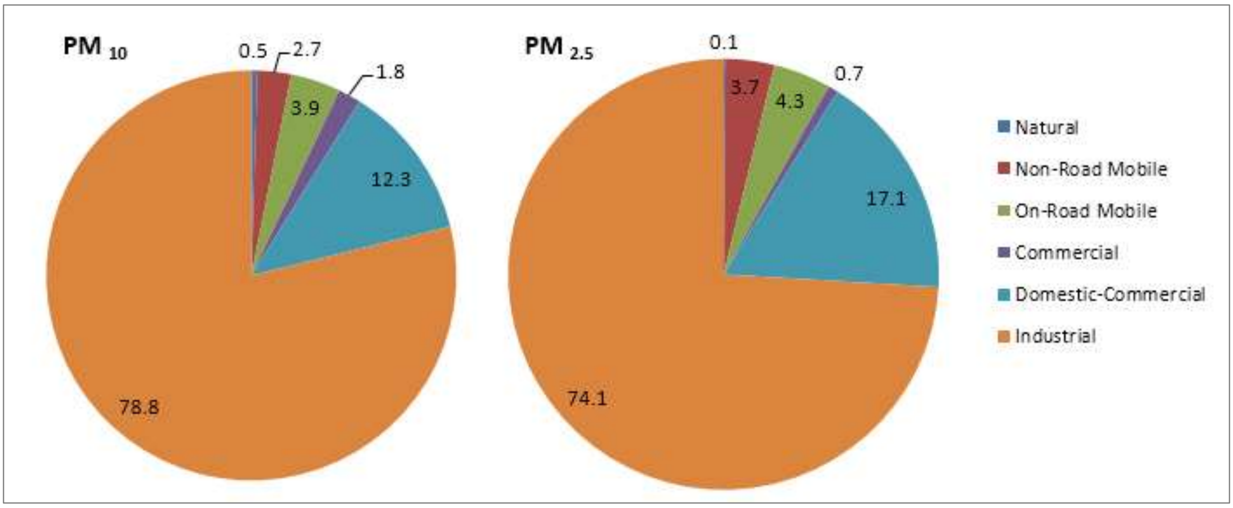


Figure 30: Major source group contributions to PM_{10} and $PM_{2.5}$ emissions in Wollongong LGA(%)

5.3.2 Trends in particle emissions over time

PM_{10} and $PM_{2.5}$ emissions from major source groups in the Illawarra region are summarised in Table 8 for the 2003 and 2008 calendar years. Total PM_{10} and $PM_{2.5}$ emissions decreased by 12% and 19% respectively between 2003 and 2008, however overall changes in emissions vary across major source groups.

Total on-road mobile emissions reduced over the 2003 to 2008 period, despite increases in vehicle activity rates in the region. Passenger vehicle activity typically increases in line with population growth, while freight vehicle activity grows in accordance with economic growth. This reduction in on-road mobile emissions is due to vehicle emission limits (Australian Design Rules) becoming progressively more stringent and the use of cleaner fuels (Australian Government fuel quality standards). Reductions in total vehicle emissions are expected over the next 10 to 20 years in spite of the continued increase in vehicle activity (EPA 2014b). Notwithstanding this overall trend in total emissions, areas within regions may experience an increase in vehicle emissions due, for example, to increased road haulage of freight along a route. Furthermore, increased residential development pressure along major transport corridors increases the potential for exposure to air pollutants released.

Particle emissions from the industrial and commercial sources decreased over the 2003 to 2008 period. Regulation of EPA-licensed premises through the application of more stringent emission standards in the Protection of the Environment Operations (Clean Air Regulation) 2010 and as licence conditions and regulatory action including pollution reduction programs, has in part contributed to this reduction. Advances in emission estimation techniques also accounted for lower commercial sector emissions in 2008.

Despite Australia having introduced increasingly stringent national emissions standards for on-road diesel trucks and vehicles since 1996, there are no similar national standards in place controlling emissions from non-road diesel plant and equipment. This includes non-road diesel powered construction and mining equipment, rail locomotives, equipment at ports and ships. The non-road sector is the largest source of fine particles that remains largely unregulated. $PM_{2.5}$ emissions from non-road sources (primarily emitted from diesel vehicles and equipment) were estimated to increase by 17% between 2003 and 2008 despite reductions in regulated on-road and industrial sources. In 2008, industrial vehicles and equipment accounted for 56% of $PM_{2.5}$ emissions from non-road mobile sources, with shipping and locomotive emissions contributing 20% and 16% of non-road mobile $PM_{2.5}$ emissions respectively. More information on $PM_{2.5}$ emissions from shipping, drawn from the national shipping air emissions inventory, is given in Box 5.

The greatest percentage growth in particle emissions in the Illawarra is from domestic–commercial sources, with emissions dominated by residential wood heaters which account for over 90% of PM_{10} and $PM_{2.5}$ from this sector. Lawn mowing, household liquid fuel burning and barbecues are minor sources compared to residential wood heaters. The 23–24% increase in particle emissions over the 2003 to 2008 period was due to equivalent increases in residential wood heater emissions.

Biogenic and geogenic emissions include wind erosion of exposed areas, agricultural burning, bushfires and prescribed burning. These emissions typically vary from year to year, with higher emissions occurring during hotter, dryer years. Higher biogenic and geogenic emissions occurred in 2003 due to greater emissions from vegetation burning.

Table 8: PM_{10} and $PM_{2.5}$ emissions from major source groups for 2003 and 2008 in the Illawarra

Major source groups	PM_{10} emissions			$PM_{2.5}$ emissions		
	2003	2008	Change	2003	2008	Change
	(tonnes/year)			(tonnes/year)		
Biogenic	19	18	-5%	16	4	-75%
Non-road mobile	99[(a)]	87	-12%	71[(a)]	83	17%
On-road mobile	165	141	-15%	157	107	-32%
Commercial	107[(b)]	66	-38%	44[(b)]	18	-59%
Domestic–commercial	383	474	24%	371	456	23%
Industrial	3666[(c)]	3116	-15%	2110[(c)]	1564	-26%
Total	4435	3901	-12%	2766	2231	-19%

(a) The 2003 NSW GMR Air Emissions Inventory includes exhaust and wheel-generated dust from industrial and commercial vehicles within the ‘non-road’ source group. However, in the 2008 NSW GMR Air Emissions Inventory wheel-generated dust is included in the ‘commercial’ and ‘industrial’ source groups. To allow comparisons, the wheel-generated dust for commercial and industrial vehicles was removed from the 2003 ‘non-road’ source group and included in the ‘commercial’ and ‘industrial’ source groups respectively.

(b) PM_{10}/$PM_{2.5}$ emissions from commercial vehicle wheel-generated dust were included to allow comparison with 2008 emissions data.

(c) PM_{10}/$PM_{2.5}$ emissions from industrial vehicle wheel-generated dust were included to allow comparison with 2008 emissions data.

Box 5 – Fine particle ($PM_{2.5}$) emissions from shipping at Port Kembla

Many ships are powered by large engines operating on high sulfur fuel and emit high levels of fine particles and sulfur dioxide (EPA 2015). $PM_{2.5}$ emissions released within Port Kembla port boundaries in 2010–11 were estimated as part of a national shipping air emissions inventory (Goldsworthy & Goldsworthy 2015). Total $PM_{2.5}$ emissions from shipping were estimated to be about 51 tonnes/year for the port area.

At Port Kembla, most $PM_{2.5}$ shipping emissions were estimated to occur when vessels are at berth, with auxiliary engines being the most significant source of emissions (Figure 31). Although emissions associated with ships at anchor were relatively low, it is notable that most anchorage associated with Port Kembla occurs outside port boundaries (and therefore is not included in the inventory for the port).

Most fine-particle emissions from shipping at Port Kembla in 2010–11 were estimated to come from bulk carriers (51%), general cargo (21%) and vehicle carriers (21%) (Figure 32). More recently (2012–13), general cargo activity has reduced by a factor of about four, with little change in bulk exports (Goldsworthy & Goldsworthy 2014).

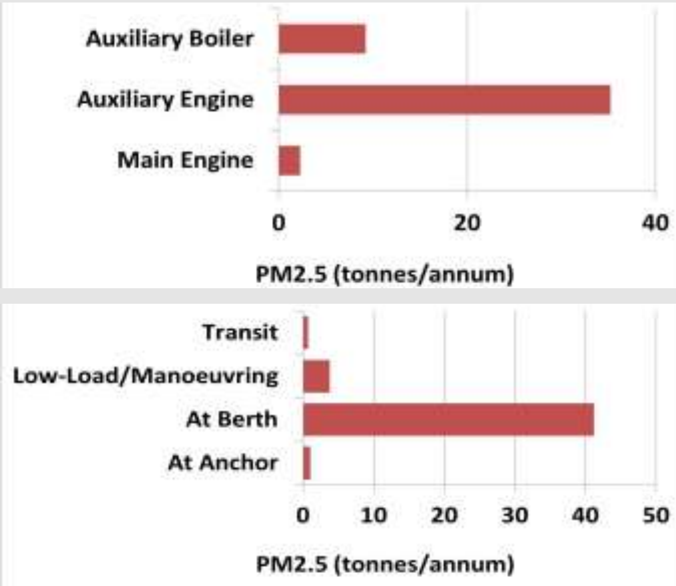


Figure 31: $PM_{2.5}$ shipping emissions for Port Kembla by machinery type (top) and activity (bottom) (2010–11) (Goldsworthy & Goldsworthy 2014)

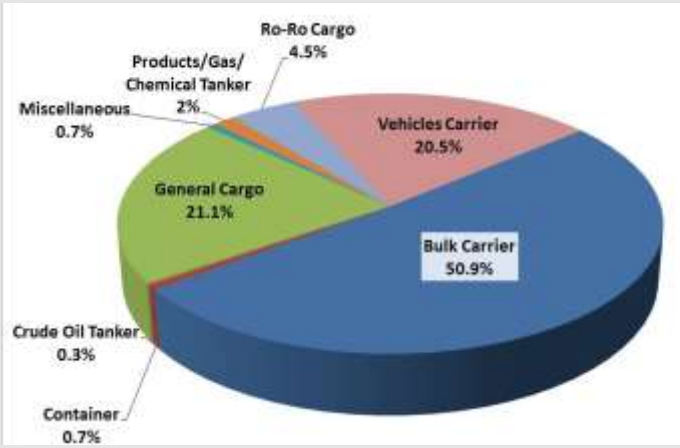


Figure 32: Vessel type contributions to $PM_{2.5}$ emissions for Port Kembla (2010–11) (Goldsworthy & Goldsworthy 2014)

5.3.3 Spatial trends in particle emissions

The spatial distribution of PM_{10} and $PM_{2.5}$ emissions is illustrated in Figure 33 and Figure 34, respectively. Higher levels of primary particle emissions coincide with the industrial areas at Port Kembla.

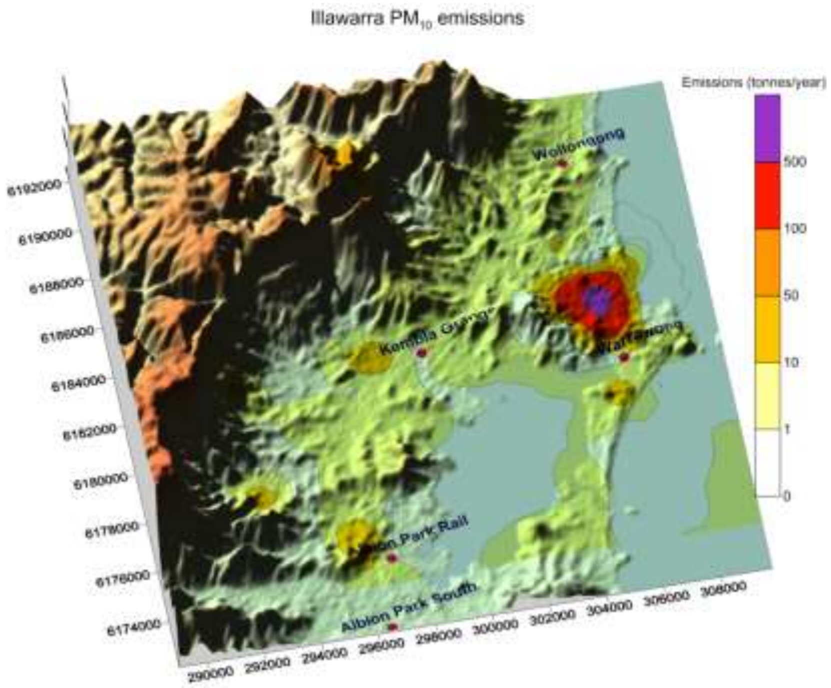


Figure 33: Spatial distribution of PM_{10} emissions in the Illawarra region

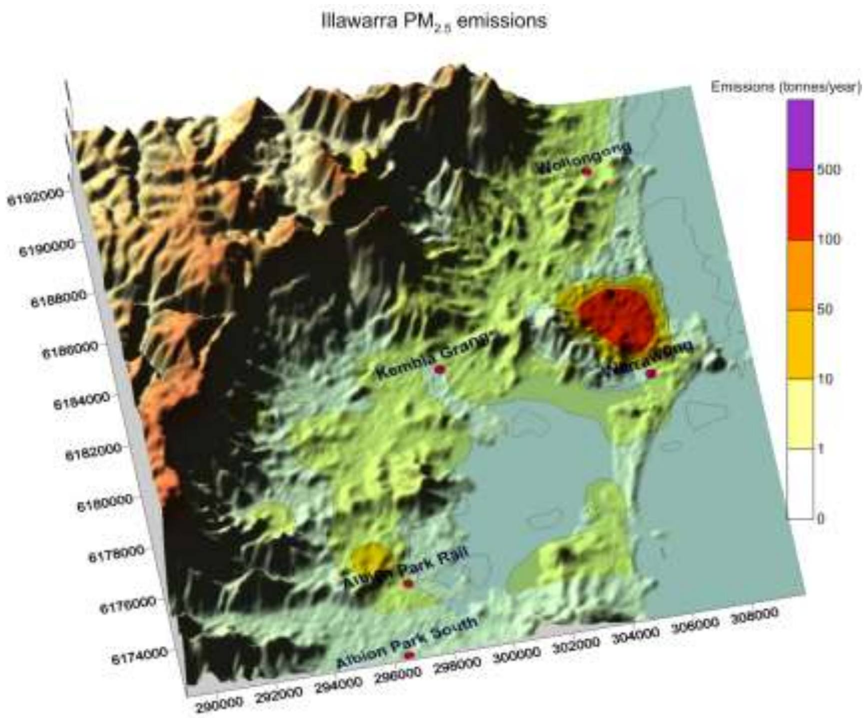


Figure 34: Spatial distribution of $PM_{2.5}$ emissions in the Illawarra region

5.4 Sources of gaseous emissions

Total annual SO_2, NOx and VOC emissions and emission intensities for Kiama, Shellharbour and Wollongong LGAs for 2008 are illustrated in Figure 35. The highest total annual SO_2, NOx and VOC emissions were estimated for the Wollongong LGA, followed by Shellharbour and Kiama LGAs. Higher NOx and SO_2 emission intensities are estimated for the Wollongong LGA, with the highest VOC emission intensities estimated for Shellharbour LGA.

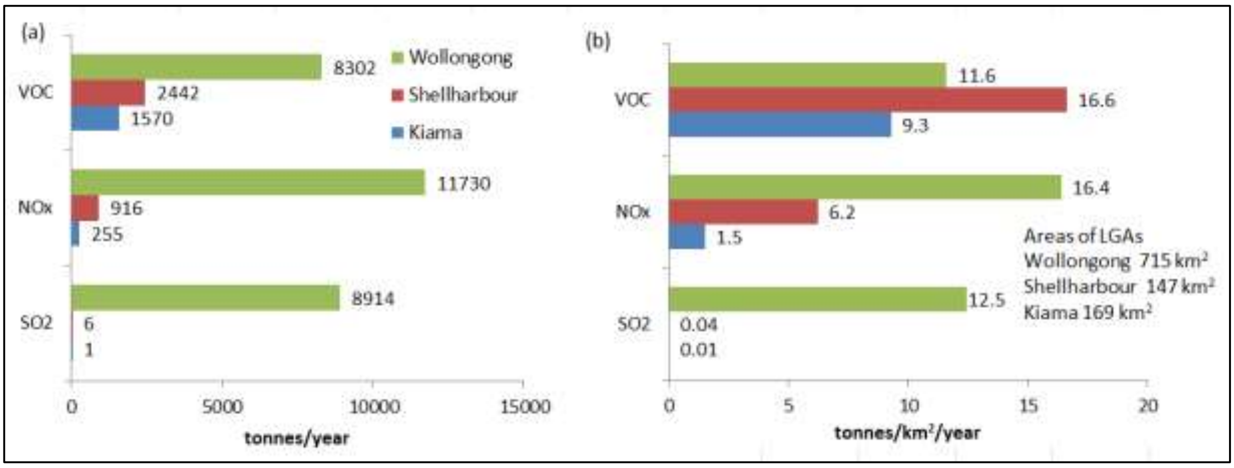


Figure 35: Geographic comparisons for SO_2, NOx and VOC (a) annual emissions (tonnes/year) and (b) emission intensities (tonnes/year/km^2) in Kiama, Shellharbour and Wollongong LGAs

5.4.1 Major sources of SO_2 and ground-level ozone precursor emissions

Figure 36, Figure 37 and Figure 38 present major source group contributions to SO_2, NOx and VOC emissions in Kiama, Shellharbour and Wollongong LGAs. The top ten individual source types contributing to these emissions are presented in Appendix C.

Sulfur dioxide

Domestic–commercial and on-road mobile sources contribute the greatest proportion of the estimated SO_2 emissions in Kiama and Shellharbour LGAs, with minor contributions from non-road mobile sources. In Shellharbour LGA, industrial sources are also a minor contributor of SO_2 emissions. In contrast, industrial sources are the predominant source of SO_2 emissions within the Wollongong LGA, accounting for nearly 98% of total SO_2 emissions. The top individual sources contributing to SO_2 emissions within each LGA are:

- Kiama – residential wood heating and petrol vehicle exhaust
- Shellharbour – residential wood heating and petrol vehicle exhaust
- Wollongong – basic ferrous metal manufacturing and petroleum and coal product manufacturing.

See Appendix C for further details.

Oxides of nitrogen

On-road mobile sources account for 59% and 68% of NOx emissions in Kiama and Shellharbour LGAs respectively, while contributing only 22% of NOx emissions in the Wollongong LGA with industrial sources contributing about 67% of emissions in Wollongong LGA. Other sources of NOx include non-road mobile, natural and domestic–commercial activities. Natural source emissions contribute 18% of NOx emissions in the Kiama LGA, but have a smaller contribution within other LGAs. The top individual sources contributing to NOx emissions by LGA are:

- Kiama – diesel vehicle exhaust and petrol vehicle exhaust
- Shellharbour – petrol vehicle exhaust and diesel vehicle exhaust
- Wollongong – basic ferrous metal manufacturing and petrol vehicle exhaust.

See Appendix C for further details.

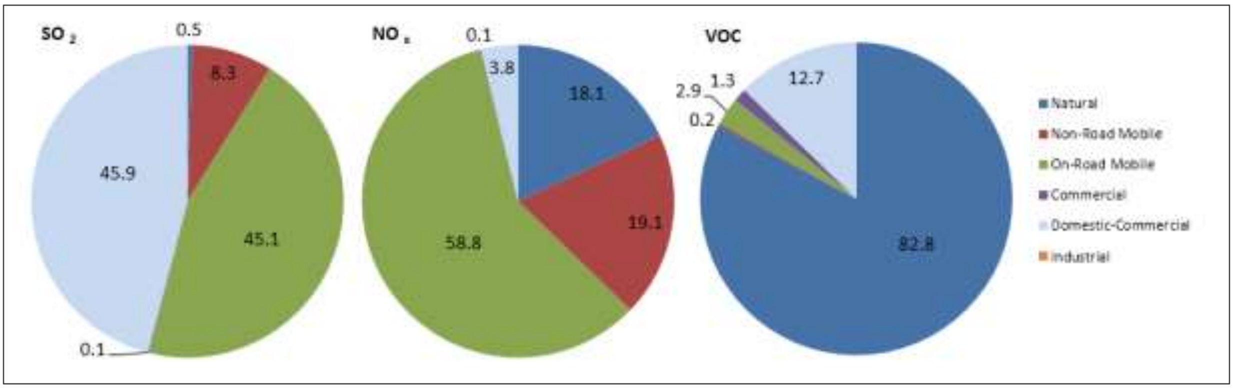


Figure 36: Major source group contributions to SO_2, NOx and VOC emissions in Kiama LGA (%)

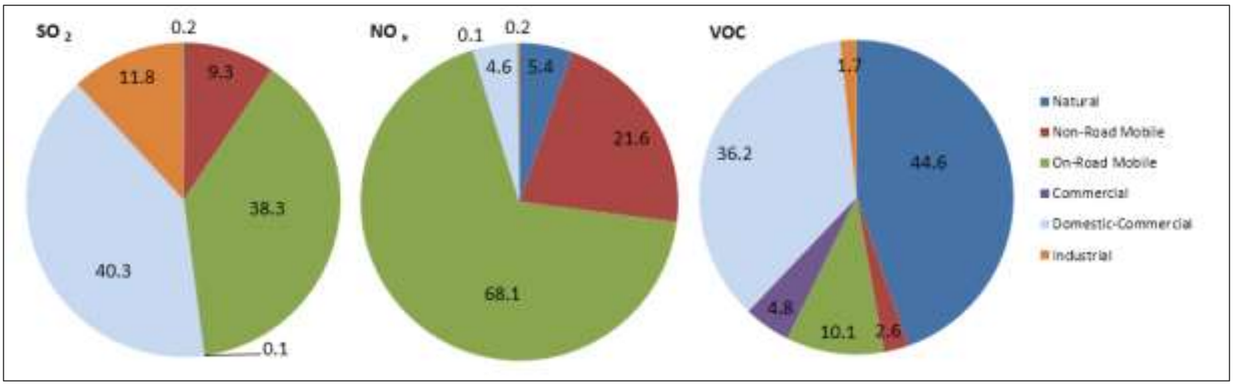


Figure 37: Major source group contributions to SO_2, NOx and VOC emissions in Shellharbour LGA (%)

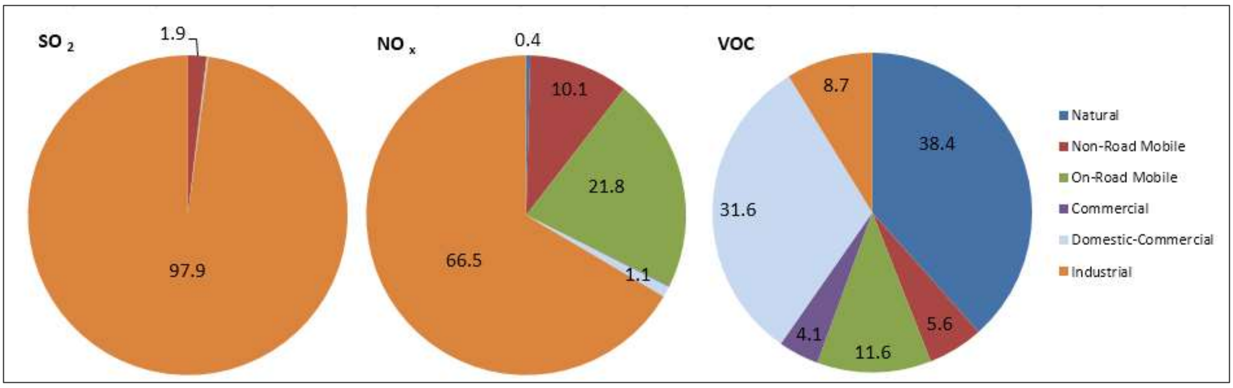


Figure 38: Major source group contributions to SO_2, NOx and VOC emissions in Wollongong LGA (%)

Volatile organic compounds

Natural and domestic–commercial sources together contribute around 70% of VOC emissions in Shellharbour and Wollongong LGAs. Natural sources are the predominant contributor to VOC emissions within the Kiama LGA, accounting for about 83% of emissions. Tree canopy and grassland emissions are the top individual source types contributing to VOC emissions in the three LGAs followed by emissions from the use of aerosols and solvents.

5.4.2 Trends in SO_2 and ground-level ozone precursor emissions

SO_2, NOx and VOC emissions from major sources in the Illawarra region in 2003 and 2008 are summarised in Table 9.

Table 9: SO_2, NOx and VOC emissions from major source groups in 2003 and 2008 within Illawarra region

Major source groups	SO_2 emissions			NOx emissions			VOC emissions		
	2003	2008	Change	2003	2008	Change	2003	2008	Change
	(tonnes/year)			(tonnes/year)			(tonnes/year)		
Biogenic	0.4	0.1	-73%	141	147	4%	5475	5580	2%
Non-road mobile	197	168	-15%	1115	1427	28%	228	532	133%
On-road mobile	84	12	-85%	4663	3334	-29%	3130	1250	-60%
Commercial	1.1	0.7	-33%	115	13	-89%	832	480	-42%
Domestic–commercial	8	10	19%	148	179	20%	3593	3705	3%
Industrial	10578	8731	-17%	7962	7802	-2%	905	767	-15%
Total	10868	8921	-18%	14144	12901	-9%	14163	12315	-13%

As for particle emissions, total on-road mobile gaseous emissions reduced over the 2003 to 2008 period, despite increases in vehicle activity rates in the region. Advances in vehicle technology, implementation of increasingly more stringent vehicle emission standards and the use of cleaner fuels contributed to this reduction (EPA 2014b). However, some transport routes may experience an increase in vehicle emissions due to more substantial growth in activity rates. Residential development along major transport corridors can also increase the potential for greater exposure to air pollutants being released from transport corridors.

No emission standards are in place for non-road mobile sources. NOx and VOC emissions increased from non-road mobile source mainly due to higher activity rates. Due to reductions in the sulfur content of diesel fuel required by Australian Government fuel quality standards, SO_2 emissions from industrial non-road vehicles reduced in 2008. The lower SO_2 emissions from non-road mobile sources was largely due to refinements in the data and methods used to quantify shipping emissions.

Increases in population were in part responsible for the growth in emissions from domestic–commercial sources. SO_2, NOx and VOC emissions from the industrial and commercial source groups were estimated to decrease over the 2003 to 2008 period. Regulation of EPA-licensed premises, including the application of increasingly stringent emission standards under the POEO Act and the implementation of pollution reduction programs by sites, is expected to have contributed to this reduction. Advances in emission estimation techniques accounted in part for the lower commercial sector emissions estimated in 2008. The derivation of site-specific emission factors for boilers used at hospitals based on surveys, and improved surface coating consumption data for the smash repair industry, represent the most significant improvements, resulting in lower, more robust emission estimates for 2008.

5.4.3 Spatial trends in SO_2 and ground-level ozone precursor emissions

The spatial distribution of SO_2, NOx and VOC emissions is illustrated in Figure 39, Figure 40 and Figure 41 respectively. Areas of maximum emissions for these pollutants are all located around the Port Kembla region.

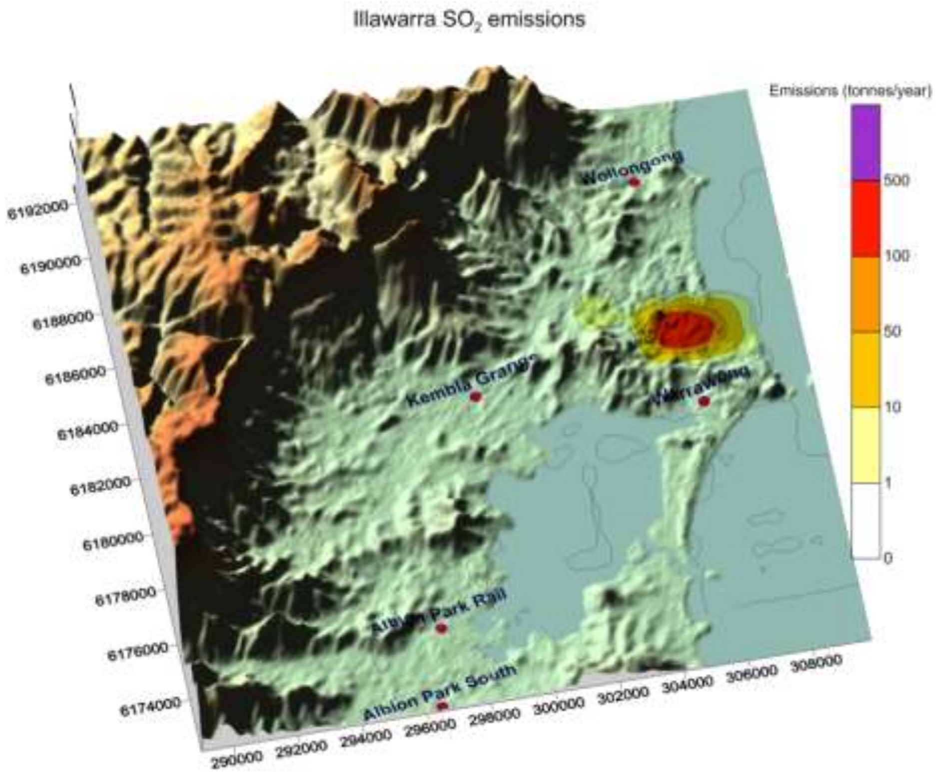


Figure 39: Spatial distribution of SO_2 emissions in the Illawarra region

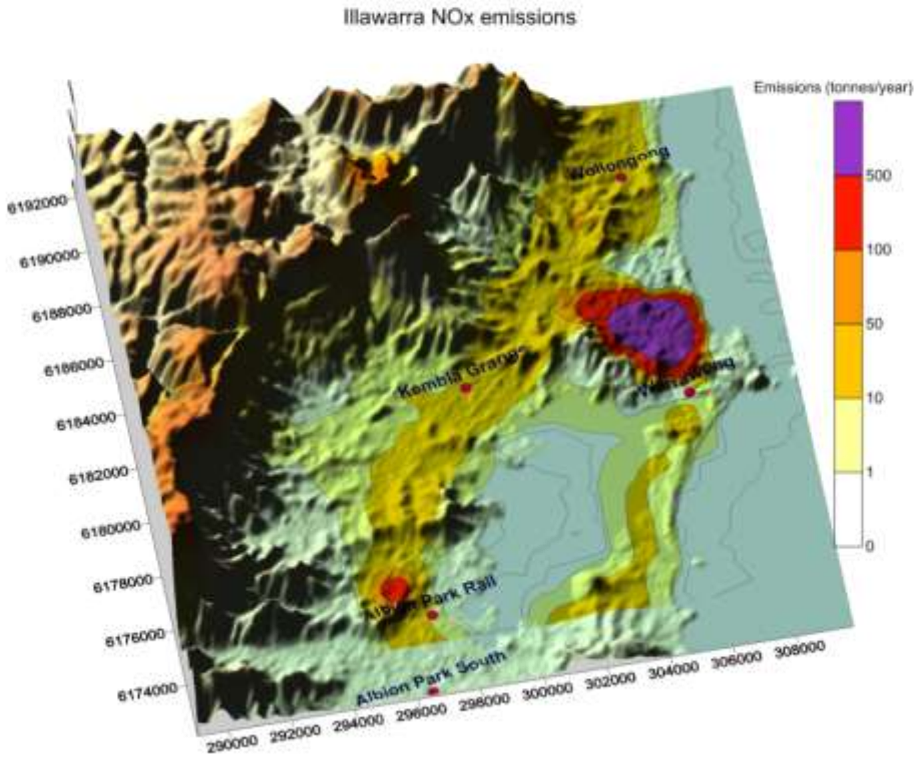


Figure 40: Spatial distribution of NOx emissions in the Illawarra region

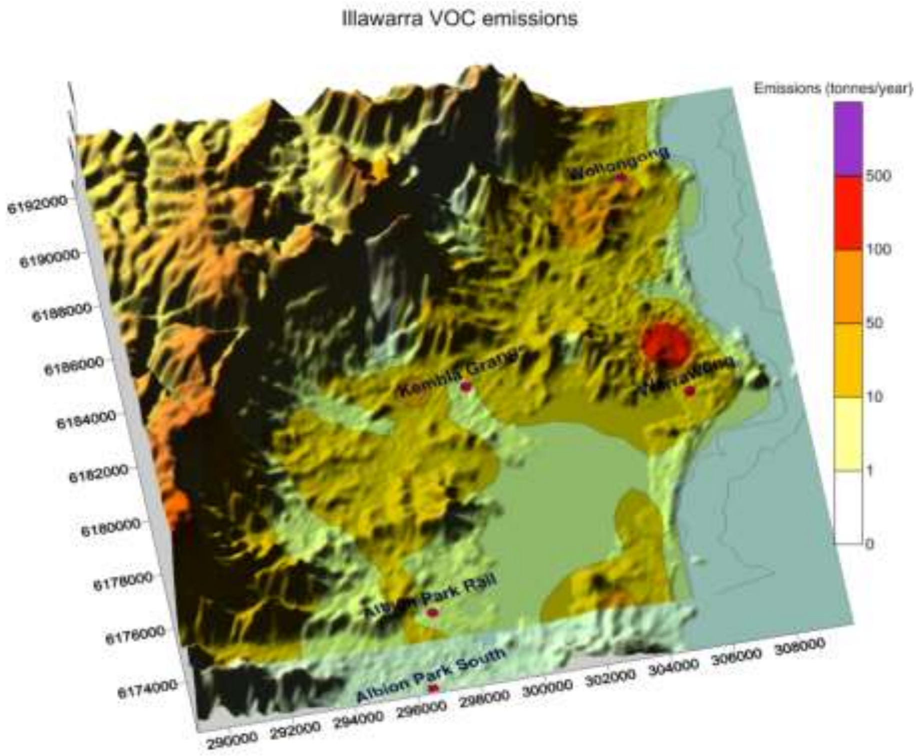


Figure 41: Spatial distribution of VOC emissions in the Illawarra region

5.5 Recent trends in industrial emissions

The National Pollutant Inventory (NPI) is a source of industry-reported information. Given that emissions information is published annually, this inventory provides useful information on recent changes in industrial emissions for the Illawarra region.

Annual PM_{10}, SO_2, NOx and VOC emissions from all NPI-reporting industrial facilities in the Illawarra are shown for the 2008 to 2013 period in Figure 42. Annual PM_{10} emissions increased from 1323 tonnes in 2008–09 to 2265 tonnes in 2010–11, then decreased to 1984 tonnes in 2012–13. Reported reductions in PM_{10} emissions from BlueScope Steel Port Kembla Steelworks contributed significantly to the overall trend. Estimated industrial $PM_{2.5}$ emissions for 2012–13 were more than double that in 2008–09.

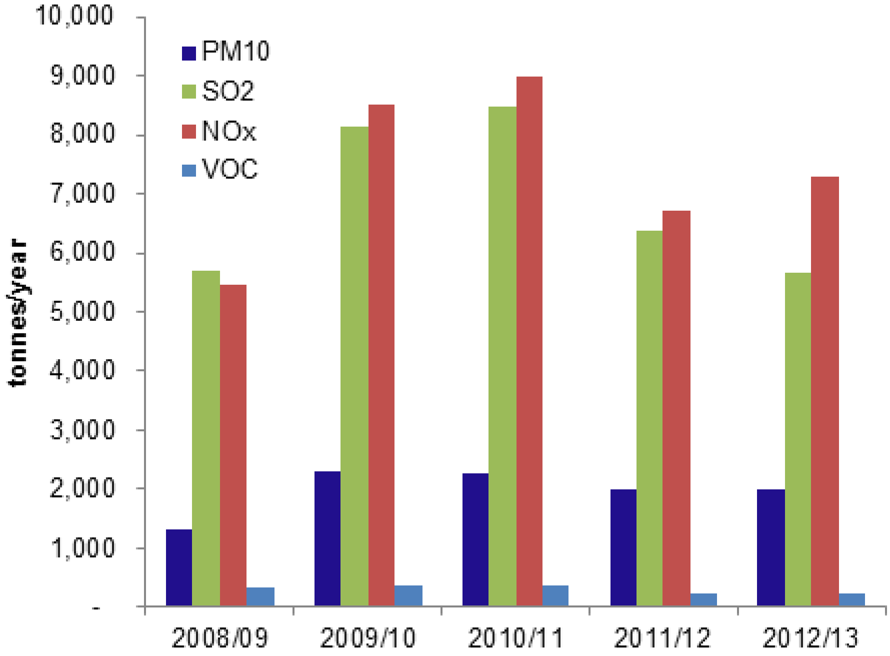


Figure 42: Total industrial facility emissions for PM_{10}, SO_2, NOx and VOC in the Illawarra

Annual SO_2 emissions from NPI-reporting industrial facilities were estimated to increase to 8464 tonnes in 2010–11, following which decreases to 5655 tonnes in 2012–13 were reported. During this period, SO_2 emissions from the BlueScope Steel Port Kembla Steelworks reduced from 7692 tonnes in 2010–11 to 4952 tonnes in 2012–13, contributing significantly to the overall trend in industrial SO_2 emissions.

Annual VOC emissions of 380 tonnes were reported in 2009–10, reducing by 40% to 231 tonnes in 2011–12 and 2012–13. A 50% reduction in VOC emissions was reported for the BlueScope Steel Port Kembla Steelworks over the same period (reducing from 240 tonnes in 2009–10 to 121 tonnes in 2012–13).

Over the period illustrated, total industrial facility NOx emissions peaked in 2010–11 (8986 tonnes), then decreased significantly in 2011–12 (6707 tonnes), with slightly increased levels reported for 2012–13 (7291 tonnes).

Industrial facilities comprising the top five sources of particulate matter emissions in the Illawarra are listed in Table 10 based on the NPI data for the 2012–13 reporting year. The BlueScope Steel Port Kembla Steelworks was the largest source, with Port Kembla Coal Terminal, Albion Park and Boral Dunmore quarry operations, and Metropolitan and Dendrobium coal mines identified as significant contributors.

Table 10: NPI-reporting industrial facilities in the Illawarra with the greatest PM_{10} and $PM_{2.5}$ emissions for 2012–13

Substance	Facility name	LGA	2012–13 emissions in NPI database (tonnes/year)	Contribution to total NPI-reported industrial emissions in the Illawarra
PM_{10}	BlueScope Steel Port Kembla Steelworks [Port Kembla NSW]	Wollongong	1432.8	72%
	Albion Park Quarry [Albion Park NSW]	Shellharbour	179.9	9%
	Boral Dunmore Quarry [Dunmore NSW]	Shellharbour	80.8	4%
	Metropolitan Collieries Pty Ltd [Helensburgh NSW]	Wollongong	70.1	4%
	Port Kembla Coal Terminal [Port Kembla NSW]	Wollongong	50.7	3%
$PM_{2.5}$	BlueScope Steel Port Kembla Steelworks [Port Kembla NSW]	Wollongong	172.2	81%
	Metropolitan Collieries Pty Ltd [Helensburgh NSW]	Wollongong	12.1	6%
	Dendrobium Mine [Mount Kembla NSW]	Wollongong	5.9	3%
	Albion Park Quarry [Albion Park-NSW]	Shellharbour	4.4	2%
	Boral Dunmore Quarry [Dunmore NSW]	Shellharbour	4.3	2%

Table 11 lists industrial facilities comprising the top five sources of ground-level ozone precursor emissions (NOx, total VOC) and SO_2 emissions in the NPI database for 2012–13. BlueScope Steel Port Kembla Steelworks in Wollongong is the most significant industrial source of NOx, VOC and SO_2 emissions.

Table 11: NPI-reporting industrial facilities in the Illawarra with the greatest NOx, VOC and SO_2 emissions for 2012–13

Substance	Facility name	LGA	2012–13 emissions in NPI database (tonnes/year)	Contribution to total NPI-reported industrial emissions in the Illawarra
NOx	BlueScope Steel Port Kembla Steelworks [Port Kembla NSW]	Wollongong	6,469	89%
	Energy Australia Tallawarra Pty Ltd [Yallah NSW]	Wollongong	257	4%
	Metropolitan Collieries Pty Ltd [Helensburgh NSW]	Wollongong	145	2%
	Dendrobium Mine [Mount Kembla NSW]	Wollongong	75	1%
	Albion Park Quarry [Albion Park NSW]	Shellharbour	65	1%
VOC	BlueScope Steel Port Kembla Steelworks [Port Kembla NSW]	Wollongong	121	52%
	Caltex Port Kembla Petroleum Depot [Port Kembla NSW]	Wollongong	27	11%
	BANZ, Mills & Coating – Springhill [Port Kembla NSW]	Wollongong	19	8%
	Energy Australia Tallawarra Pty Ltd [Yallah NSW]	Wollongong	18	8%
	Metropolitan Collieries Pty Ltd [Helensburgh NSW]	Wollongong	15	6%
SO_2	BlueScope Steel Port Kembla Steelworks [Port Kembla NSW]	Wollongong	4,952	88%
	Coalcliff Coke Works [Coalcliff NSW]	Wollongong	326	6%
	Corrimal Coke Works [Corrimal NSW]	Wollongong	311	5%
	Orica Port Kembla Site [Port Kembla NSW]	Wollongong	45	1%
	Energy Australia Tallawarra Pty Ltd [Yallah NSW]	Wollongong	11	0.2%

5.6 Summary of findings

Air quality in the Illawarra is affected by sources located in the region and remote sources situated further afield, with interregional transport contributing to local air pollution levels, as discussed in more detail in other sections of this report. This section focuses on air pollutants emitted within the Illawarra region.

The relationship between ambient air quality and air emissions is quite complex and influenced by a range of factors, including meteorology, topography, chemical reactions of pollutants in the air and source type. Source contributions to total emissions in the region do not compare well with source contributions to air pollution levels at specific locations. This must be kept in mind when interpreting the emissions inventory data.

Human sources contribute most of the emissions of particles, SO_2 and NOx in the Illawarra and also contribute substantially to VOC emissions. Natural sources, and notably biogenic emissions from forested areas, are an important source of VOC emissions in the region.

The 2008 NSW GMR Air Emissions Inventory supports the following conclusions about source contributions to total emissions for the Illawarra region:

- Major sources of particle emissions in the Illawarra are industrial (70% of $PM_{2.5}$ and 81% of PM_{10} emissions) and domestic–commercial sources (12% of $PM_{2.5}$ and 20% of PM_{10} emissions) (Figure 43). Iron and steel production, and mining and extractive activities account for the bulk of industrial emissions. Residential wood heating accounts for over 90% of particle emissions from domestic–commercial sources. Other sources of particle emissions include on-road and non-road mobile sources.
- Significant sources of VOC emissions are natural (45%), domestic–commercial (30%) and on-road mobile (10%). In the natural source category, biogenic emissions from vegetation is the largest source. The use of solvents, aerosols and surface coatings by households and commercial businesses accounts for about half of the VOC emissions from domestic–commercial sources.
- Notable sources of NOx emissions are industrial (60%), on-road mobile (26%), and non-road mobile (11%). Iron and steel production is the greatest industrial source.
- Industrial sources account for about 98% of the SO_2 emissions in the Illawarra in 2008, with iron and steel production contributing the bulk of these emissions.
- The highest levels of particle, SO_2 and ground-level ozone precursor emissions in the Illawarra occur in the industrial areas at Port Kembla.

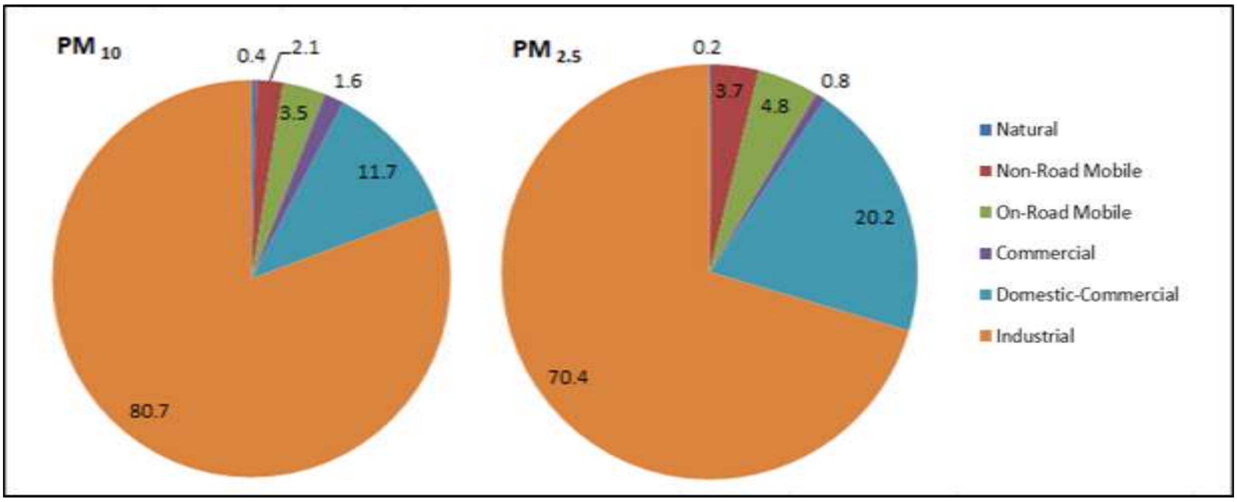


Figure 43: Contribution of major source categories to total annual PM_{10} and $PM_{2.5}$ emissions for the Illawarra based on the 2008 GMR Air Emissions Inventory

Trends in emissions were evaluated by comparing information from the 2003 and 2008 NSW GMR Air Emissions Inventory. Reference was also made to industry-reported emissions data from the NPI to assess more recent trends in industrial emissions.

On-road mobile emissions reduced over the 2003 to 2008 period, despite increases in vehicle activity. This is due to advances in vehicle technology, implementation of increasingly more stringent national vehicle emission standards and cleaner fuels introduced through Australian Government fuel quality standards. Reductions in vehicle emissions are expected to continue over the next 10 to 20 years in spite of the continued increase in vehicle activity (EPA 2014b). However, some transport routes may experience an increase in vehicle emissions due to more substantial growth in activity rates. Residential development along major transport corridors can also increase the potential for greater exposure to air pollutants being released from transport corridors.

No emission standards are in place for non-road mobile sources. This sector includes non-road diesel-powered construction and mining equipment, rail locomotives, equipment at ports and ships. The non-road sector is the largest source of fine particles that remains largely unregulated. Increases in particle, NOx and VOC emissions from non-road mobile sources between 2003 and 2008 occurred mainly because of increased activity levels. The lower SO_2 emissions from non-road mobile sources was largely due to refinements in the data and methods used for estimating shipping emissions. Due to reductions in the sulfur content of diesel fuel prescribed by Australian Government fuel quality standards, lower SO_2 emissions were estimated for industrial non-road vehicles.

Particle, SO_2, NOx and VOC emissions from industrial and commercial sources decreased over the 2003 to 2008 period. Regulation of EPA-licensed premises including the application of increasingly stringent emission standards under the POEO Clean Air Regulation and the implementation of pollution reduction programs is expected to have contributed to the reduction in emissions (EPA 2013b). Based on NPI-reported facility data, emissions increased in 2009–10 to 2010–11 but have decreased in more recent years with emission reductions at the Port Kembla Steelworks contributing to the peak and the subsequent reduction. Advances in emission estimation techniques accounted in part for lower commercial source emissions in the 2008 emissions inventory.

The 24% increase in fine particle emissions from domestic–commercial sources over the 2003 to 2008 period was due to equivalent increases in residential wood heater emissions which account for over 90% of the particles from domestic–commercial sources.

Biogenic and geogenic emissions include wind erosion of exposed areas, agricultural burning, bushfires and prescribed burning. These emissions typically vary from year to year, with higher emissions occurring during hotter, dryer years. Higher biogenic and geogenic emissions were estimated to occur in 2003 due to greater bushfire activity.

6 Air quality modelling

6.1 Contribution of interregional transport to ozone and particle events

Air quality modelling carried out as part of the large Metropolitan Air Quality Study (EPA 1996) provided evidence of factors contributing to ozone event days. The study demonstrated that precursor emissions from local sources can contribute to ozone events in the Illawarra region, with major sources of precursors in the Illawarra including vehicle traffic, iron and steel production and associated coke-making and primary metallurgical works. The Illawarra region is only about 80 kilometres south of Sydney, with modelling showing that air pollutants are occasionally transported between the two regions, and particularly from Sydney to the Illawarra. Ozone events in the Illawarra were concluded to occur typically as a combined effect of both local emissions and the transport of precursors and photochemical smog from other regions (Cope & Ischtwan 1996). Similar conclusions have been reached in the *Interregional Transport of Air Pollutants Study* (Nelson et al. 2002) and the more recent ozone modelling conducted by CSIRO (Cope et al. 2008).

Bushfires occurring outside the Illawarra have also been found to contribute to high ozone and particle events in the region. This was evident during the October 2013 bushfire period when the transport of smoke plumes from inland fires coincided with high ozone and fine particle levels in the Illawarra. Further details on such events are provided in Section 4.

6.2 Future air quality

Factors affecting future air quality in the Illawarra include regional growth, changes in transport and industrial activity levels, changes in climate and air quality management practices. Potential reductions in on-road and industrial emissions in the region due to progressively more stringent regulation and the general decline in industrial activity may be offset by increased non-road mobile emissions and residential emissions (wood heaters; aerosols, solvent and surface coatings use). Changes in climate are also projected to affect future air quality in the region.

CSIRO modelling shows the conditions associated with climate change are likely to result in an increase in the number of days exceeding the ozone standard in the Illawarra and the geographical extent of ozone impacts, as a result of increased temperatures. Changes to rainfall, temperature and weather patterns may also increase the frequency of dust storms and bushfire-related pollution events, leading to higher particle emissions. The results of the CSIRO modelling work are provided below and provide information on the predicted increase in land area where there will be three ozone exceedances per year (Cope et al. 2008).

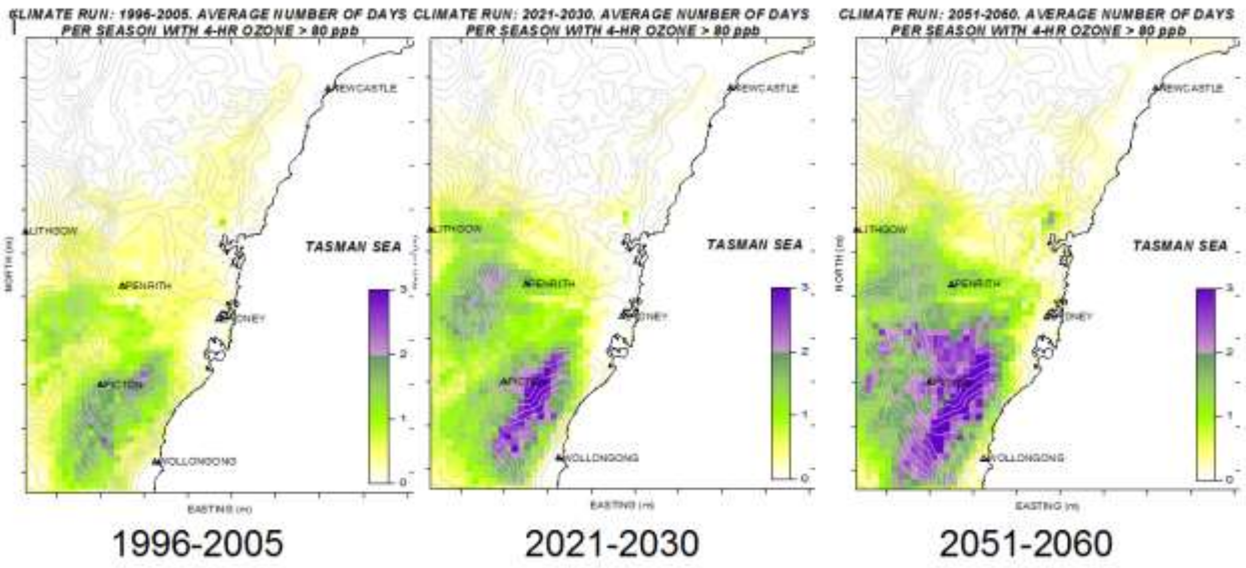


Figure 44: Spatial distribution of exceedences for 4 hour ozone > 80 ppb for recent years (1996–2005) and projected for the near future (2021–30) and far future (2051–60) (Cope et al. 2008).

Projections of climate change and related impacts on regional air quality are being undertaken as part of the NSW and ACT Regional Climate Modelling (NARCliM) project, a multi-agency research partnership between the NSW and ACT governments and the Climate Change Research Centre at The University of New South Wales. The NARCliM project has produced a suite of 12 regional climate projections for south-east Australia spanning the range of likely future changes in climate. Over 100 climate variables, including temperature, rainfall and wind, are available at fine resolution (10-kilometre and hourly intervals). The data is being used for impacts and adaptation research, and made available to decision makers. The data is also available to the public and will help to better understand possible changes in NSW climate (http://climatechange.environment.nsw.gov.au/).

Climate projections for the Illawarra region are available on the Adapt NSW website (OEH 2014b). Based on long-term (1910–2011) observations, surface air temperature in the Illawarra region has been increasing since about 1960, with higher temperatures experienced in recent decades. Based on the NARCliM results, the region is projected to continue to warm in the near future (2020–39) and far future (2060–79), compared to recent years (1990–2009). The warming is projected to be on average about 0.6°C in the near future, increasing to about 1.9°C in the far future. The number of hot days is projected to increase, with fewer potential frost-risk days anticipated in parts of the region. An increase in the number of severe fire-weather-risk days (i.e. days with a Forest Fire Danger Index [FFDI] above 50) is projected for summer and spring.

The region experiences considerable rainfall variability from year to year, as is evident from long-term precipitation records dating back to 1910. Natural variations in the climate system result in periods of droughts and flood. Regional climate models do not agree on how annual precipitation in the region will change, however, the majority of the 12 NARCliM climate models project a decrease in spring rainfall and an increase in autumn rainfall for the Illawarra region.

The implications of climate change for regional air quality, based on the NARCliM projections, is the subject of ongoing research by OEH. This research will address future trends in both ozone and particle pollution.

7 Research to further extend the evidence base

An overview of research areas of relevance to the Illawarra is provided in this section, with reference to major programs being implemented by OEH and EPA, in addition to research being conducted by leading science partners. Although not all of the research efforts referenced involve measurements in the Illawarra, the information generated by such research will contribute to a better understanding of air pollution sources and impacts in the region.

7.1 2013 NSW GMR Air Emissions Inventory

The EPA is updating the NSW GMR Air Emissions Inventory for the 2013 calendar year to improve the evidence about current contributions from all sources and past and future trends in emissions. The inventory update will include a number of improvements, such as the inclusion of additional sources not considered previously (e.g. lightning NOx), and additional particle components to support regional particle modelling.

This work will enable the EPA to communicate accurate, up-to-date information to community, environmental and industry stakeholders; evaluate the effectiveness of existing programs and develop new cost-effective programs aimed at improving air quality. The 2013 NSW GMR Air Emissions Inventory will be completed in 2016. The web-based tool Air Emissions in My Community will continue to provide stakeholders with access to updated air emissions, displayed for different geographical areas, ranging from the entire NSW Greater Metropolitan Region down to postcode level.

Source and emissions data from the NSW GMR Air Emissions Inventory also represents a critical input to regional airshed modelling for the Greater Metropolitan Region.

7.2 Regional airshed modelling

Whereas OEH's air quality monitoring network provides robust, continuous air pollution concentration data for selected sites, regional airshed modelling provides a way of projecting high-resolution spatial variations in air pollution concentrations. Regional meteorological and chemical transport modelling supports air quality forecasting, source contribution study and scenario analysis to assesses the impact of development proposals and planned mitigation measures on regional air quality.

Because ozone and fine particle concentrations in New South Wales exceed national air quality standards from time to time, regional airshed modelling efforts in New South Wales focus on simulating ozone photochemistry and particle formation and removal processes. OEH's Regional Airshed Modelling Program aims to progressively enhance modelling capabilities, with the following key projects being undertaken over the 2014–16 period:

- Tailoring and verification of the Conformal-Cubic Atmospheric Model (CCAM) meteorological model and Chemical Transport Model (CTM) chemical transportation model for regional airshed modelling applications in New South Wales. CSIRO demonstrated the use of CCAM–CTM during the Sydney Particle Study (Cope et al. 2013). Building on this study, OEH is collaborating with CSIRO to establish tailored and verified ozone and secondary particle modelling for New South Wales, with a focus on the GMR which includes the Illawarra, Newcastle and the Upper Hunter.

- A collaborative OEH–University of Wollongong project to establish a model evaluation framework to evaluate the performance of meteorological and chemical transport models. This project also involves the configuration and verification of the Weather Research and Forecasting (WRF) meteorological model and the selection, configuration and verification of an open source chemical transport model for application in New South Wales.

Advanced ozone and particle modelling will enhance the evidence base for NSW air policy, with the establishment of verified 3-D deterministic numerical modelling systems making it possible to provide local communities with accurate air quality forecasts.

7.3 Air quality forecasting

Accurate air quality forecasting provides information that can help people susceptible to poor air quality take preventative actions to minimise personal health impacts. Forecasting can also be used to inform emission reduction measures to avoid air pollution episodes.

OEH currently provides 24-hour ozone pollution forecasts for the Sydney region, expressed in Air Quality Index class and updated daily at 4pm on the OEH website (OEH 2014d). A qualitative forecasting method is applied, drawing on forecasters' technical and domain knowledge and experience, meteorological forecasts provided by the Bureau of Meteorology and information received from the NSW Rural Fire Service on current fires and planned hazard reduction burns. OEH's current ozone forecasting for the Sydney region is of moderate skill and capability for forecasting high particle pollution days.

The OEH Air Quality Forecasting Program aims to progressively expand the scope and enhance the accuracy of air quality forecasting capabilities in New South Wales over the next five years through collaboration and the development of advanced tools and analysis. The focus is on forecasting ozone and particle pollution within the Greater Metropolitan Region and key regional areas of New South Wales. Specific projects being undertaken or participated in under this program include:

- Development, verification and deployment of statistical and deterministic air quality forecasting tools and techniques by the Climate and Atmospheric Science branch of OEH. Information on deterministic modelling being developed is given in the previous section.
- OEH is collaborating with the Bureau of Meteorology, CSIRO and NSW Rural Fire Service on the Fire and Air Quality subproject of the Bureau's Forecast Demonstration Project (FDP). This 2014–15 subproject, led by CSIRO, is evaluating the use and accuracy of high-resolution quantitative fire weather and air pollution forecasts based on the medium-range ensemble numerical weather prediction from the Bureau's ACCESS model.
- OEH is collaborating with The University of New South Wales on a project funded by the NSW Environmental Trust which aims to produce a tool for forecasting air pollution impacts caused by hazard reduction burns over the greater Sydney region. This tool is intended to improve the planning of burn times to reduce the potential for extreme air pollution risk to the community, while still allowing NSW land managers and fire agencies to carry out critical burns required to reduce bushfire risk.

The previously mentioned collaborative OEH–University of Wollongong project to evaluate and enhance regional airshed modelling will also contribute to improvements in deterministic forecasting capabilities.

7.4 Particle characterisation

OEH, EPA and NSW Health have collaborated with ANSTO and CSIRO to undertake particle speciation and source apportionment studies in New South Wales. To date, particle speciation studies have been undertaken for Sydney (OEH 2014a) and the Upper Hunter (Hibberd et al. 2013) and a further study is underway in the Lower Hunter (OEH 2015a). Further information on ANSTO's ongoing east coast $PM_{2.5}$ speciation and source apportionment work, including at Warrawong in the Illawarra, is described in Section 7.9.1.

7.5 Emerging monitoring techniques

7.5.1 Rapid response monitoring

The recent Hazelwood mine fire in Morwell, Victoria, highlighted the need for rapid-response monitoring for air quality incidents. OEH has established rapid-response air quality monitoring capabilities for deployment within New South Wales. This monitoring includes:

- two portable monitoring stations able to hold up to seven air quality monitors that comply with Australian Standards and with the AAQ NEPM (Figure 45)
- non-compliance monitors that could be rapidly deployed for 'indicative' measurements to support immediate decision-making (e.g. DustTraks aerosol dust monitors)
- meteorological monitors
- telemetry and communications systems
- web reporting capabilities for incident monitoring.

Figure 45: OEH portable monitoring station able to hold up to seven air quality monitors that comply with Australian Standards and with the AAQ NEPM

To further extend and enhance rapid response monitoring capabilities, OEH is investigating air toxics sampling methods and a range of emerging technologies including non-compliance, continuous monitors that are cheaper, easier and quicker to deploy for indicative monitoring.

OEH and EPA are also devising procedures to guide the implementation of incidence monitoring and the assessment and communication of measurement results.

7.5.2 Black carbon monitoring

Black carbon is a major component of airborne fine particulate matter in urban areas and has received increasing attention internationally due to its effects on urban air quality, public health and global climate. These fine particles are directly emitted into the air during the incomplete combustion of fossil fuels used for transport, heating and industrial activities, and from biomass burning due to vegetation fires. The monitoring of black carbon as a proxy for traffic combustion exhaust is being applied in a number of European, American and Asian urban environments.

OEH is investigating the measurement of Equivalent Black Carbon (EBC) using multi-wavelength aethalometers at two sites located in the Lower Hunter. These aethalometers support continuous, real-time, temporally resolved measurements of EBC at seven wavelengths (370, 470, 520, 590, 660, 880 and 950 nanometres). The measurement of absorption at 880 nanometres is interpreted as concentrations of black carbon.

Simultaneous measurement at multiple wavelengths is able to support studies of aerosol light absorption and source apportionment, with black carbon from fossil fuel being distinguishable from biomass combustion. OEH research into the operation of aethalometers and the interpretation of the trends measured is ongoing.

7.6 Health effects of air pollution

The EPA, OEH and NSW Health collaborate with the independent Centre for Air Quality and Health Research and Evaluation (CAR)[4] to initiate new research to increase understanding of the health impacts, risks and costs of air pollution in New South Wales. An evaluation into the health impacts of difference sources, types and levels of airborne particles in New South Wales is due for completion in 2015.

The EPA, NSW Health, CAR and CSIRO are collaborating on a study to estimate the health impacts of $PM_{2.5}$-related shipping emissions in the Greater Metropolitan Region, including Port Kembla. This research is expected to be completed in 2015.

The EPA is supporting the University of Tasmania in an interstate study on the relative health effects of smoke pollution from bushfire events and planned hazard reduction burns. This is a multi-year study initiated in 2014.

7.7 Air quality management research

The EPA leads a range of research assessing the technical feasibility and benefits and costs of a range of air pollution mitigation measures. This has included the assessment of measures implementable by the industrial and commercial sector, in addition to measures for addressing emissions from residential wood burning and the non-road mobile sector.

[4] www.car-cre.org.au

Recently the EPA has commissioned an assessment of the technical feasibility, ship-owner/operator costs and emission impacts of adopting emission reduction measures for shipping in the Greater Metropolitan Region. This assessment is due for completion in 2015.

7.8 Climate change impacts on air quality

Projections of climate change and related impacts on regional air quality are being undertaken as part of the NSW and ACT Regional Climate Modelling (NARCliM) project, a multi-agency research partnership between the NSW and ACT governments and the Climate Change Research Centre at The University of New South Wales (see Section 6.2). This research will address future trends in both ozone and particle pollution.

7.9 Research by science partners

7.9.1 Particle speciation and source apportionment by ANSTO

The Australian Nuclear Science and Technology Organisation (ANSTO) has been using ion beam analysis (IBA) techniques to analyse fine particle pollution samples collected from key sites around Australia, and internationally, for more than 20 years (ANSTO 2015a). Accelerator-based IBA techniques (PIXE, PIGE, PESA and RBS) play a key role in this research, being able to simultaneously determine 21 key air pollution elements (H, F, Na, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Cu, Ni, Zn, Br and Pb) collected on exposed filters (ANSTO 2015b).

$PM_{2.5}$ sampling and characterisation at Warrawong conducted as part of ANSTO's east coast Aerosol Sampling Program (ASP) is ongoing, allowing changes in particle composition over time to be tracked and compared to particle composition measured at other sites.

ANSTO has recently released fine-particle concentration contour maps based on the long-term ANSTO ASP data collected for the NSW GMR from 2007–14. Monthly average $PM_{2.5}$ concentrations from 2007–13 have been used to produce contour maps which provide an indication of fine particle concentration levels from Wollongong through Sydney to Newcastle. Contour map video animations are available for black carbon, soil, ammonium sulfate and total $PM_{2.5}$ mass (Figure 46).

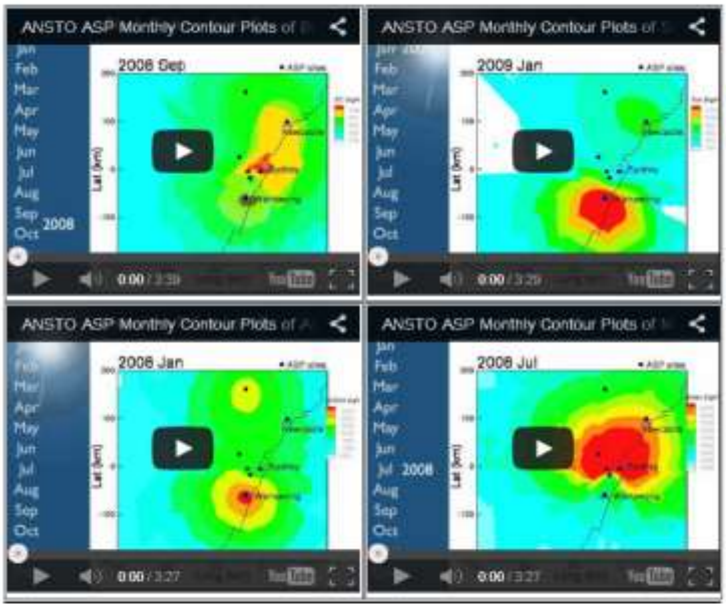


Figure 46: Contour map video animations for black carbon, soil, ammonium sulfate and $PM_{2.5}$ mass

Available at www.ansto.gov.au/ResearchHub/IER/Capabilities/ASP/

7.9.2 Centre for Atmospheric Chemistry, University of Wollongong

The Centre for Atmospheric Chemistry at the University of Wollongong (UOW) has been studying air in the Illawarra for over 20 years. The group runs observatories at both Wollongong (Figure 47) and Darwin that measure the changing amounts of trace gases in the troposphere and stratosphere, including greenhouse gases and ozone-depleting gases. These measurements are used to monitor the changing atmosphere as part of several international networks, such as the Total Carbon Column Observing Network (TCCON) (www.tccon.caltech.edu) and the Network for the Detection of Atmospheric Composition Change (NDACC) (www.acd.ucar.edu/irwg/index.html). They are also used for testing satellite-based instruments.

The Centre for Atmospheric Chemistry also makes ground-level measurements of greenhouse gases, volatile organic compounds, reactive species, aerosols and atmospheric radiation measurements (which are linked to Australia's Cape Grim station in Tasmania). Measurement campaigns study remote or poorly understood regions with a comprehensive range of instruments to more fully characterise the local atmosphere and emissions. UOW has orchestrated or collaborated in many such campaigns to measure both greenhouse gases and air quality, including agricultural sites as well as ship-borne and train-borne voyages.

Figure 47: TCCON ground validation site at UOW

Figure 48: Primary MUMBA campaign site in Wollongong

The Measurements of Urban, Marine, and Biogenic Air (MUMBA) campaign was recently organised by UOW to better characterise the atmosphere within the Illawarra region (Figure 48). More than 20 different instruments were deployed at three sites to complement OEH's routine air quality monitoring program. The detailed information obtained is useful for improving air quality models. More recently UOW is developing skills in atmospheric composition modelling ranging from global (e.g. GEOS-Chem, ACCESS) through regional and local scales (STILT, CHIMERE) to paddock scale for agricultural flux measurements (Windtrax). UOW is working with OEH to further improve the air quality forecasting capabilities in the region.

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Appendix A – Seasonal wind roses for the Illawarra region

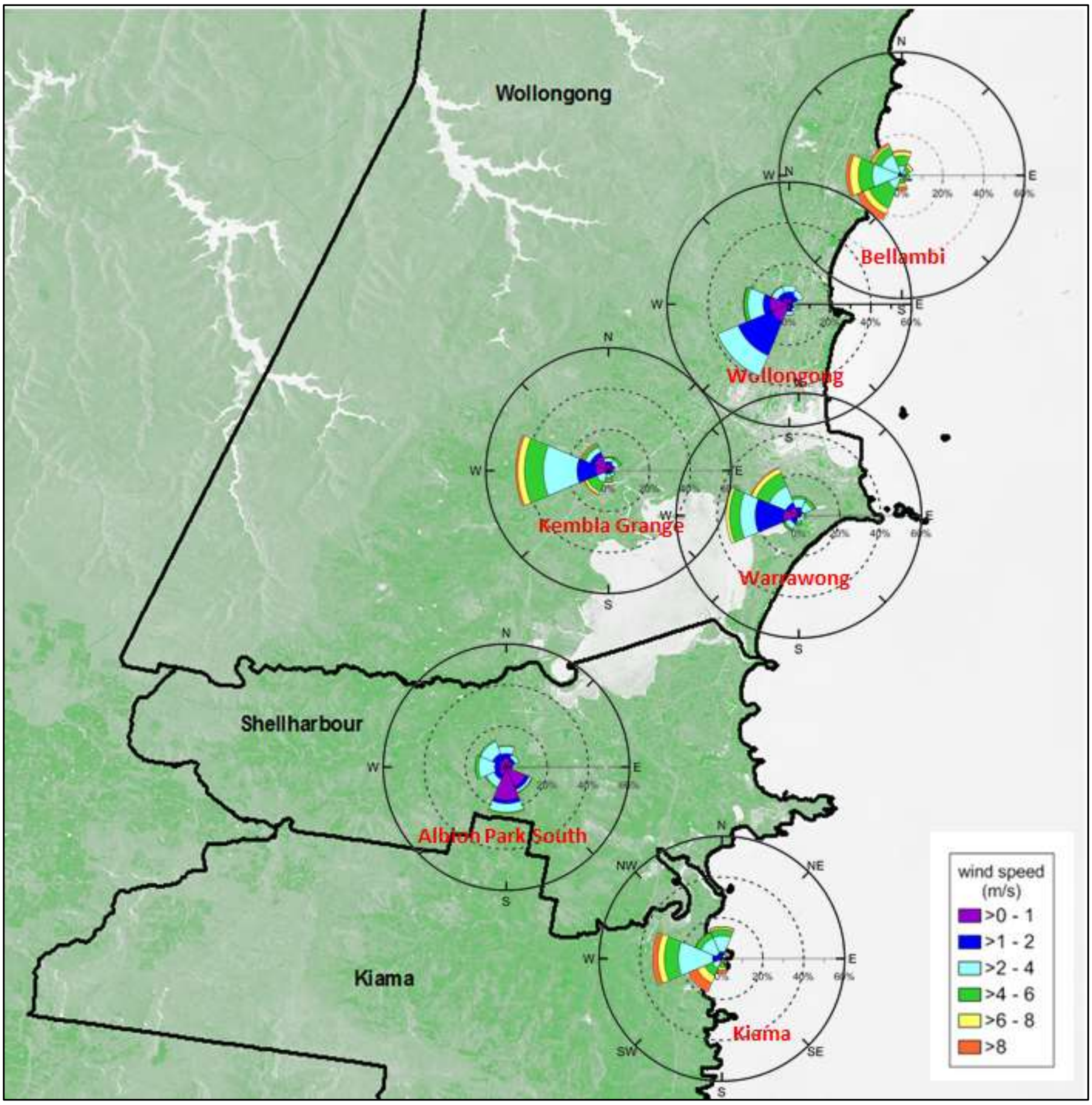

Figure A.1: Winter-average wind roses in OEH air quality monitoring stations Wollongong, Kembla Grange, Albion Park South for 2013 and Warrawong (decommissioned) for 2005; and BOM weather stations Bellambi, Kiama for 2013

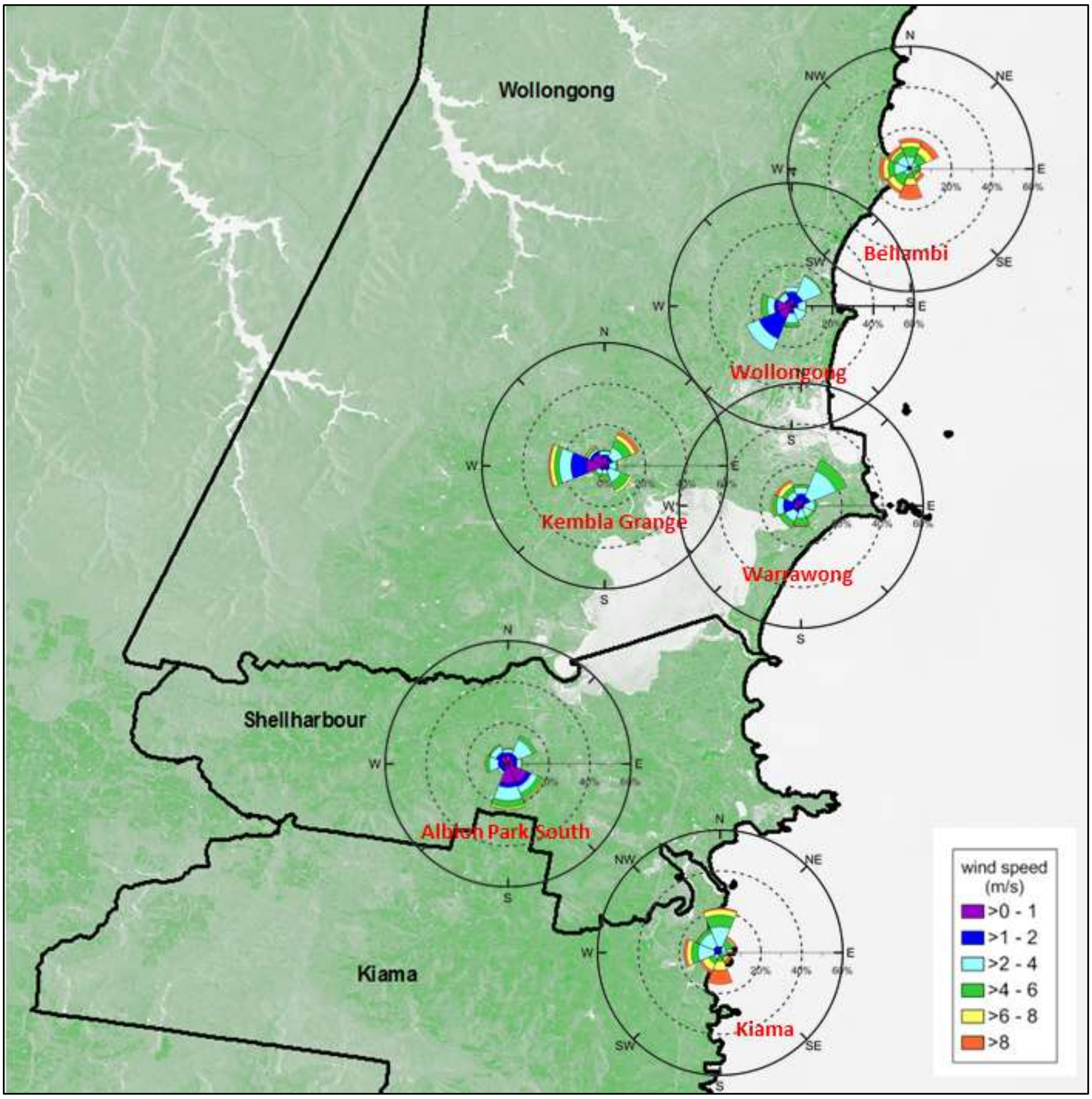

Figure A.2: Spring-average wind roses in OEH air quality monitoring stations Wollongong, Kembla Grange, Albion Park South for 2013 and Warrawong (decommissioned) for 2005; and BOM weather stations Bellambi, Kiama for 2013

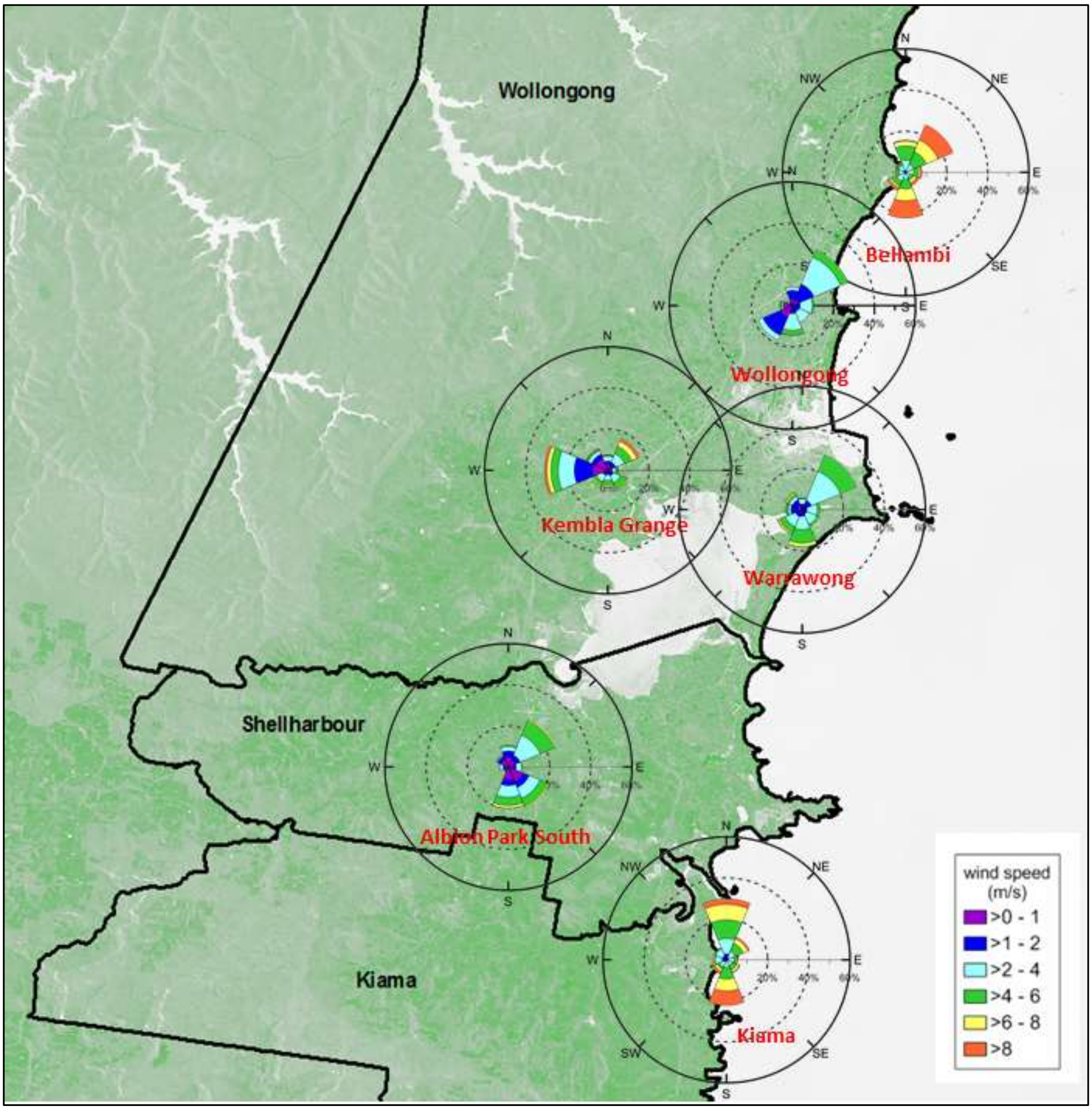

Figure A.3: Summer-average wind roses in OEH air quality monitoring stations Wollongong, Kembla Grange, Albion Park South for 2013 and Warrawong (decommissioned) for 2005; and BOM weather stations Bellambi, Kiama for 2013

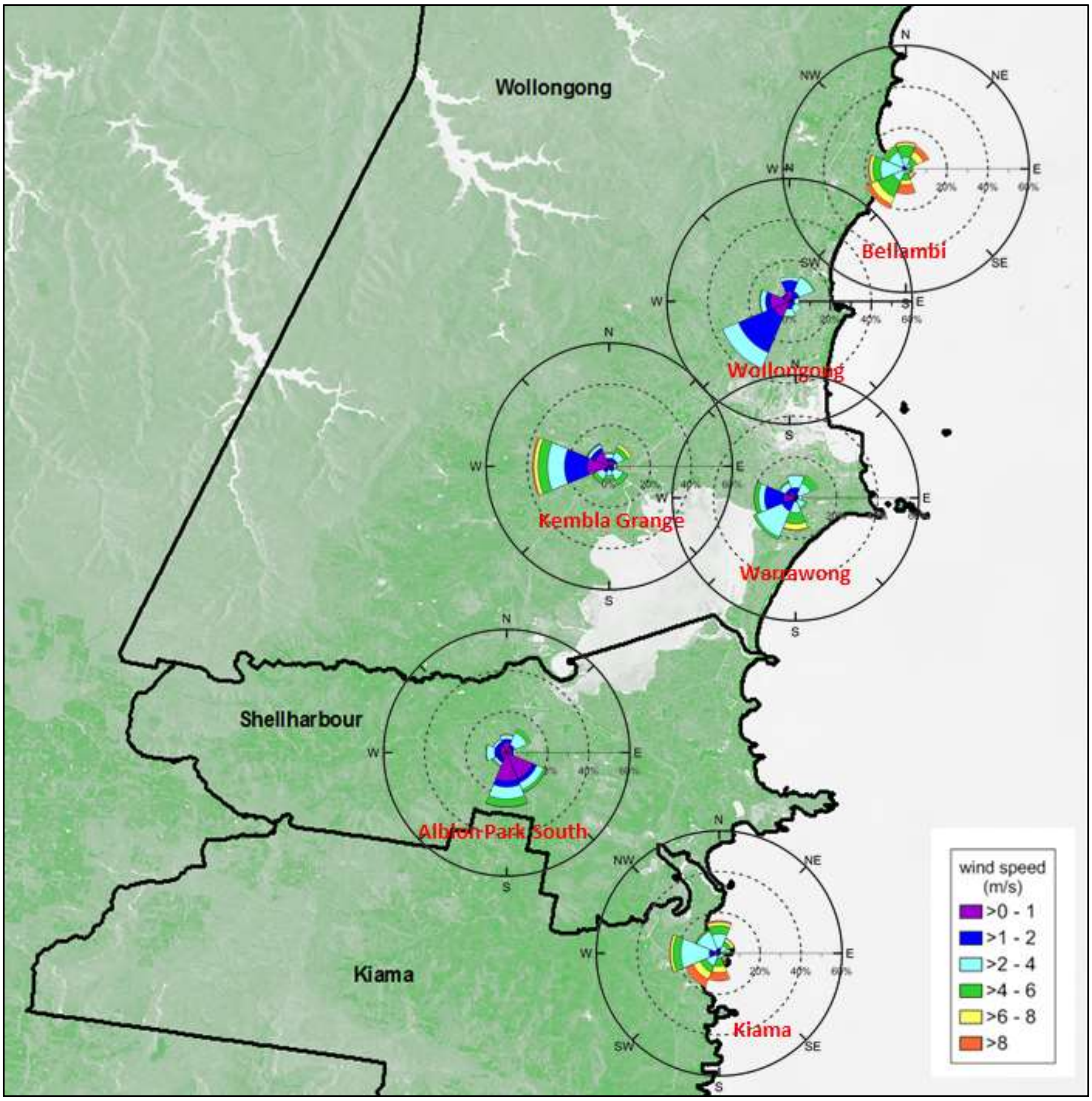

Figure A.4: Autumn-average wind roses in OEH air quality monitoring stations Wollongong, Kembla Grange, Albion Park South for 2013 and Warrawong (decommissioned) for 2005; and BOM weather stations Bellambi, Kiama for 2013

Appendix B – Diurnal wind roses for Wollongong

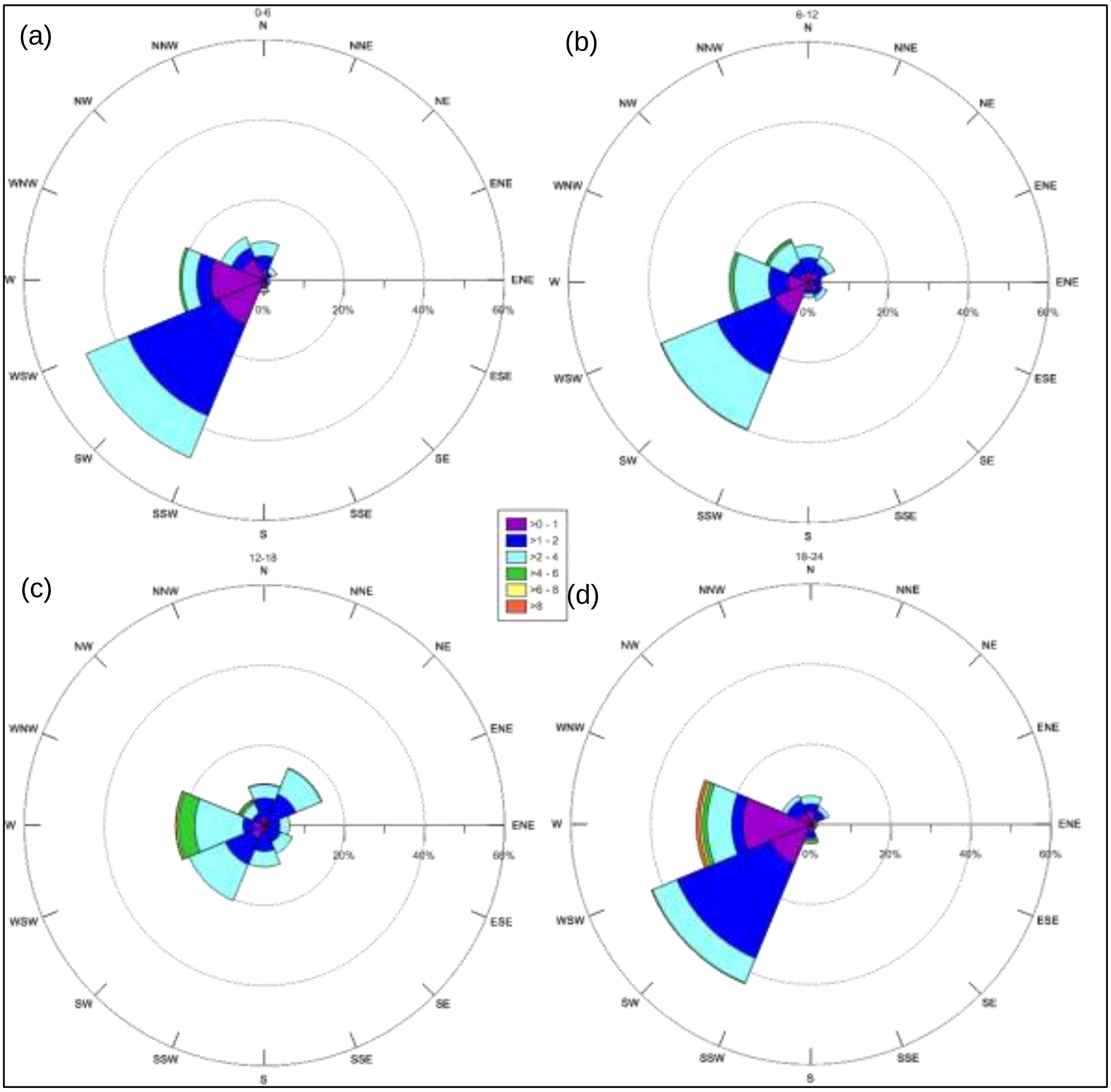

Figure B.1: Winter-average diurnal wind roses (a) 0-6, (b) 6-12, (c) 12-18 and (d) 18-24 local standard time (LST)

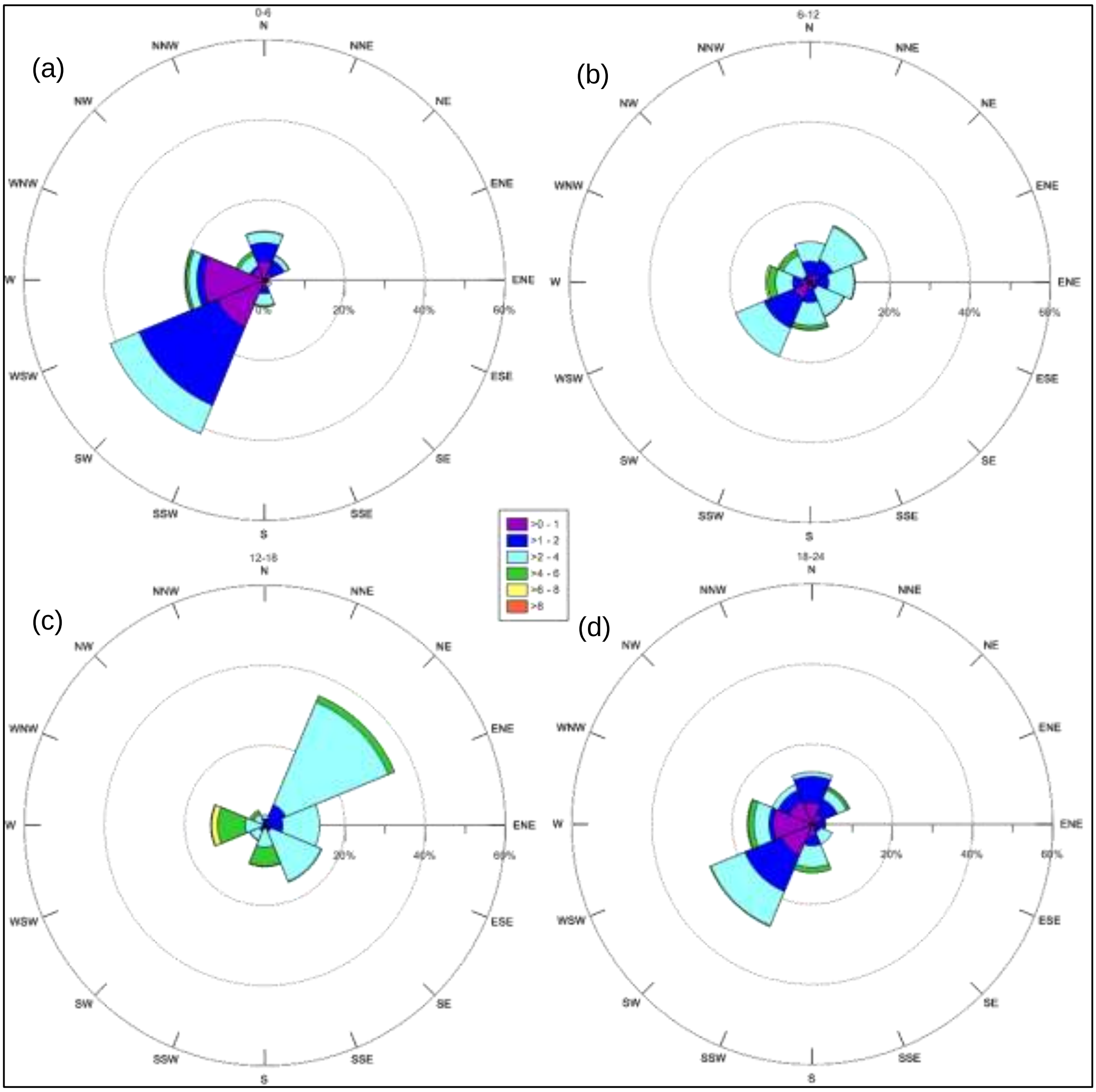

Figure B.2: Spring-average diurnal wind roses (a) 0-6, (b) 6-12, (c) 12-18 and (d) 18-24 LST

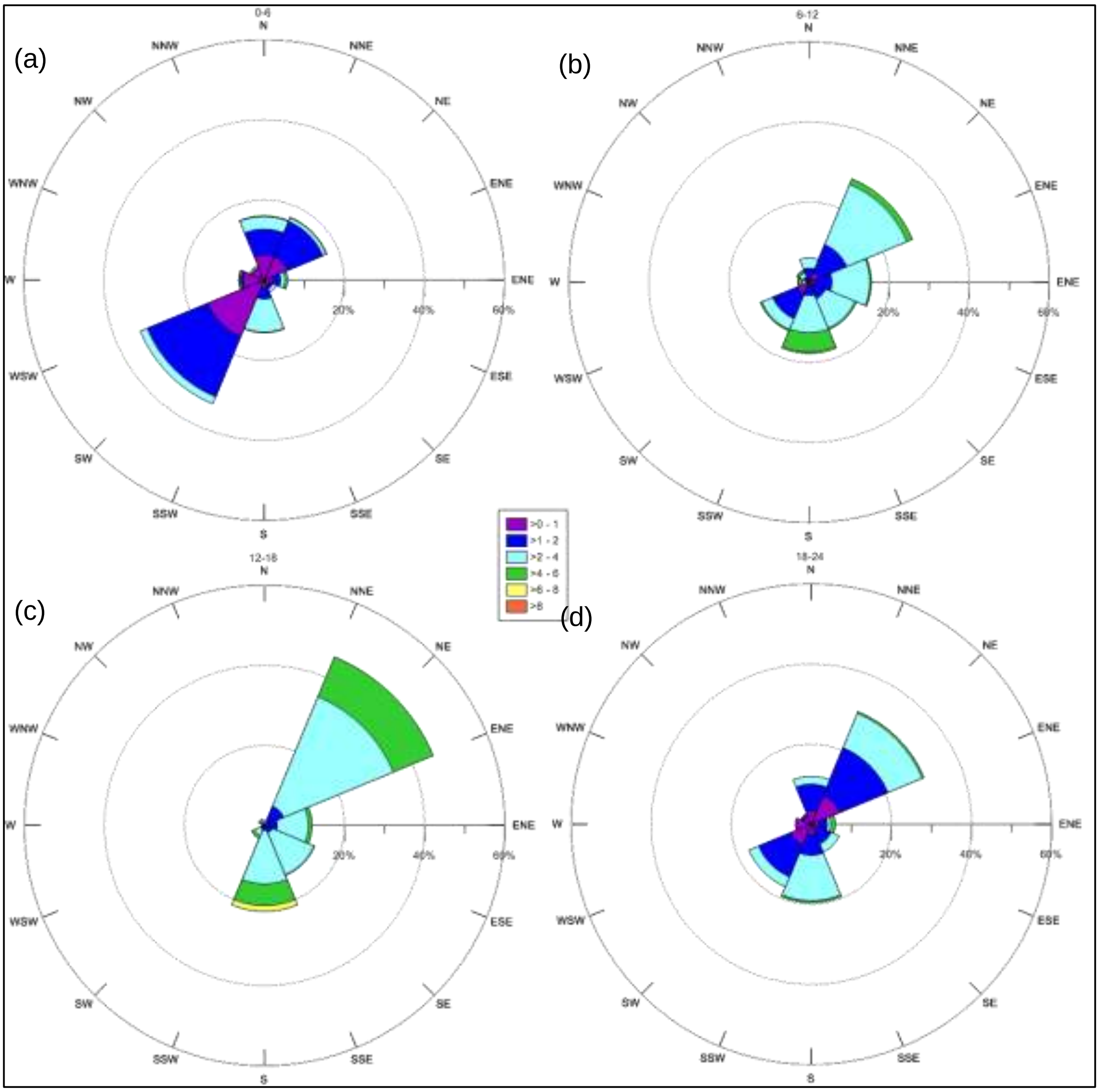

Figure B.3: Summer-average diurnal wind roses (a) 0-6, (b) 6-12, (c) 12-18 and (d) 18-24 LST

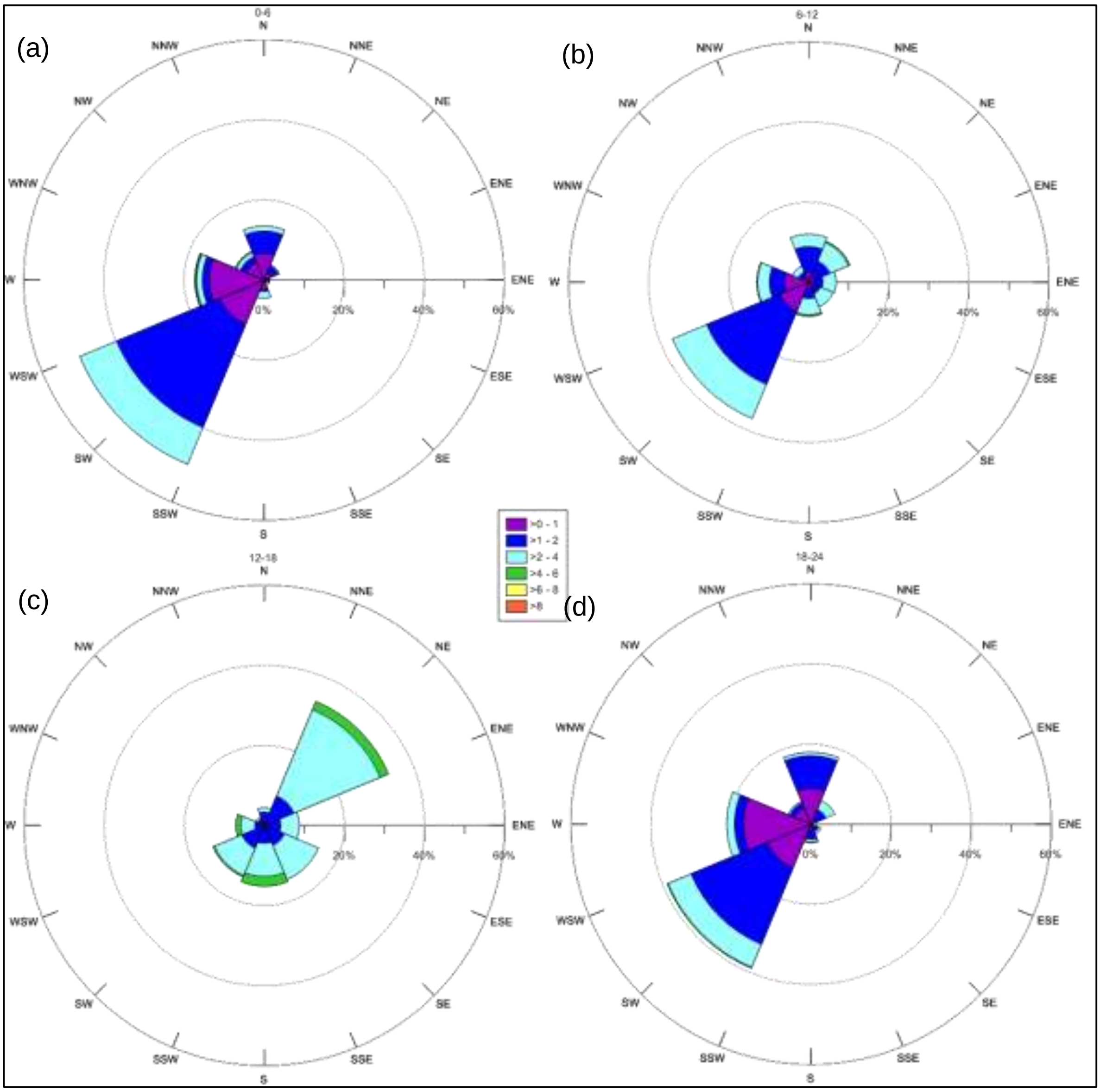

Figure B.4: Autumn-average diurnal wind roses (a) 0-6, (b) 6-12, (c) 12-18 and (d) 18-24 LST

Appendix C – Top source contributions to emissions within the Kiama, Shellharbour, and Wollongong LGAs (EPA 2012)

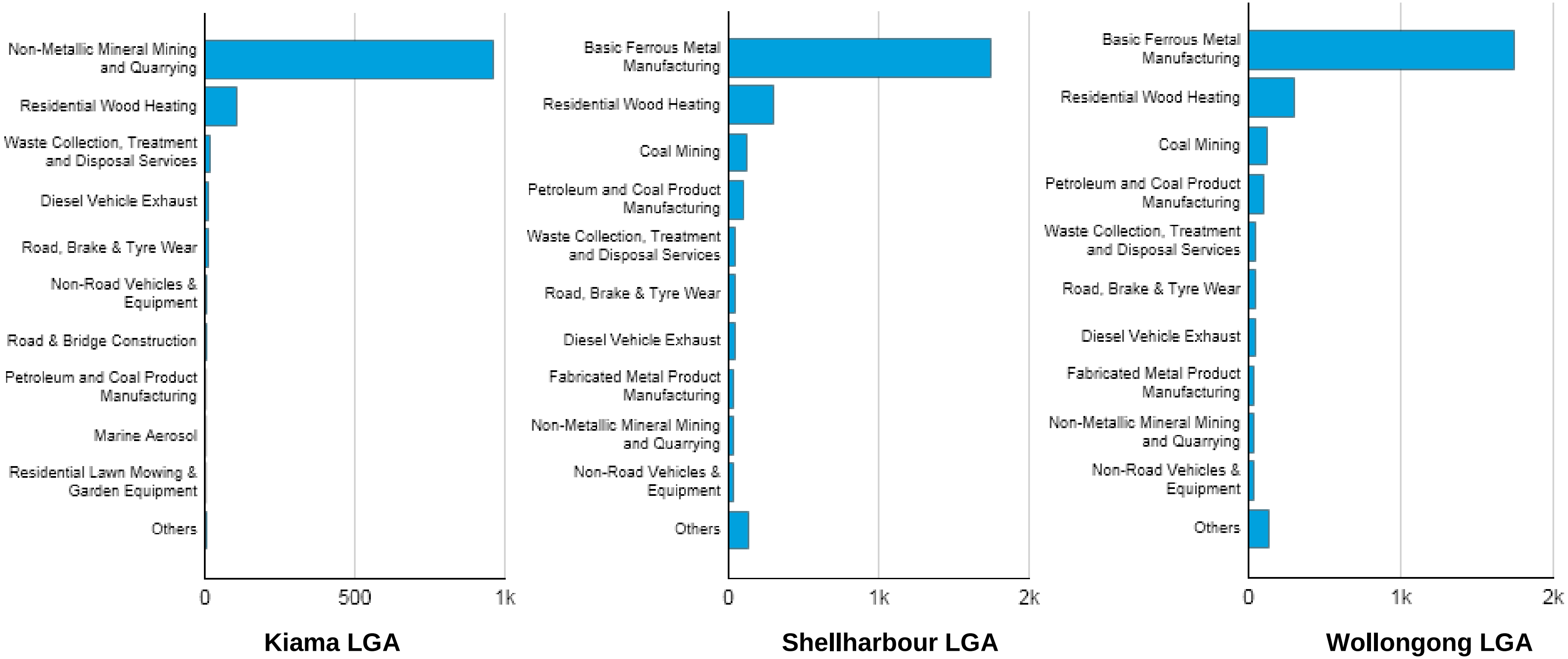

Figure C.1: Top ten PM_{10} emission sources (tonnes per year)

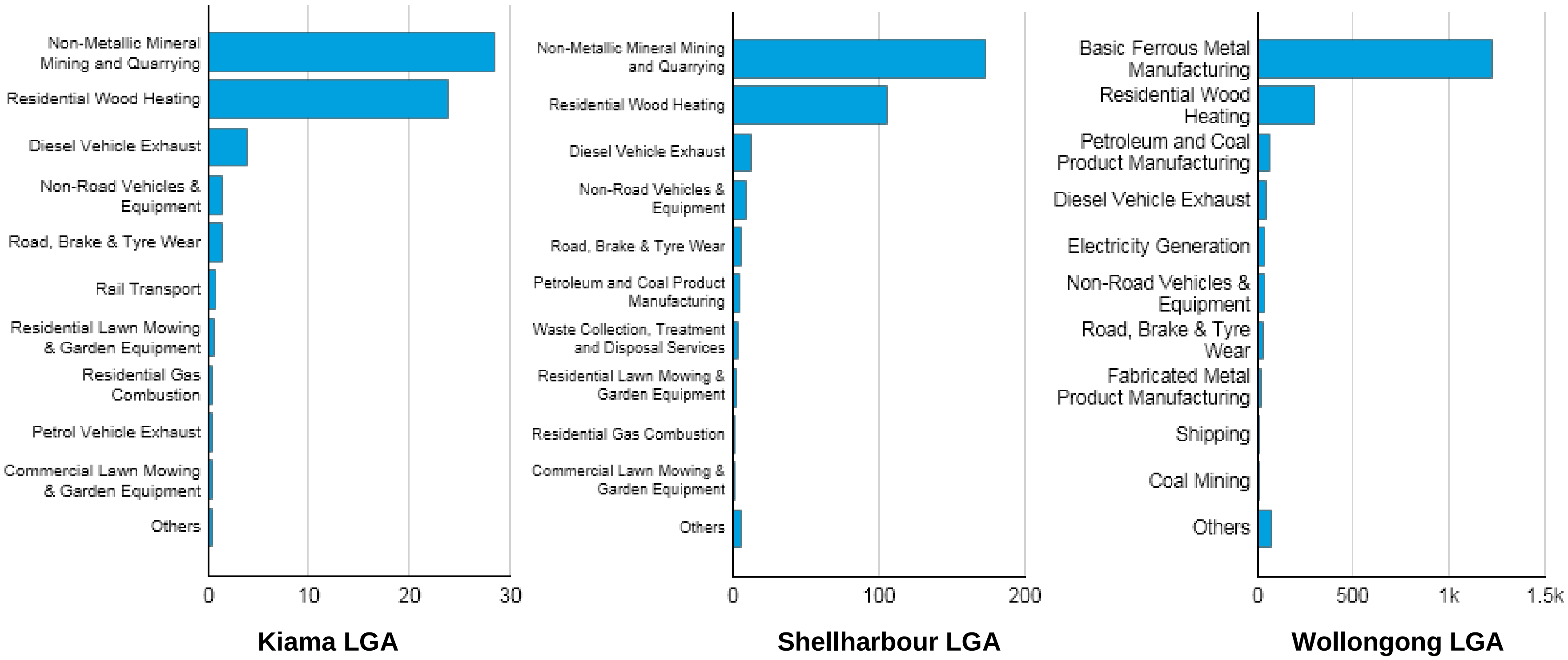

Figure C.2: Top ten $PM_{2.5}$ emission sources (tonnes per year)

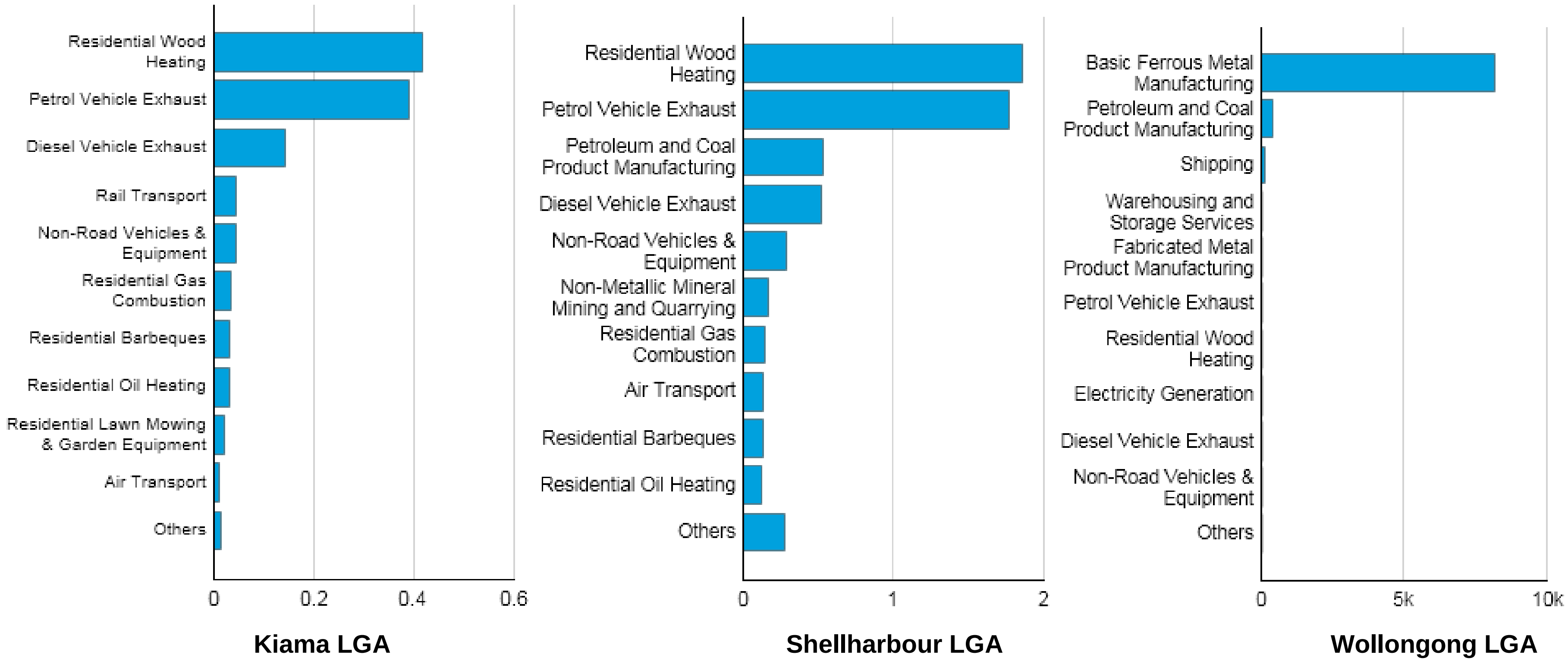

Figure C.3: Top ten SO_2 emission sources (tonnes per year)

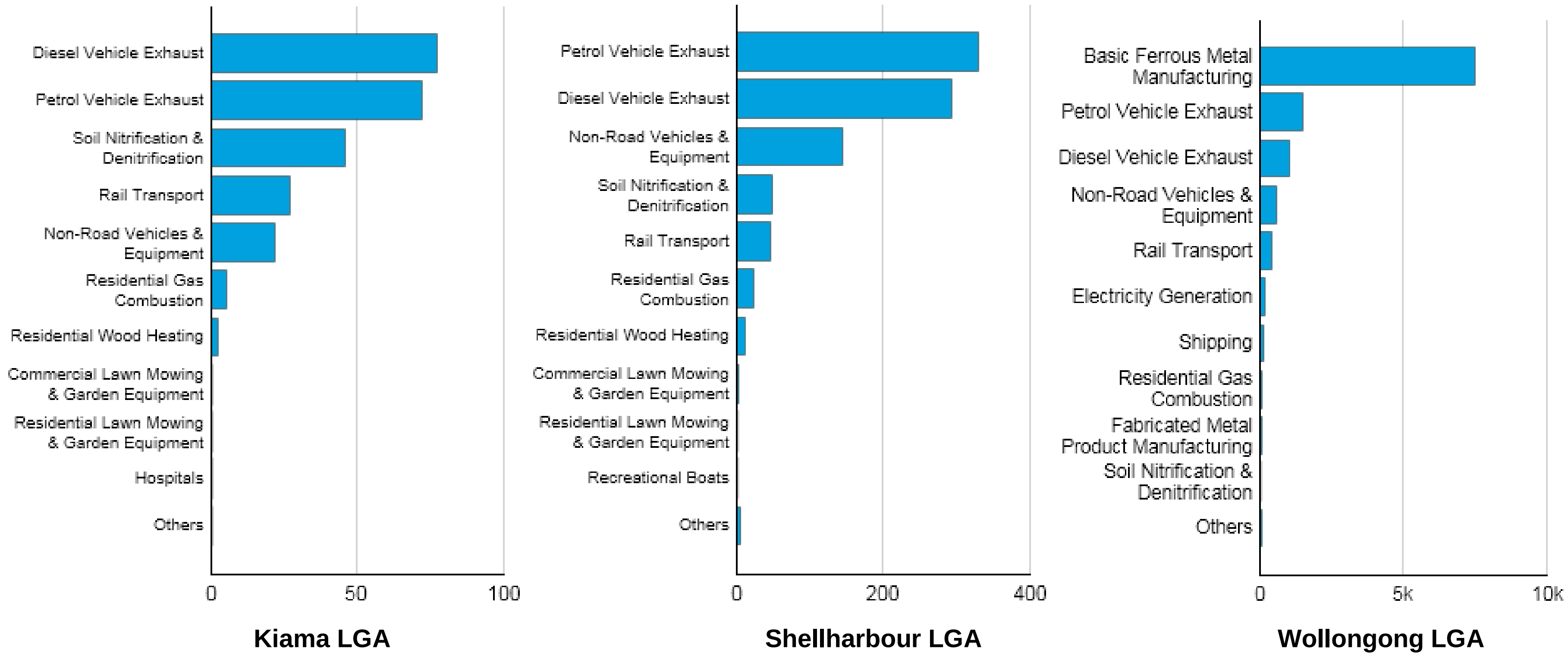

Figure C.4: Top ten NOx emission sources (tonnes per year)

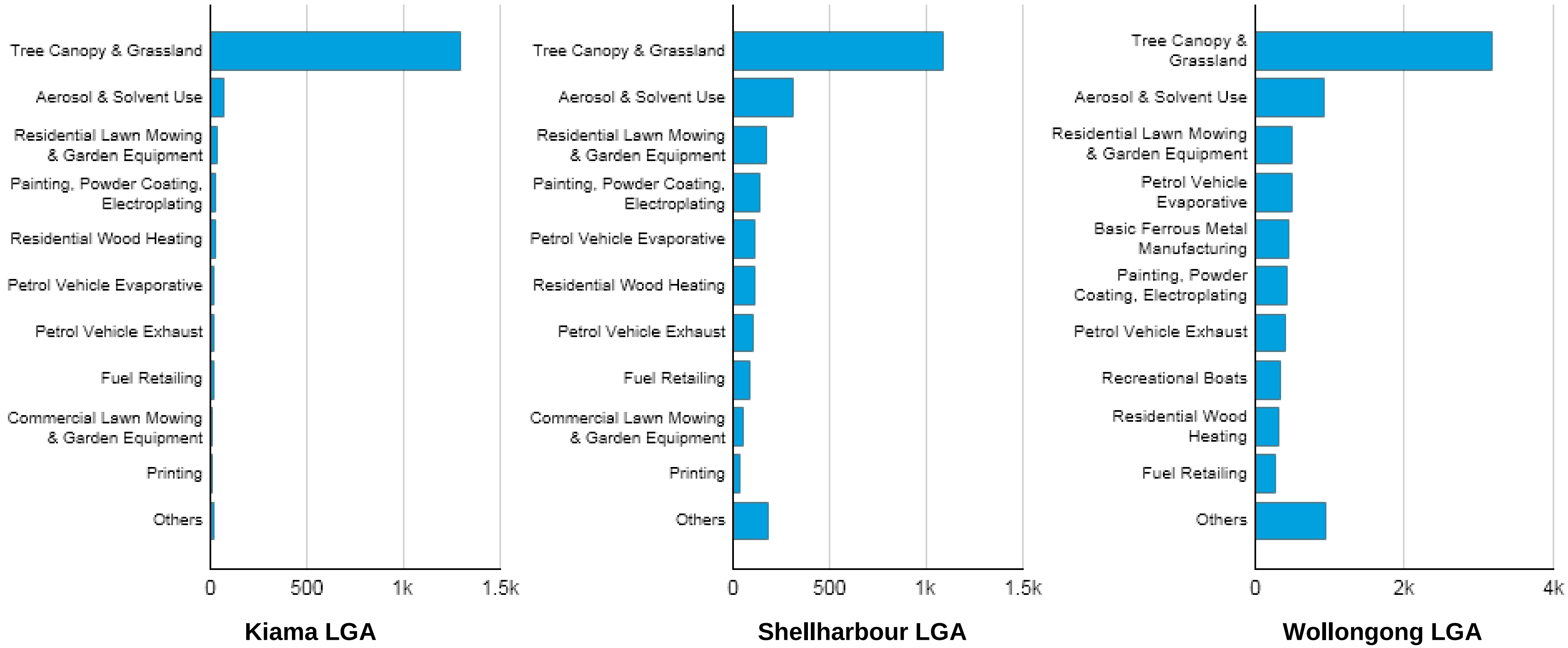

Figure C.5 Top ten VOC emission sources (tonnes per year)