Environmental Research 143 (2015) 19–25

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

The health benefits of reducing air pollution in Sydney, Australia

Richard A. Broome [a,*], Neal Fann [b], Tina J. Navin Cristina [a], Charles Fulcher [b], Hiep Duc [c], Geoffrey G. Morgan [d,e]

[a] Public Health Observatory, Sydney Local Health District, Sydney, Australia
[b] Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, USA
[c] NSW Office of Environment and Heritage, Sydney, Australia
[d] University Centre for Rural Health – North Coast, University of Sydney, Sydney, Australia
[e] North Coast Public Health Unit, Mid North Coast Local Health District, NSW, Australia

ARTICLE INFO

Article history:
Received 19 May 2015
Received in revised form
11 August 2015
Accepted 7 September 2015

Keywords:
$PM_{2.5}$
Ozone
Sydney
Australia
Health impact
Environmental benefits mapping andanalysis program – community edition
Fine particles

ABSTRACT

Among industrialised countries, fine particle ($PM_{2.5}$) and ozone levels in the Sydney metropolitan area of Australia are relatively low. Annual mean $PM_{2.5}$ levels have historically remained below 8 μg/m^3 while warm season (November–March) ozone levels occasionally exceed the Australian guideline value of 0.10 ppm (daily 1 h max). Yet, these levels are still below those seen in the United States and Europe. This analysis focuses on two related questions: (1) what is the public health burden associated with air pollution in Sydney; and (2) to what extent would reducing air pollution reduce the number of hospital admissions, premature deaths and number of years of life lost (YLL)? We addressed these questions by applying a damage function approach to Sydney population, health, $PM_{2.5}$ and ozone data for 2007 within the BenMAP-CE software tool to estimate health impacts and economic benefits. We found that 430 premature deaths (90% CI: 310–540) and 5800 YLL (95% CI: 3900–7600) are attributable to 2007 levels of $PM_{2.5}$ (about 2% of total deaths and 1.8% of YLL in 2007). We also estimate about 630 (95% CI: 410–840) respiratory and cardiovascular hospital admissions attributable to 2007 $PM_{2.5}$ and ozone exposures. Reducing air pollution levels by even a small amount will yield a range of health benefits. Reducing 2007 $PM_{2.5}$ exposure in Sydney by 10% would, over 10 years, result in about 650 (95% CI: 430–850) fewer premature deaths, a gain of 3500 (95% CI: 2300–4600) life-years and about 700 (95% CI: 450–930) fewer respiratory and cardiovascular hospital visits. These results suggest that substantial health benefits are attainable in Sydney with even modest reductions in air pollution.

1. Introduction

The risks to human health of even low levels of ambient air pollution are well established in the epidemiological, clinical and toxicological literature (Burnett et al., 2014; Lim et al., 2012; US EPA, 2009). Exposure to particles less than 2.5 μm in diameter ($PM_{2.5}$) and photochemical oxidants, measured as ozone (O_3), are of particular concern as these pollutants are linked to increased risk of premature death and acute and chronic morbidity. Epidemiological studies have shown that long-term exposure to $PM_{2.5}$ is associated with increased cardiopulmonary mortality (Cesaroni et al., 2013; Krewski et al., 2009; Pope et al., 2004; Pope, 2002; Schwartz et al., 2008) and short-term exposure is associated with increased daily mortality and hospital admissions (Katsouyanni et al., 2009; Simpson et al., 2005). More recently, reductions in $PM_{2.5}$ have been associated with longer life-expectancy at birth in the U.S. (Correia et al., 2013; Pope et al., 2009). Exposure to ozone has been associated with increased daily mortality, reduced survival and morbidity (Bell et al., 2004; Ito et al., 2005; Jerrett et al., 2009; Levy et al., 2005a).

Compared to cities in other industrialised countries, air pollution levels in Sydney (population approximately 4.6 million) are relatively low. Monitored annual mean $PM_{2.5}$ concentrations are generally below the 8 μg/m^3 Australian annual advisory standard, while the 1-h ozone standard (0.10 ppm) was exceeded an average of eight days each year between 1994 and 2011 and the 4-h standard (0.08 ppm) was exceeded an average of 11 days each year. Although Sydney levels of $PM_{2.5}$ and ozone are below both European the United States air quality standards, air quality in Europe and the USA has been improving in recent decades, while $PM_{2.5}$ and ozone levels in Sydney have remained relatively static (European Environment Agency, 2014; Pope et al., 2009).

In Sydney, domestic solid fuel burning was the largest source of

* Correspondence to: PO Box 374, Camperdown, NSW 1450, Australia.
E-mail address: richard.broome@sswahs.nsw.gov.au (R.A. Broome).

http://dx.doi.org/10.1016/j.envres.2015.09.007
0013-9351/

$PM_{2.5}$ emissions in 2008, responsible for 51% of all emissions. The second and third largest sources were non-exhaust PM from on-road mobile sources (5.5%) and on-road heavy duty diesel exhaust (5.3%). In regard to precursors of ozone, exhaust from on-road vehicles (gasoline and diesel) accounted for 58% of emissions while domestic and commercial solvents were the largest source of volatile organic compounds (20%) (NSW EPA, 2008). Estimates of the burden of disease provide an indication of the scale of the air pollution problem. Estimates of the benefits associated with reductions in ambient $PM_{2.5}$ and ozone support the design of air pollution control strategies. One such strategy currently under review is the Australian National Environment Protection (Ambient Air Quality) Measure (NEPM) for outdoor air pollution. As part of this review, the government is considering a compliance standard for $PM_{2.5}$ and a framework to encourage reductions in population exposure, even where $PM_{2.5}$ levels are below the standard. Specific control strategies that could reduce air pollution in Sydney include increased regulation of non-road diesel engines and wood-burning heaters (NSW Environment Protection Authority, 2010; National Environment Protection Council, 2013a).

In this assessment, we quantify: (1) the burden of disease attributable to recent levels of anthropogenic (human made) $PM_{2.5}$ and ozone in Sydney in terms of hospital admissions, mortality and years of life lost (YLL); and (2) the potential health benefits to the Sydney population of reductions in $PM_{2.5}$ and ozone.

Estimates of the burden of disease provide an indication of the scale of the air pollution problem. Estimates of the benefits associated with reductions in ambient $PM_{2.5}$ and ozone support the design of air pollution control strategies. One such strategy currently under review is the Australian National Environment Protection Measure (NEPM) for outdoor air pollution. As part of this review, the government is considering a compliance standard for $PM_{2.5}$ and a framework to encourage reductions in population exposure, even where $PM_{2.5}$ levels are below the standard. Specific control strategies that could reduce air pollution in Sydney include increased regulation of non-road diesel engines and wood-burning heaters (NEPC, 2013a; NSW Department of Environment, Climate Change and Water, 2010).

2. Methods

We followed the well-established "damage function" approach to relate anthropogenic air pollution in Sydney to hospital admissions and premature deaths in 2007. 2007 was chosen because this was the most recent year for which mortality data were available. This approach has been used to estimate the burden of disease associated with air pollution in the US and Europe (Berman et al., 2012; Davidson et al., 2007; Hubbell et al., 2005; Künzli et al., 2000) and employs a health impact function (HIF), defined as:

$$\Delta y = (1 - e^{\beta \Delta x}) \cdot y_0 \cdot Pop$$

where Δy is the change in the number of cases of the health outcome of interest, Δx is the change in air pollution exposure, β is a risk coefficient of the health outcome of interest drawn from an epidemiological study, y_0 is the baseline incidence rate of the health outcome and *Pop* is the size of the exposed population.

We used the open source Environmental Benefits Mapping and Analysis Programme – Community Edition v1.06 (BenMAP-CE)[28] to quantify the numbers of premature deaths and hospital admissions attributable to $PM_{2.5}$ and ozone. BenMAP-CE is a tool developed for the US Environment Protection Authority (EPA) that systematises air pollution health impact assessment, incorporating user defined inputs. YLL estimates were calculated outside BenMAP-CE using the procedures described in the relevant sections below.

To minimise the risk of double-counting health effects related to both $PM_{2.5}$ and ozone exposure, or to both long- and short-term exposure to $PM_{2.5}$, we limited our analysis to the following exposure-outcome pairs: (1) long-term exposure to $PM_{2.5}$ and all-cause mortality; (2) short-term exposure to $PM_{2.5}$ and admission to hospital with cardiovascular and respiratory disease; (3) short-term exposure to ozone and non-trauma mortality; and (4) short-term exposure to ozone and respiratory hospital admission. Each selected pair is supported by strong evidence of a causal association (US EPA, 2009, WHO Regional Office for Europe, 2013). Analysis of YLL was limited to long-term exposure to $PM_{2.5}$ and all-cause mortality because the β-coefficient for this pair is derived from a survival model.

2.1. Inputs

2.1.1. Exposure to $PM_{2.5}$ and ozone

We estimated population exposure to $PM_{2.5}$ and ozone in Sydney from measurements taken at NEPM performance monitoring stations. The number of NEPM monitoring stations and their location is chosen to ensure they contribute to a representative measure of the air quality experienced by the general population of Sydney. We began with daily observations of 24 h average $PM_{2.5}$ and maximum one hour average ozone for the year 2007, provided by the NSW Office of Environment and Heritage. $PM_{2.5}$ was measured using a tapered element oscillating microbalance (TEOM) at four monitoring sites in the Sydney Metropolitan Area (Fig. 1). One monitoring site (Richmond) had only recorded 42% of daily $PM_{2.5}$ observations in 2007, and was excluded from further analyses of $PM_{2.5}$ to avoid biasing our estimates of population exposure. Ozone was measured at eleven monitoring sites in the Sydney Metropolitan Area in 2007 (Fig. 1). One site (Lindfield) had just 55% of daily ozone observations recorded, and was excluded from further analyses of ozone. Summary statistics of the monitoring stations used in the assessment are provided in Supplemental Tables 1 and 2.

Population exposure was assigned at the Local Government Area (LGA) level by interpolating the annual averages of measured daily $PM_{2.5}$ and 1 h-maximum ozone concentrations to Sydney

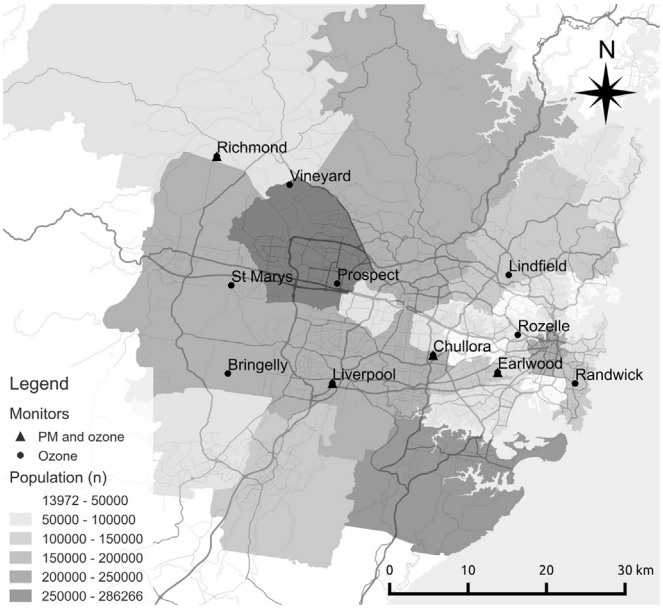

Fig. 1. Sydney LGAs, their population size and the location air pollution monitors.