Technical Paper

TP02: Air Quality Trends in Sydney

Advisory Committee on Tunnel Air Quality

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Key Points

- In the Sydney region, carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and lead concentrations are consistently well below national standards.
- Ambient levels of ozone and particles can exceed national standards in the Sydney region, with no definite downward trend in the concentrations of these pollutants apparent.
- Total emissions of ozone precursors and particles have decreased in Sydney over the last decade despite the growth in vehicle activity, energy consumption, population and the economy.
- Reductions in on-road mobile source emissions have been significant over the last decade due to improved fuel quality and more stringent vehicle emission standards.
- Despite reductions in vehicle emissions, transport remains a major source of air pollution in Sydney, being the largest source of oxides of nitrogen (NO_x) and CO emissions, and contributes significantly to the total emissions of volatile organic compounds (VOCs) and fine particles.
- The contribution of motor vehicle emissions to $PM_{2.5}$ (particulate matter) concentrations in Sydney have reduced from 2000 to 2014; however, motor vehicle emissions remain a significant source of fine particles.
- Regional modelling for Sydney has indicated that the pattern of motor vehicle emissions is a major factor determining the timing and peak of ozone concentrations in the region.
- The monitors in the NSW air quality monitoring network operated by the Office of Environment and Heritage (OEH) are situated to meet the requirements of the National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM). The AAQ NEPM specifies that performance monitors measure air quality that is representative of that experienced by the general population rather than peak pollution near an industrial site or busy road.

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Glossary

Term	Description
AAQ NEPM	National Environment Protection (Ambient Air Quality) Measure
CO	carbon monoxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NSW	New South Wales
O_3	ozone
PLCV	Petrol light commercial vehicles (utes and vans)
PM	Particulate matter
PM_1	Particulate matter with an equivalent aerodynamic diameter of 1 micrometres or less
PM_{10}	Particulate matter with an equivalent aerodynamic diameter of 10 micrometres or less
$PM_{2.5}$	Particulate matter with an equivalent aerodynamic diameter of 2.5 micrometres or less
ppm	Parts per million
pphm	Parts per hundred million
SO_2	Sulfur dioxide
VKT	Vehicle kilometres travelled is the total distance travelled by the specified group of vehicles. For example, total annual VKT in Sydney is the number of kilometres travelled by all vehicles in Sydney during one year
VOC	Volatile organic compounds. Organic compounds that vaporise (become a gas) at room temperature

1. Introduction

Motor vehicle emissions are a major source of urban air pollution, with exposure to air pollution linked to a range of health outcomes. Pollutants released include CO, NO_x, VOCs, fine particles and SO_2, with NO_x and VOCs interacting to form ozone (O_3).

This Technical Paper provides a technical briefing on air quality related trends in Sydney. The Paper includes:

- an overview of ambient air quality statistics and issues for the Sydney metropolitan area to place vehicle emissions within the broader urban context
- air quality trends and projections for criteria pollutants (CO, NO_2, O_3, PM_{10}, $PM_{2.5}$, SO_2, lead (Pb))
- overall trends in emissions and relative contributions of motor vehicle emissions.

2. Air Quality in Sydney

Sydney is the largest metropolitan region in NSW, accommodating over 60 per cent of the State's total population.[1] The major urban areas are characterised by high population density, high traffic volumes, industrial facilities and social and economic activities. Pollutants emitted from major urban centres have a potential to impact the entire airshed,[2] posing adverse health risks to both humans and ecosystems.[3]

2.1 Office of Environment and Heritage air quality monitoring

To help protect the health of the Australian population, the AAQ NEPM sets national ambient air quality standards for six criteria pollutants: O_3, CO, NO_2, SO_2, particles (as PM_{10} and $PM_{2.5}$) and Pb (Table 1). The AAQ NEPM also prescribes the characteristics and operations of ambient air quality monitoring stations – in particular, the air quality monitoring station(s) 'must be located in a manner such that they contribute to obtaining a representative measure of the air quality likely to be experienced by the general population in the region or sub region'.

The AAQ NEPM criteria pollutants have been measured in the Sydney basin continuously since the early 1990s. However, Pb monitoring ceased in 2004, as ambient Pb levels fell well below the national standard due to the phasing-out of Pb in the formulation of petrol.[4] The NSW OEH operates a network of around 80 air quality monitoring stations across the State. There are 16 AAQ NEPM air quality monitoring stations across the Sydney region (Figure 1). These stations are located (as per the AAQ NEPM requirements) to record air quality data representative of that experienced by the general population within the region.

1 Australian Bureau of Statistics (ABS), 2011.
2 An airshed is a part of the geography that shares a common flow of air and that is exposed to the same things.
3 EPA, 2012a. 2008 Calendar Year Air Emissions Inventory for the Greater Metropolitan Region in NSW.
4 EPA, 2012b New South Wales State of Environment 2012.

The data from the AAQ NEPM stations are recorded continuously and available to the public online at https://www.environment.nsw.gov.au/aqms/hourlydata.htm in near real-time.

OEH does not conduct roadside monitoring within the ambient air quality monitoring network. It is therefore not possible to distinguish clearly between roadside and urban background concentrations based on data from this network. In 2017, the NSW Government committed to establishing a roadside air quality monitoring station to inform future investigations of air quality along busy roads in Sydney, with this station expected to be commissioned in the latter half of 2018.

In general, air quality in Sydney is comparable with other Australian cities and is relatively good compared with other urban regions overseas. Concentrations of CO, NO_2, SO_2 and Pb are low and stable, and consistently meet the national air quality standards. However, O_3 and particle (PM_{10} and $PM_{2.5}$) levels can exceed the national standards from time to time locally or across the region (see Table 1), posing pollution-related health risks to local communities as well as the environment.

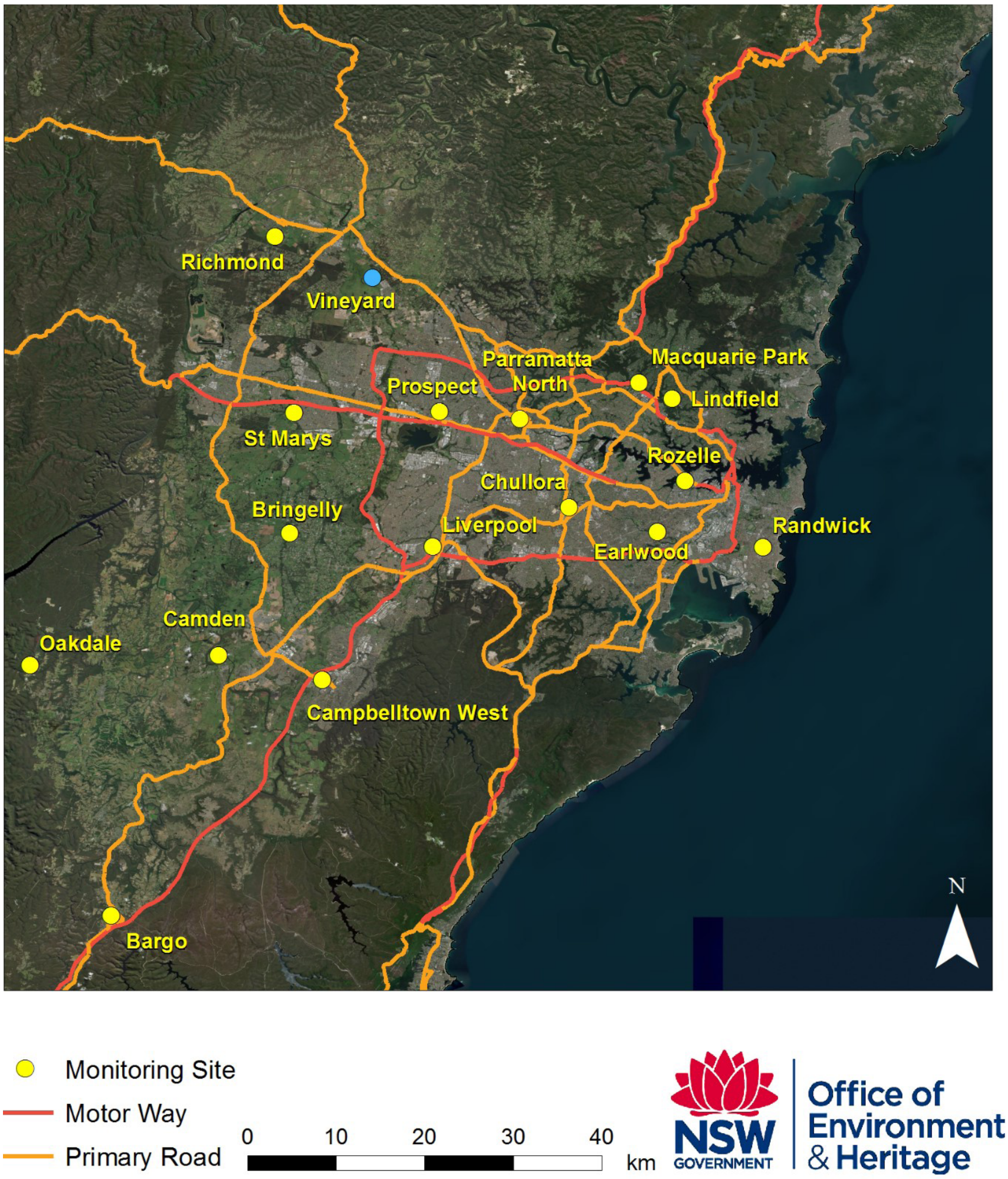

Figure 1: Locations of OEH operated air quality monitoring stations in the Sydney region

Note: The Vineyard monitoring station was decommissioned in November 2016 and OEH is seeking a suitable replacement site; the Parramatta North monitoring station was commissioned in December 2017; the Macquarie Park monitoring station was commissioned in August 2017 to replace the Lindfield monitoring station, which will be decommissioned in 2018.

Table 1: AAQ NEPM air quality standards along with maximum ambient air pollutant concentrations in 2017

Pollutant	Averaging Period	Standard	Maximum Concentration in 2017	% of the Standard
CO	8 hours	9.0 ppm	1.8	20
NO_2	1 hour	0.12 ppm	0.067	56
	1 year	0.03 ppm	0.012	40
SO_2	1 hour	0.20 ppm	0.034	17
	1 day	0.08 ppm	0.008	10
	1 year	0.02 ppm	0.001	5
Photochemical oxidants (as O_3)	1 hour	0.10 ppm	0.135	135
	4 hour	0.08 ppm	0.117	146
Particles as PM_{10}	1 day	50 µg/m³	83.7	167
	1 year	25 µg/m³	20.8	83
Particles as $PM_{2.5}$	1 day	25 µg/m³	56.4	226
	1 year	8 µg/m³	9.5	119

2.2 Long-term trends

Air quality in Sydney has improved significantly since the 1980s with initiatives to reduce emissions implemented across industry, business, homes and motor vehicles. Annual average CO, NO_2 and SO_2 concentrations have declined since 1995 (Figure 2).

Annual average O_3 concentrations increased from 1994–2004 but have remained fairly stable since with some annual variation. Particle concentrations ($PM_{2.5}$ and PM_{10}) show large year-to-year variation in response to annual changes in weather, bushfires and dust storms with no clear long-term trends apparent.

Given that concentrations of O_3 and particles in Sydney can exceed the national standards (Section 2.1), and show no discernible downward trend, further discussion of these pollutants is provided in the next two sections (Sections 2.3 and 2.4).

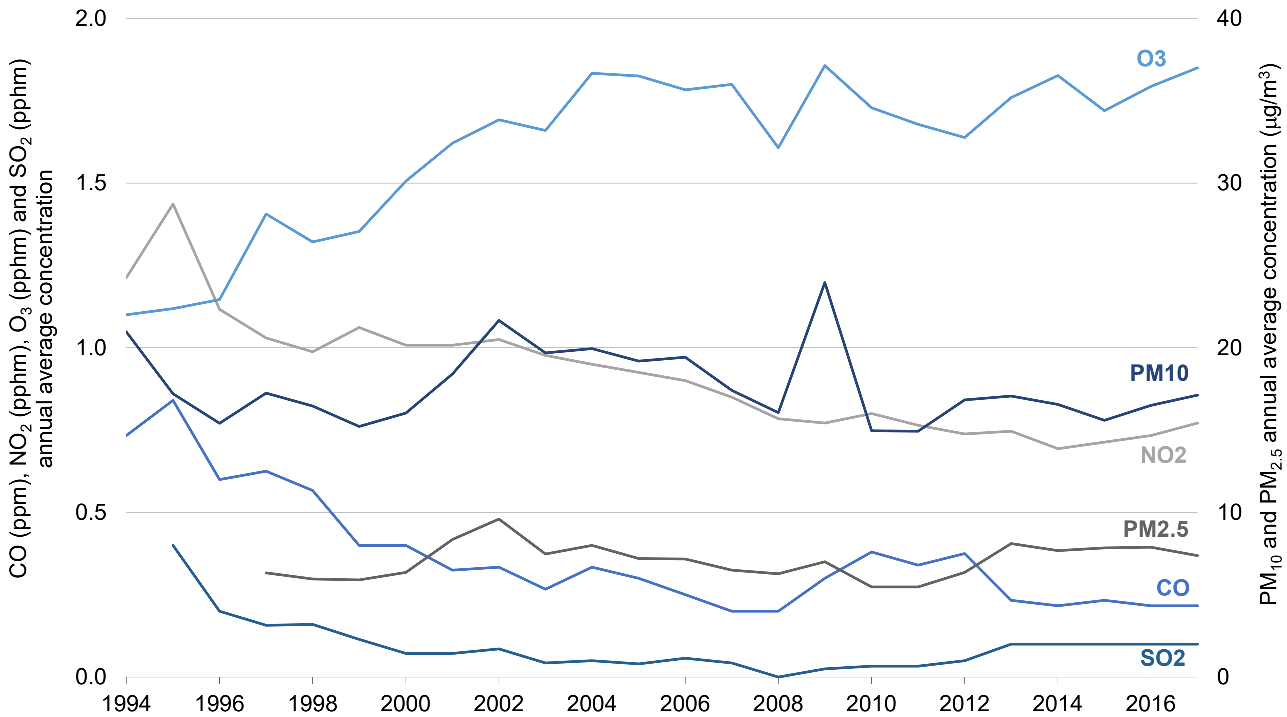

Figure 2: Maximum annual average pollutant concentrations recorded at the monitoring stations in Sydney during 1994–2017

2.3. Particles

Particle pollution varies significantly from year to year (Figure 3). High PM_{10} and $PM_{2.5}$ levels are typically recorded during years affected by large bushfires, hazard reduction burns or regional dust storm events. Examples include the bushfires occurring in 2001–2003 and 2013 and the state-wide dust storms in September 2009. Local sources such as industrial and construction activity, small planned burns and residential wood heater emissions can also result in higher particle levels at some monitoring sites.

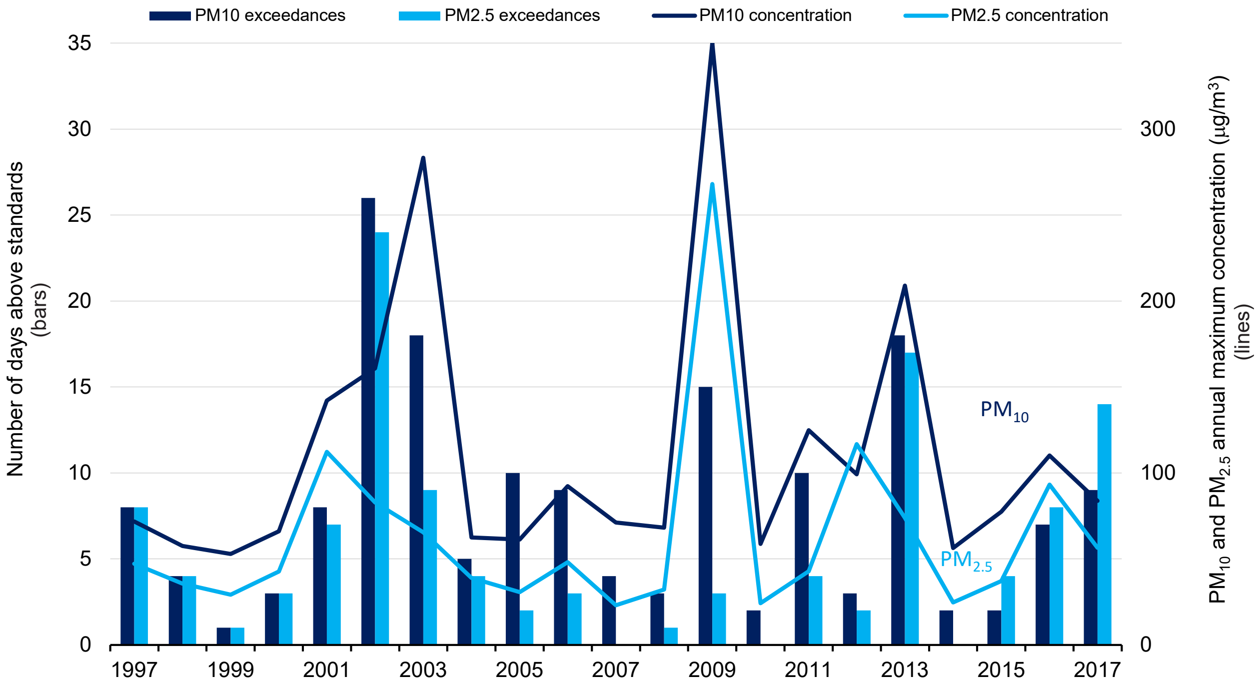

Figure 3: PM_{10} (a) and $PM_{2.5}$ (b) maximum 24-hour average concentrations and numbers of days exceeding national 24-hour standards in Sydney

Note: Analysis was conducted across all historical monitoring stations and exceptional events are included.

Particles can be released directly into the air by sources (primary particles) or formed as 'secondary particles' in the air from the chemical transformation of precursor gases such as NO_X, VOCs, SO_2, and ammonia (NH_3).

Studies into the chemical composition and sources of airborne fine particles ($PM_{2.5}$) conducted in Sydney have found:[5]

- the major sources as illustrated in Figure 4. The contributions from each source may vary depending on location
- the contribution of motor vehicle emissions to $PM_{2.5}$ concentrations in Sydney have reduced over the 2000 to 2014 period, with the greatest reduction occurring in earlier years and motor vehicle emissions remaining a significant source of fine particles
- wood smoke, mainly from residential wood heating, contributes significantly to fine particle pollution in Sydney in the winter, particularly in western Sydney
- secondary sulfate particles from SO_2 emissions from sources such as power generation, industry and motor vehicles make up a significant part of fine particle pollution in Sydney, being highest in summer months
- organic matter (in both autumn and summer) and sea salt (in summer) are significant sources of $PM_{2.5}$ in Sydney
- major sources of secondary organic particles in the air include VOCs from vegetation in summer and wood heaters in colder months.

5 Cope et al. 2014; Cohen et al. 2016.

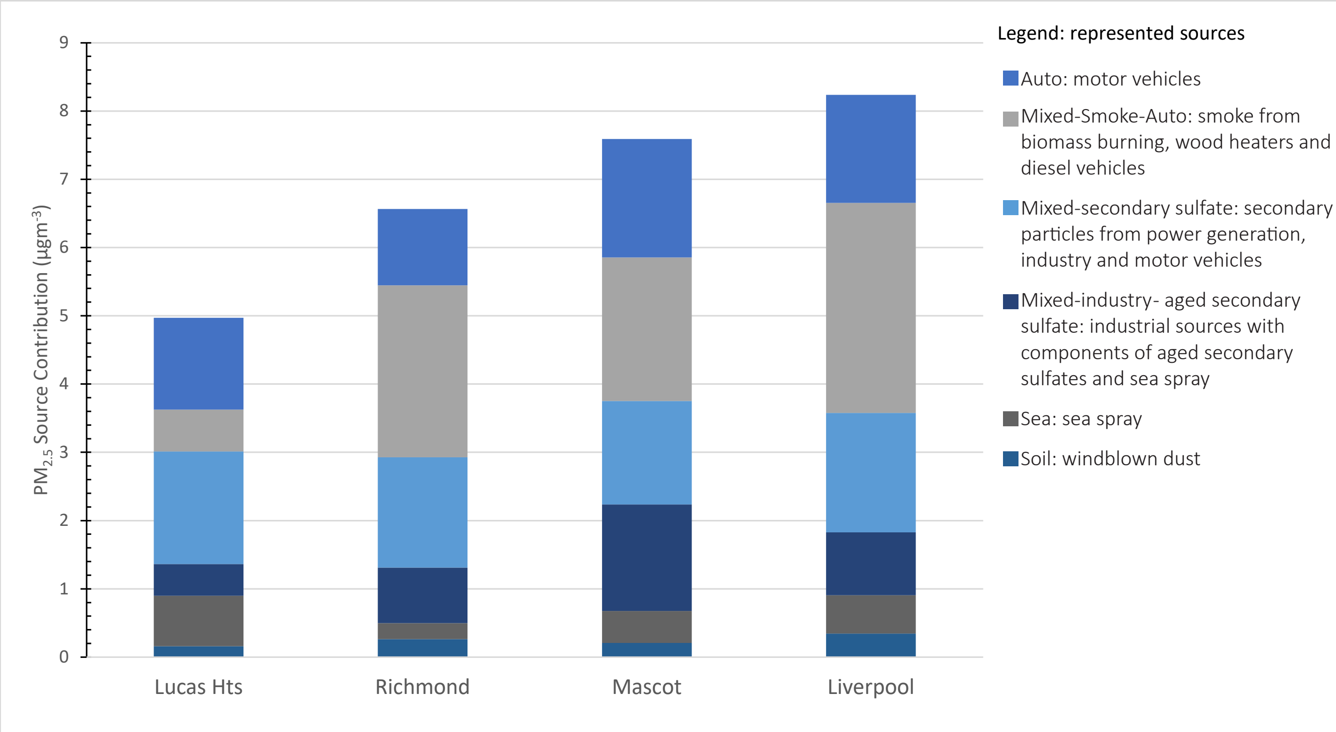

Figure 4: Average 15-year (2000 to 2014) source contribution of fine particles ($PM_{2.5}$) at four air quality monitoring stations in Sydney. Source: adapted from Cohen et al (2016)

2.4. Ozone

O_3 is formed in the lower atmosphere when a number of 'precursor' compounds, mainly NO_x and VOCs, react in warm, sunny conditions. Factors affecting O_3 concentrations in Sydney include changes to precursor emissions, meteorological conditions and changes in background O_3 concentrations.

O_3 is typically higher during the warmer months with peak levels in Sydney occurring during November to March. Since 1994, O_3 concentrations in Sydney have exceeded the one hour standard on up to 17 days per season, with the four hour standard exceeded on up to 21 days (Figure 5). Poor O_3 days peaked for both standards during the 1997/1998 season. In general, the year-to-year variations in one hour and four hour exceedances follow a similar pattern.

Trends in O_3 concentrations are difficult to distinguish from large inter-annual variations in meteorology. Indications are that there has been a decrease in the number of poor O_3 days since 2003; however, statistical analyses over the 1994 to recent period have concluded that there is no significant O_3 trend in Sydney.[6]

While all parts of Sydney can experience O_3 concentrations above the AAQ NEPM standards at some time, O_3 levels are generally higher in the west and south-west of the city as a result of the dominant summertime atmospheric circulation within the Sydney Basin.

Bushfires and hazard reduction burns can be significant sources of O_3 precursors and therefore impact O_3 pollution levels. However, even without the influence of bushfires, emissions from human activities are sufficient to cause high O_3 pollution in Sydney when the prevailing meteorology is conducive to O_3 formation.[7]

As high O_3 levels occur more frequently in summer, O_3 levels may be exacerbated by future climate change, which is expected to result in more hot and sunny days. The NSW and ACT Regional Climate Modelling (NARCliM) project led by OEH has delivered fine-scale climate projections for the State to support impact studies including investigations into potential climate change impacts on ambient O_3 and fine particle concentrations.

6 Johnson and Quigley, 2013; Riley, 2015; OEH, 2017.
7 Jiang, 2016.

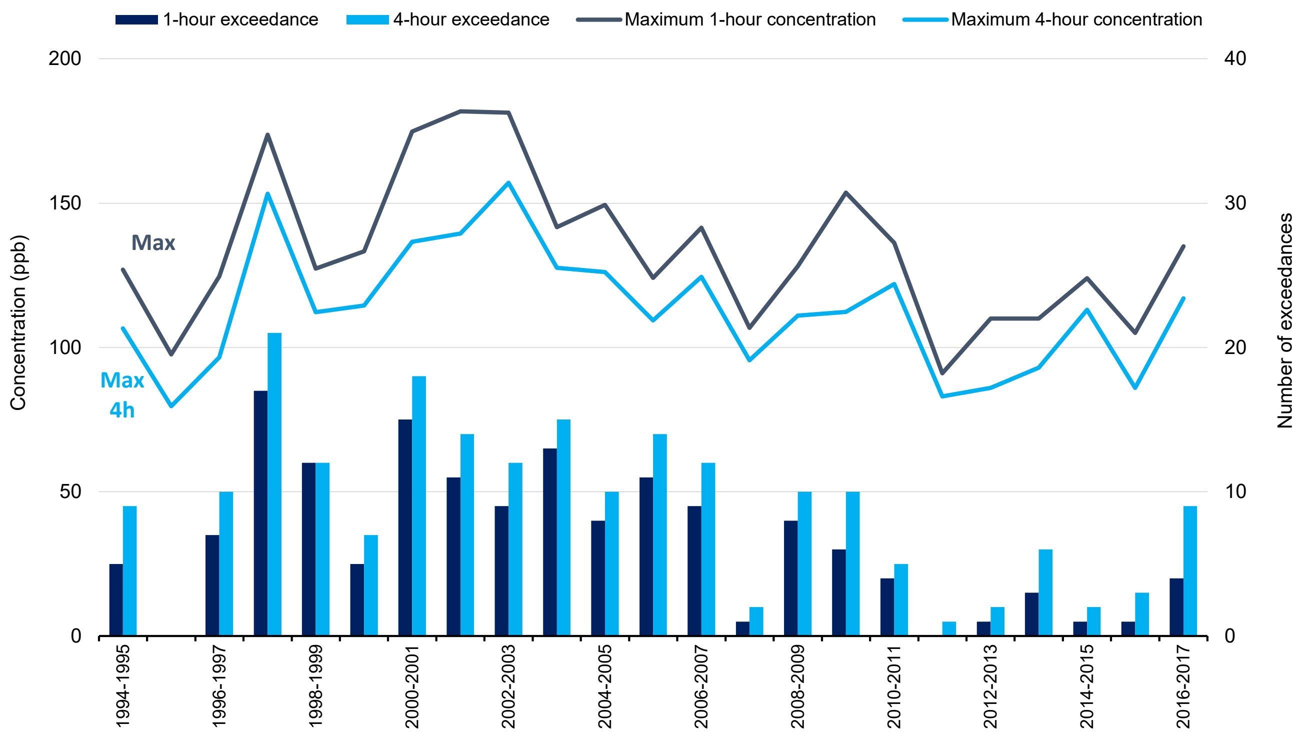

Figure 5: Maximum one hour and four hour average O_3 concentrations and number of exceedance days during November (previous year) to March (following year)

3. Emissions

3.1 Trends in emissions in Sydney

Emissions estimates for Sydney have been made for base years 1991, 2003, and 2008.[8] These estimates show a reduction in total emissions in Sydney during this period despite economic and population growth. From 1992 to 2008, emissions steadily decreased, with NO_x decreasing by 27 per cent, VOCs by 40 per cent and PM_{10} by 20 per cent (Figure 6). These decreases occurred despite increases in gross state product (68 per cent), vehicle kilometres travelled (VKT) (26 per cent), energy consumption (28 per cent) and population (18 per cent).

Reductions in emissions during the 1992 to 2008 period are due to more stringent regulation of industry, residential wood heaters, fuel quality and motor vehicle emissions (EPA, 2012a).

However, emission projections to 2036 (Figure 6) indicate the level of target pollutants will plateau and then rise gradually without additional actions to protect air quality.[9]

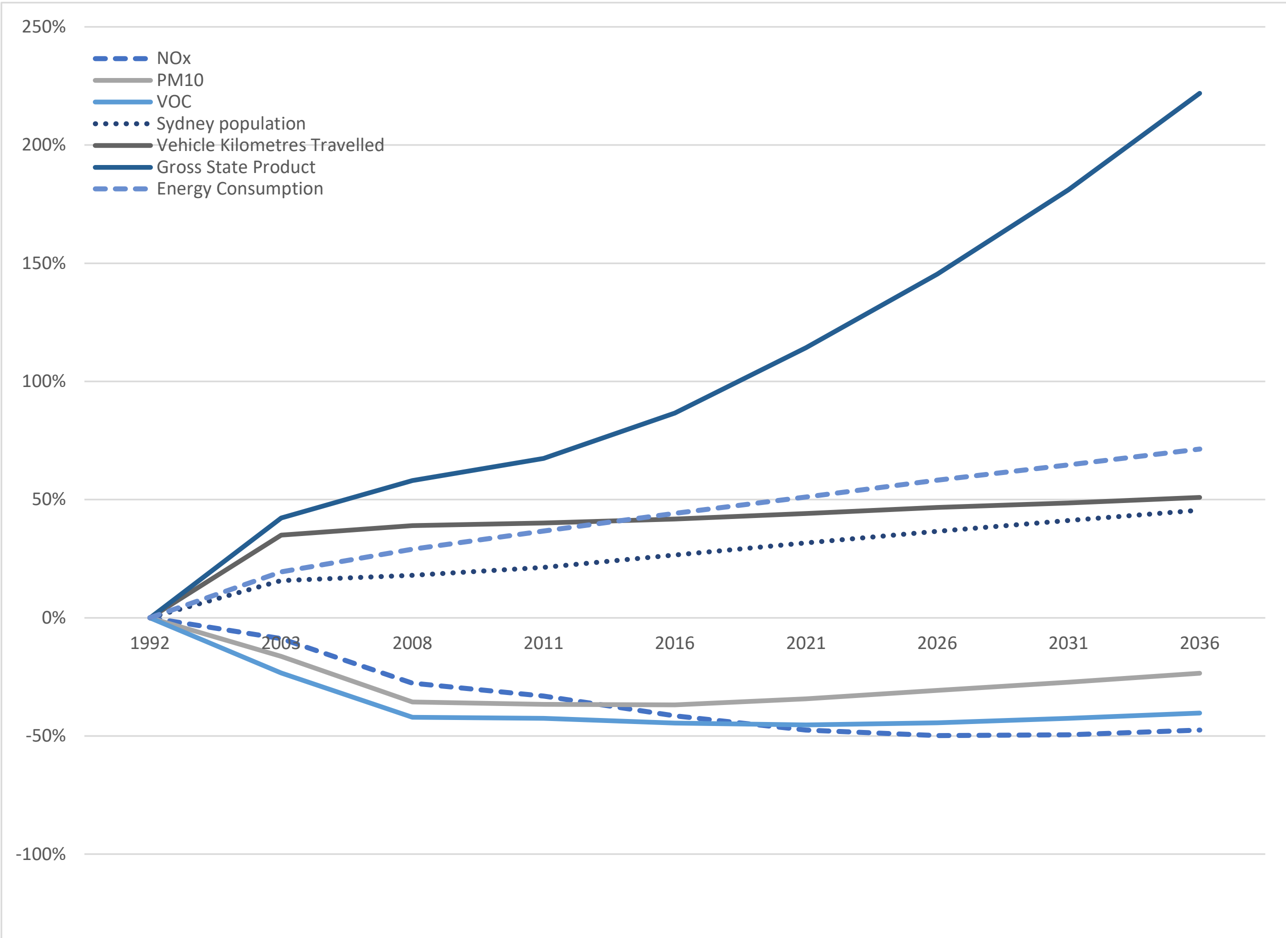

Figure 6: Trends in total emissions in Sydney compared with key NSW statistics. Source: adapted from EPA (2012b)

3.2 Trends in emissions from on-road mobile sources

Many initiatives have been implemented over the past decade to reduce emissions from on-road motor vehicles by making fuels and vehicles cleaner and encouraging people to use their cars less in favour of other transport options. These initiatives have delivered significant reductions in emissions from transport (EPA, 2012b).

For example, as shown in Table 2, emissions from on-road mobile sources (i.e. emissions from motor vehicles travelling on-road) decreased significantly from 2008 to 2016, with the highest reductions in CO (47 per cent). Emissions of NO_x (36 per cent) and VOCs (28 per cent), decreased as did $PM_{2.5}$ emissions (26 per cent).

8 Carnovale et al., 1997; DECC, 2007; EPA, 2012a.
9 EPA 2016.

Table 2: Emissions from on-road mobile sources in Sydney for 2008 and 2016[10]

	On-road Mobile Source Emissions in Tonnes/year		
	2008	**2016**	**Change (%)**
PM_{10}	2,110	1,744	-17.3
$PM_{2.5}$	1,553	1,153	-25.7
NO_x	45,392	28,940	-36.2
Total VOCs	23,512	16,837	-28.4
SO_2	210	171	-18.4
CO	123,712	65,227	-47.3

3.3 Contributions of on-road mobile sources to Sydney emissions

Despite reductions in on-road vehicle emissions (Table 2) and their contribution to total emissions (Table 3), motor vehicles remain a major source of air pollution in Sydney. Based on the 2016 emissions projection, on-road mobile sources are the largest source of NO_x (48 per cent of total emissions) and CO (34 per cent of total emissions) in the Sydney region. On-road mobile sources are also estimated to contribute 13 per cent of the total VOCs emissions and 11 per cent of the fine particle emissions in the region.

Table 3: Contribution of on-road mobile sources to total emissions in Sydney for 2008 and 2016[11]

	On-road Mobile Source Contribution to Total Emissions (%)		
	2008	**2016**	**Change (%)**
PM_{10}	10.3	9.4	-9.1
$PM_{2.5}$	13.2	11.2	-15.2
NO_x	60.8	47.7	-21.6
Total VOCs	17.9	13.2	-26.3
SO_2	1.9	1.5	-21.8
CO	50.2	33.7	-32.8

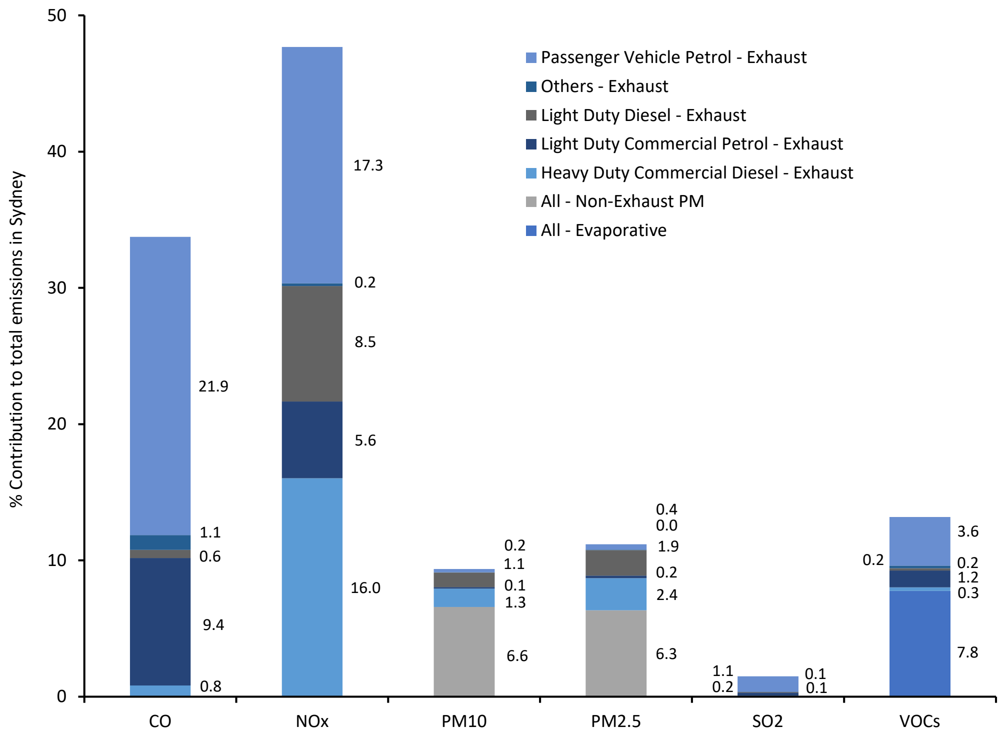

Figure 7: Contribution of on-road mobile sources to total Sydney emissions in 2016. Source: EPA, 2012a; EPA 2017

10 DECC, 2007; EPA, 2012a; EPA 2017.
11 ibid

Passenger petrol and heavy duty diesel vehicle exhausts are the largest sources of NO_x emissions within the on-road mobile source group (Figure 7). Non-exhaust emissions (e.g. brake and tyre wear) and heavy duty commercial diesel exhaust emissions are the most significant on-road sources of particle emissions.

3.4 Future trends in vehicle emissions

Despite the steady increases in VKT, the strong reduction in vehicle emission rates has resulted in significant reductions in the total fleet emissions, and these reductions are projected to continue for gaseous pollutants through to 2031–36. Emissions are projected to start to increase after this time unless progressively stronger standards continue to be introduced (EPA 2017).

As vehicle numbers and travel grows, gains from PM emission standards will be offset by unregulated non-exhaust particulate emission sources, such as tyre, brake and road wear. As there is no current abatement technology or legislated standards for the non-exhaust sources of PM, emissions from this source grow as a direct function of VKT. Hence the total $PM_{2.5}$ reaches a minimum around 2026 and then starts to grow. Adoption of Euro 6 standards for light vehicles, and Euro VI for heavy vehicles will reduce the projected $PM_{2.5}$ exhaust emissions and significantly reduce projected NO_x emissions (EPA 2017). Additional Information on vehicle standards is provided in *Technical Paper No. 1 – Trends in motor vehicles and motor vehicle emissions*.

3.5 Modelling of source contributions to ozone formation in Sydney

The relative importance of mobile and other (non-mobile) sources in contributing to O_3 formation in Sydney was investigated by Duc et al. (2013)[12] using airshed modelling over the summer periods of 2002–2006.

The early morning and afternoon peaks in NO_x and VOCs emissions from motor vehicles were found to be the most significant influence on the timing of peak O_3 concentrations. O_3 formation is strongly determined by the amount of VOCs and NO_x available for the photochemical process during the peak in solar radiation shortly after midday. The modelling study concluded that controlling the growth in motor vehicle emissions represents a viable option for reducing peak O_3 concentrations in the Sydney basin.

12 Duc H., Spencer J., Quigley S. and Trieu T. 2013. Source contribution to ozone formation in the Sydney airshed.

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