Centre for Safe Air

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SAFER AIR HEALTHIER COMMUNITIES

Ten reasons for investment in Australia

September 2023

Safer Air, Healthier Communities: Ten reasons for investment in Australia

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About us

The Centre for Safe Air is a NHMRC Centre of Research Excellence in Australia focusing on the health impacts of air pollution. Our vision for healthier communities is the driving force behind our work. The collaboration is led by the Menzies Institute for Medical Research at the University of Tasmania.

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ACKNOWLEDGEMENT OF COUNTRY

We recognise Aboriginal and Torres Strait Islander people as the sovereign Traditional Owners of Australia. We thank them for their continuing stewardship of this Country, its lands, waters, and skies which protects the health and wellbeing of all Australians. We respectfully acknowledge their cultural and customary practices and pay respects to their Ancestors, Elders, and future leaders.

EXECUTIVE SUMMARY

Introduction

Air pollution is the single greatest environmental cause of preventable disease and premature death in the world today.[1, 2] It ranks alongside unhealthy diets, inadequate physical activity, and tobacco smoking, as a major global risk factor for mortality.[1] Globally, air pollution is responsible for approximately 7 million premature deaths each year.[2] In Australia annual mortality is conservatively estimated to be more than 3,200[3] with a cost greater than AUD $6.2 billion from years of life lost.[4] However, the full health and social impacts are much more extensive. This report explains why the effects of air pollution are so far reaching and, equally, why coordinated action to make air safer is one of the best investments in Australian health.

TEN REASONS TO INVEST IN SAFER AIR

1. Air pollution increases rates of non-communicable diseases in the community.

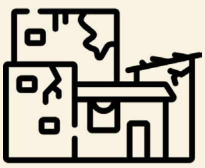
Heart disease, stroke, dementia, type 2 diabetes, lung diseases and cancer are all leading causes of illness and death for Australians. Air pollution increases rates of all these conditions.[5-7] There is mounting evidence that air pollution also affects many other human body systems and functions including fertility and reproduction, bone health, learning and cognition, and immune function.[6-16]

2. Air pollution is an important risk factor for communicable diseases.

Air pollution increases the risk of respiratory infections and may potentiate respiratory epidemics.[17-21] Confined indoor spaces can increase the risk of transmission of some infectious diseases.[22] Improving indoor and outdoor air quality will reduce the community burden of respiratory infections.

3. Air pollution affects our health from conception and throughout life.

Air pollution can have lasting health and social consequences for an individual over their life course. Exposure affects the growth, development, and overall health of unborn babies. These influences can contribute to the risk of developing non-communicable diseases later in life[6, 23, 24] and may be associated with poorer cognition and educational outcomes in children.[25-27]



4. Air pollution worsens health inequities – lessening air pollution reduces them.

The health impacts on those affected by air pollution are unevenly distributed across the Australian population. Some of the most vulnerable people in our society are at higher risk of worse health outcomes from air pollution exposure: older adults, pregnant people and unborn babies, children, people with pre-existing chronic conditions, socially disadvantaged populations, and Aboriginal and Torres Strait Islander people. With few other interventions offering simultaneous health benefits to vulnerable people, air pollution represents a powerful opportunity to reduce health inequities in Australia.

5. Climate change is driving more air pollution and air pollution accelerates climate change.

Climate change is deteriorating air quality and the health of Australians through more frequent and severe bushfires, smog, dust storms, and other extreme weather events.[28-30] In turn, severe bushfires are influencing the global climate and weather systems. This is creating a feedback loop that is worsening both air quality and climate change. Reducing air pollution is vital for mitigating climate change and maximising the benefits of decarbonisation and electrification for health and wellbeing.

6. Addressing air pollution has many co-benefits.

Climate change and air pollution share common drivers. Policies to mitigate combustion emissions, for example, will have the benefits of mitigating climate change, air pollution, and other social and environmental drivers of chronic diseases. Many opportunities exist to achieve this – from decarbonising our energy and transport systems, to greening our cities, improving urban and housing design to bushfire prevention strategies.

7. The impacts of air pollution are increasing.

Population growth and ageing, urbanisation, and increasing transport and energy demands pose additional risks to air quality, climate change and population health. This is why timely interventions are needed.

8. The economic impacts of air pollution are high and underestimated.

Australian estimates to date have placed fine particulate matter ($PM_{2.5}$) air pollution related mortality costs at AUD $6.2 billion annually.[4] However, the costs of other pollutants (e.g. nitrogen dioxide from traffic emissions) and non-health costs like labour, productivity, welfare, and other societal costs, are largely unaccounted for in existing economic analyses on air pollution.

9. Return on investment is high.

Every dollar spent generates returns in the forms of reduced health costs, healthier people and longer lives. Reducing the annual average population exposure to fine particulate matter ($PM_{2.5}$) by a modest and highly achievable 5% could avoid the economic burden from years of life lost by around AUD $1.6 billion every year.[31]

10. Small improvements in air quality will drive large population health and economic benefits.

The rate of increase of many air pollution related health outcomes is steeper at lower concentrations, tapering off at higher levels. For Australia, this means that any small improvements, even to levels below current national air quality standards, will bring measurable population health and economic benefits.

What are the ways forward?

Drivers of unsafe air and their potential mitigation options are multifaceted. Management responses require consideration of the sources of airborne hazards (such as fires, traffic and industry) and the types of pollutants they create, the mitigation options appropriate for different exposure settings (such as indoor, outdoor, and workplace settings), and the needs of different population subgroups and individuals who are more susceptible to harm (such as older adults, children, and pregnant women). For example, interventions useful for addressing indoor air hazards, such as increasing ventilation to reduce respiratory virus transmission, can increase exposure to outdoor air hazards such as bushfire smoke.

The breadth and complexity of air quality challenges necessitate national leadership, a holistic approach, and collaboration between different sectors (e.g., health, environment, and urban planning), levels of government (local to national), and non-government organisations.

Just as we do for other essentials for life like food and water, Australia needs comprehensive, integrated management for air. The Centre for Safe Air supports evidence-based action to ensure all Australians can enjoy the benefits of safer air.

Centre for Safe Air

INTRODUCTION

From our very first breath, air is our first and most urgent physiological need. Humans inhale 11,000 litres of air every day on average. That's nearly eight litres every minute and more than 300 million litres over a lifetime. Even small amounts of pollution in air can have a major impact on our health over time. With 99% of the world's population exposed to unsafe air,[32] air pollution represents the single greatest environmental cause of preventable disease and premature death in the world today.[1]

Air quality may not trigger community alarm in the way that unsafe food and water does, even though the health burden overall is greater. Specific individuals harmed by air pollution are not easily identified; air quality affects the risk profile of the entire population. For example, the death rate for ambient (outdoor) air pollution in Australia is estimated by the World Bank to be 84 times that of unsafe water.[33] Fine particulate matter ($PM_{2.5}$) air pollution alone was estimated to be responsible for 3,200 Australian deaths in 2018.[3] This compares with 86 documented deaths from food poisoning,[34] and 1145 from Australian road traffic fatalities in that same year.[35] Despite its higher health burden, air quality does not receive commensurate investment in mitigation, regulation, monitoring and enforcement. In light of the Australian Government's $33.4 billion investment in road safety over four years,[36] or Food Standards Australia New Zealand's $22.7 million expenditure budget,[37] there is a strong case for greater investment in safe air.

While particle pollution is currently estimated to be responsible for 1.3% of Australia's total disease burden[38] with an annual average cost of $6.2 billion,[4] the true burden (and cost) of sub optimal air quality is likely to be far greater. Current health impact assessments are based only on well-quantified mortality impacts of fine particulate matter ($PM_{2.5}$). There are other important pollutants and hazards beyond PM, and growing evidence of a range of negative health impacts beyond heart and lung outcomes which are not captured by current economic estimates. Air pollution affects people across the course of life, from unborn babies to children, adolescents, and the elderly. It also disproportionately harms people with a wide range of chronic diseases, Aboriginal and Torres Strait Islander people, and socially disadvantaged population groups.

Given the far-reaching burden across Australian society, this report makes the case for strong economic and policy investment in improving air quality. Central to this task is the need to conceptualise what we mean by 'safe'. Historically, air quality has been deemed 'safe' if it falls below a given threshold. However, a well-established body of evidence clearly tells us that negative health effects occur at levels below the standards set by governments as a tool for regulation.[39, 40] This is why agencies such as the European Union and World Health Organisation (WHO) are advocating for a continual exposure reduction framework.[1, 41, 42] Any reduction in air pollution makes air safer and has myriad benefits for health, the environment, economy, and society.

A comprehensive strategy to ensure safer air needs to encompass three key components:

1. **Sources** of air pollution (such as vehicles, industry, domestic wood heaters, landscape fires)

2. **Settings** where people are exposed to air pollution (such schools, aged care facilities and workplaces)

3. **Susceptible populations** who are most at risk of harm from air pollution (such as older adults, children and babies, pregnant people, people with chronic health conditions or social disadvantage).

The objective of this report is to summarise key evidence about the health, equity, climate and economic impacts of air pollution for decision-makers, policymakers, and the public, to explain why policies and interventions to improve air quality are one of the best investments for public health in Australia. Action on air pollution has clear benefits for communicable and non-communicable disease control, child health development and climate change mitigation. It is therefore an economically efficient way to achieve better health for all Australians.

This report focuses on six key areas: (1) air pollution, non-communicable and communicable diseases, (2) priority populations, (3) climate change and air pollution, (4) economic benefits, (5) small improvements have large benefits and (6) ways forward.

BACKGROUND

What is air pollution?

Air pollution is a general term that can refer to any contaminant (or pollutant) in the air. Air pollution is commonly divided into particulate matter (PM) and gases (**Box 1**). PM refers to airborne particles of any size from any source, including biological particles such as pollen, crustal particles such as soil and dust, and chemical particles such as aerosolised products of combustion. Particulate matter 2.5μm or less in diameter ($PM_{2.5}$), regardless of source, has the greatest evidence for harm and greatest contribution to the global burden of disease.[43] When breathed in, these fine particles go deep into the lungs, enter the blood and travel throughout the body, impacting the cardiovascular, respiratory, and other organ systems.

Sources of air pollution can be natural or human-made (anthropogenic), however, 'natural' sources of air pollution are increasing as a result of human activity. For example, landscape fire smoke is increasing due to anthropogenic global warming.[44-47] Since the commencement of industrialisation, the globally dominant source of air pollution has been from the burning of fossil fuels or biomass (such as wood) for energy and heat. These combustion emissions are the greatest contributor to both air pollution and climate change. Industrial emissions, construction and demolition, agricultural activities, and synthetic chemicals also contribute to anthropogenic air pollution. As global populations grow, so does the demand for energy and resources, and this will further exacerbate the problem of air pollution if adequate policy and mitigation measures are not implemented.

Air pollution is now recognised as the single greatest environmental threat to human health and wellbeing[1] and the global burden of disease attributable to ambient air pollution is growing.[48] Ninety-nine percent of the world's population breathes air that exceeds the WHO air pollution guideline thresholds.[32] For more than half of the world's population, air pollution exposure levels are increasing.[49] Air pollution is recognised as a major modifiable health risk factor, along with unhealthy diets and tobacco smoking.[1] Many countries have responded by legislating air quality standards and mitigation measures to achieve cleaner air and improve the health of their populations. While air quality has generally improved in high-income countries in past decades, pollutant concentrations still exceed the most recent WHO guideline levels in most countries, including Australia.[1, 50, 51]

The WHO guidelines were lowered in 2021 in recognition of increasing evidence pointing to adverse health effects at low-level $PM_{2.5}$ and nitrogen dioxide (NO_2), and represent the tightest benchmark internationally for air quality guidance. Up to that point, Australia had some of the strongest air quality standards in the world. This provides Australia with an opportunity to review and update the existing standards in line with the best evidence.

Box 1: Common particulate and gaseous air pollutants

Particles* (aerosolised solids and liquids)

- Particulate matter (PM) (airborne particles of any size, from any source)
- $PM_{2.5}$ – PM ≤ 2.5μm in diameter
- PM_{10} – PM ≤ 10μm in diameter

Gases

- Carbon monoxide (CO)
- Nitrogen dioxide (NO_2)
- Ozone (O_3)
- Polycyclic aromatic hydrocarbons (PAHs)
- Sulphur dioxide (SO_2)
- Volatile organic compounds (VOCs)

*Combustion particles include elemental and organic carbon compounds. Crustal particles include aerosolised soil and dust. Biological particles include pollen grains, fungal spores, bacteria, and viruses.

1. AIR POLLUTION, NON-COMMUNICABLE AND COMMUNICABLE DISEASES

Non-communicable diseases

Non-communicable diseases, sometimes also called chronic diseases, include heart and blood vessel diseases, stroke, dementia, kidney diseases, asthma, diabetes and cancer. These conditions are largely the result of risk factors such as tobacco smoking, harmful alcohol use, physical inactivity, and unhealthy diets, coupled with genetic predisposition. Environmental risk factors are also important. While higher risk behaviours can often be modified, everyone has to breathe air, and individuals have little control over its quality. Of the broad range of non-communicable diseases, heart and lung disease, diabetes and certain cancers are the most common.[52] Non-communicable diseases kill more than 40 million people each year, accounting for 75% of all deaths globally.[52]

In 2019, air pollution was responsible for approximately 7 million premature deaths globally, almost all via its impact on non-communicable diseases.[2] Air pollution is the second most important risk factor for non-communicable disease mortality, behind tobacco smoking.[2, 53] The adverse health effects of air pollution are caused by both short periods of high (acute) exposure that worsen existing diseases, and long periods of low-moderate level (chronic) exposure that drive the onset and progression of disease. The burden of non-communicable disease deaths which is attributable to ambient air pollution is growing.[2, 48]

The strongest evidence of causal associations between air pollution and chronic disease exists for heart and lung disease.[21, 54-57] Evidence has established a causal relationship for exacerbations of these conditions and deaths. Strong links have also been established for stroke and lung cancer.[6, 7] The International Agency for Research on Cancer (IARC) has confirmed ambient air pollution and PM specifically as group 1 human carcinogens, meaning that they are known to cause cancer.[5]

Apart from heart and lung disease and cancer, there is a growing body of evidence linking air pollution to a range of other health conditions including: metabolic (e.g. diabetes, high blood pressure), brain and cognitive conditions, allergies, blood, reproductive and pregnancy, and impaired childhood development (**Figure 1**).[6, 8-13, 23, 24, 58-72]

In Australia, non-communicable diseases account for about two-thirds of the total disease burden.[73] Given this large burden, air pollution has the potential to worsen the health of a significant proportion of the Australian population. Since calculations of the disease burden attributable to air pollution largely focuses on heart and lung disease and do not account for the many other body systems affected, the disease burden of air pollution is underestimated. Further underestimation of the complete health toll of air pollution is likely as studies to date largely account for a few pollutants only.[1]

To date, prevention and management of non-communicable diseases has focused on modifying individuals' behaviours such as tobacco smoking, alcohol, physical inactivity, and unhealthy diets with varying degrees of success. Although targeting these behavioural risk factors is undoubtedly crucial, air pollution is not as easy to modify as individuals have limited control over the quality of the air they breathe. Taking steps to reduce air pollution at the source generates health benefits for the whole population without the need for individual behaviour change.

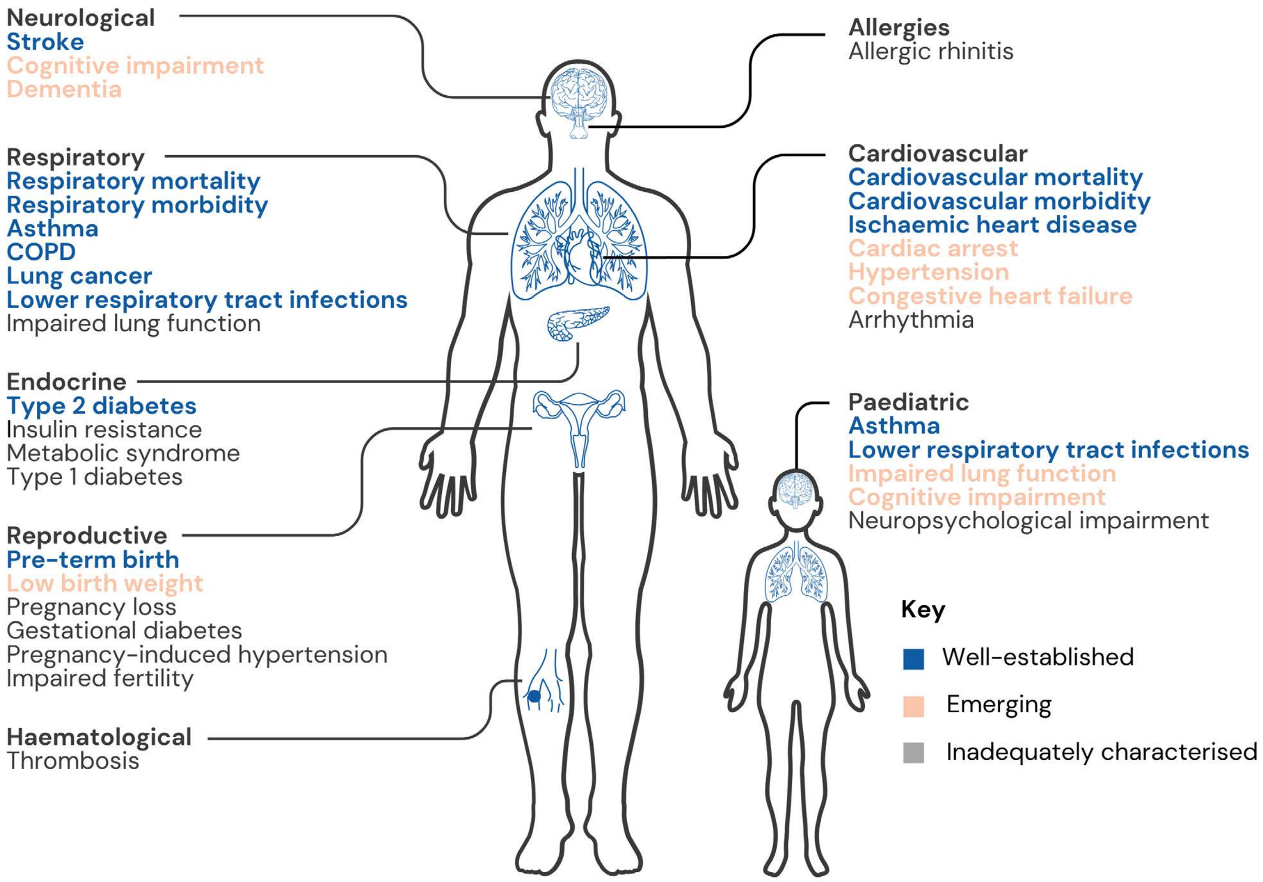


Figure 1: Air pollution affects multiple body systems and can contribute to the risk of a range of health conditions.[5, 6, 10-13, 18, 19, 21, 23-25, 51-108, 126, 171, 181-193, 197-199, 201, 206-208, 211-220, 222]

Communicable diseases

Air pollution also worsens communicable (infectious) disease outcomes. Ambient air is an important risk factor for upper and lower respiratory tract infections, and an important risk factor for childhood deaths from pneumonia in settings where indoor cooking fires are commonly used, and exposure to indoor air pollution can be extreme.[7, 74, 75] Ambient air pollution may increase the transmission, severity, duration of hospitalisation, and mortality in people infected with respiratory viruses like influenza and COVID-19.[17-19] Additionally, population groups living in areas with worse air quality are more likely to have pre-existing chronic disease, which in turn is a risk factor for poorer outcomes due to communicable diseases.[76] These impacts on communicable disease are rarely considered in air pollution impact quantification or analyses leading to an underestimation of the true burden of air pollution.

Key Messages

- Air pollution is an important risk factor for non-communicable diseases.
- In Australia, non-communicable diseases account for two-thirds of the disease burden. This means even small reductions in air pollution can have a large public health impact.
- Air pollution affects more than just the heart and lungs – there is growing evidence suggesting it affects most body systems.
- The burden of disease attributable to air pollution is significantly underestimated as most calculations account for mortality impacts of a few pollutants on the heart and lungs only.
- Air pollution worsens the health outcomes related to communicable diseases, including respiratory infections like influenza and COVID-19. In many lower and middle-income countries, poor indoor air quality from cooking fires is linked with deaths due to childhood pneumonia.
- We all must breathe. Therefore, reducing air pollution benefits the health of the whole population without the need for individual behaviour change.

2. PRIORITY POPULATIONS

Exposure to air pollution and its health effects are unevenly distributed across the population. In Australia, those who bear the health burden of air pollution are some of our most vulnerable people: socially disadvantaged populations, Aboriginal and Torres Strait Islander people, individuals with pre-existing chronic conditions, older adults, unborn babies, young children and those who are pregnant.[7, 38, 77] Certain occupations place workers at higher risk of exposure to air pollution.

Pregnancy and unborn babies

Pregnancy-related changes to the function of various body systems can increase some health risks associated with air pollution.[78] For example, there is emerging evidence that air pollution can increase the risk of gestational diabetes[79, 80, 82] and high blood pressure in pregnancy.[81, 83-85]

Air pollution can affect the growth, development, and overall health of children before birth. Reduced air quality is associated with pregnancy loss (miscarriage and still birth), growth restriction in the womb, earlier than expected birth, lower birth weight, congenital heart disease, neonatal death,[10-13, 65-70, 86, 87] and impaired development leading to an increased risk of chronic noncommunicable diseases in later life.[6, 23, 24] This includes the development of asthma[88-90] – the leading cause of burden of disease in Australian children aged 5-14 years.[91] There is growing evidence to support the hypothesis that exposure of unborn babies to air pollution increases the risk of structural brain changes, cognitive impairment, and poor neuropsychological development in childhood.[25, 92-96]

Younger age groups

Children are at higher risk from reduced air quality because they:

- have faster breathing rates,
- receive higher doses of pollution due to this faster breathing rate and being more physically active,
- are shorter in stature meaning they breathe air closer to the ground where some some pollutants are emitted and may accumulate,
- inhale a greater proportion of air through their mouths bypassing the filtering provided in the airways of the nose, and
- their organs and immune system are still developing.[23, 24 , 97-100]

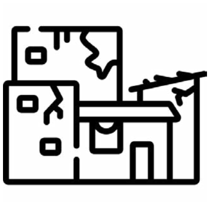
As a result, increases in air pollution increase the risk of several health outcomes in childhood: acute respiratory infections and ear infections, development of asthma, exacerbation of asthma and allergies (including allergic rhinitis, eczema and conjunctivitis), and impaired lung function[23, 24, 97-100]. There is also evidence of associations between reduced air quality and childhood obesity; impaired brain and cognitive development; and some childhood cancers.[23, 24]

Air pollution, even at low levels, may impair cognitive function across the life course.[101] Air pollution is associated with poorer educational outcomes in children[102, 103] which may consequently affect subsequent income[104, 105] and socioeconomic status. Hence, the downstream impacts of air pollution extend beyond health alone, are far-reaching and can have lasting consequences with the potential to detrimentally impact an individual over their entire life course.

Older people

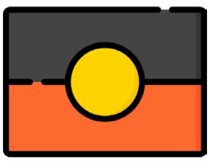
Older people (>65 years old) are more susceptible to adverse health effects from air pollution compared to younger adults because of age-related declines in physiological processes and higher rates of non-communicable diseases,[106, 107] particularly heart and lung disease.[108] As Australia's population ages,[109] elderly people will continue to make up a greater share of the total population. This shift in age demographics means the risks of air pollution to Australia's population is growing.

Social and economic disadvantage



More disadvantaged population groups in Australia can be exposed to higher concentrations of air pollution, particularly from industrial sources.[110, 111] People with greater socio-economic disadvantage also may have poorer housing, lower health literacy, poorer underlying health, and more barriers to protecting themselves against air pollution.[112] This means that even when air pollution is equally distributed, as with region-wide bushfire smoke episodes, the most disadvantaged groups will experience a much greater share of the adverse health impacts than others. For example, the Australian Institute of Health and Welfare (AIHW) estimated that the most socially disadvantaged populations in Australia have more than double the disease burden due to air pollution compared to the most advantaged.[3]

Aboriginal and Torres Strait Islander peoples



Aboriginal and Torres Strait Islander peoples, particularly those living in remote communities, are likely to experience greater exposure to some forms of air pollution[110, 113] such as windblown dust and smoke from open fires. Compared to other Australians, Aboriginal and Torres Strait Islander people have been found to be at higher risk of cardio-respiratory related hospitalisation due to air pollution from landscape fires[114, 115] and of pre-eclampsia (a serious condition in pregnancy) associated with traffic-related pollution.[81] It is well-established that Aboriginal and Torres Strait Islander people experience greater social disadvantage and are at increased risk of noncommunicable diseases. The rate of disease burden among Aboriginal and Torres Strait Islander people is more than double (2.3 times) that of other Australians,[116] and the prevalence of cardiovascular disease, asthma and chronic obstructive pulmonary disease (COPD) is also higher,[117, 118] resulting in an increased risk of adverse health effects from air pollution.

Occupational exposures

Some people are more exposed to air pollution due to the nature of their jobs. Firefighters have occupational exposure to smoke while fighting fires and during prescribed burns. Outdoor workers are also more exposed in general but can also be in situations where they are less able to protect themselves against smoke, for example extreme weather events like bushfires. Tradespeople can be at increased risk of occupational exposure to dust and silica.[119] These groups require specific consideration and interventions to protect their health from airborne hazards.

To summarise, air pollution inequitably affects vulnerable population groups both through increased exposure and disproportionately higher impacts on health. Action on air pollution can potentially have a positive impact on reducing this inequity and is a unique and powerful opportunity to ensuring safe, fair, and healthy air for all Australians to breathe.

Key Messages

- Even with similar exposures, the health impacts of air pollution are unevenly distributed in a population.
- Air pollution disproportionately affects many groups: children, pregnant people and unborn babies, older adults, individuals with pre-existing chronic conditions, Aboriginal and Torres Strait Islander peoples and socially disadvantaged populations.
- Older people are more susceptible to the health effects of air pollution. As Australia's population is ageing, the size of this group, and the health burden of air pollution impacts is growing.
- Socially disadvantaged population groups may have less ability to protect their health or access health care.
- There aren't many interventions that will benefit the health of all these groups simultaneously. Therefore, action on air pollution provides a powerful opportunity to reduce health inequities in Australia.


NEW YORK
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PARIS
BERLIN
LOS ANGELES
SEOUL

3. CLIMATE CHANGE AND AIR POLLUTION

Air pollution is closely linked with the Earth's ecosystems and climate. Carbon dioxide, in combination with other greenhouse gases, contributes to climate change which, in turn, is worsening air quality and population health by causing more frequent and severe bushfires, smog, and dust storms.[28-30]

As the Earth heats, extreme weather events and their associated health impacts are increasing.[120] The 2019-20 Black Summer bushfires directly or indirectly affected 80% of Australians.[121] It caused more than 400 smoke-related deaths, 4,500 hospitalisations and emergency department visits,[122] and resulted in unprecedented health costs.[123] Previous studies have demonstrated bushfire-related particulate matter (PM) impacts in Australia are similar to that described for PM from background urban sources including increases in all-cause mortality, increased emergency department attendances for non-trauma conditions,

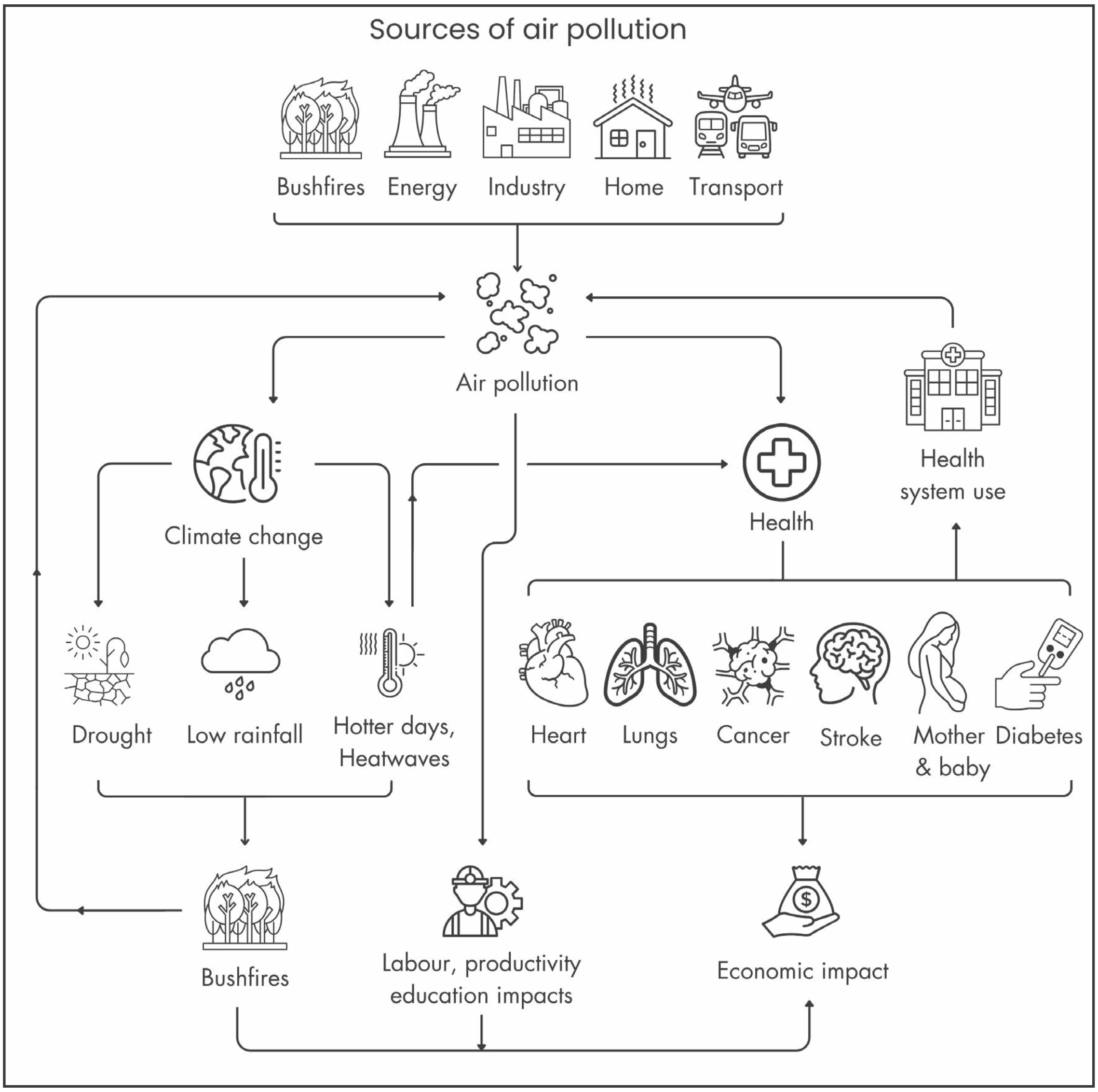

Figure 2: Connections between health, economic and social effects of climate change and air pollution.

respiratory conditions, asthma, chronic obstructive pulmonary disease (COPD) and ischaemic heart disease, increased asthma hospitalisations and emergency department visits, and increased out of hospital cardiac arrest.[124-127]

Climate change is increasing the production, abundance, potency, and geographical distribution of some aeroallergens like grass and tree pollen as well as prolonging the pollen season.[128, 129] This will likely worsen the burden of allergic disease[130] and increase the frequency and severity of epidemics of thunderstorm asthma.[131] Climate change will also contribute to air pollution and worsen population health via other pathways such as increased exposure to ozone,[132] dust,[133] and mould.[134]

Furthermore, the environmental repercussions of severe weather events linked to climate change can be far-reaching, leading to other indirect health and social impacts. The 2019-20 Black Summer bushfires have been termed an "Earth system event", emitting more than Australia's annual carbon footprint,[135] with stratospheric smoke plumes causing a 5% depletion of the protective ozone layer, winding back previous gains in this area.[136] Smoke plumes likely contributed to regional cooling and the prolonged La Niña event of 2020-2022.[137] This increased period of rainfall resulted in extreme flooding over eastern Australia and may have contributed to the novel emergence of the mosquito-borne disease, Japanese encephalitis virus in Australia.[138] Black Summer smoke plumes also extended to New Zealand and South America[139] highlighting the concern of transboundary air pollution in our region.[2]

Global heating also threatens global food security, which may be further impacted by air pollution directly (e.g., reduced plant growth) and indirectly (e.g., reduced labour productivity).[140]

Because climate change and air pollution share common drivers, mitigation policies are a win-win strategy for both climate and health. The potential global health co-benefits from improved air quality through climate action are large and could reach trillions of dollars annualy.[141] Ambitious climate policy could avoid hundreds of thousands of deaths related to air pollution by 2030, globally.[142] Additionally, the co-benefits of improved air quality on deaths and disease could offset the costs of implementing climate change policies.[142]

Key Messages

- Climate change is being worsened by air pollutants which are also harmful to human health.
- Severe pollution events like large bushfires are becoming more frequent with the potential to impact the ozone layer, global food security, infectious diseases, and ultimately, human health.
- Climate change will increase the burden of disease caused by a range of airborne hazards including pollen, dust, mould and some infectious diseases.
- Policies to reduce climate change will have the dual benefit of improving air quality and public health.

4. ECONOMIC BENEFITS

The global health-related economic costs of fine particulate matter ($PM_{2.5}$) air pollution amounted to $8.1 trillion (6.1% of global gross domestic product) in 2019.[143] In Australia, many studies have shown that the health-related economic costs of various air pollutants are in the billions of dollars (see **Table 1**). The Black Summer bushfires of 2019-20 alone generated an estimated $1.95 billion in smoke-related health costs.[123] Clearly, these costs are enormous, however they are likely to be underestimated as they typically account for PM and some health outcomes only. The costs of black carbon, volatile organic compounds, sulphur dioxide, nitrous oxides, ozone, aeroallergens, and mould, for example, remain largely unaccounted for.

Besides health-related costs, there are other costs of air pollution not often considered: labour and productivity, behavioural, performance, skills, cognitive, educational, and other societal costs. In 2013, the World Bank estimated that $PM_{2.5}$ exposure resulted in US$ 143 billion in lost labour income and US$ 3.55 trillion in welfare losses globally.[144] More recent estimates suggest welfare costs may be higher, up to $US 6 trillion.[143] Air pollution has been linked to decreased productivity of farm and factory workers, as well as the performance of certain office workers, trial judges, and professional sportspeople.[102]

Air pollution also affects the supply of labour. Increases in concentrations of some pollutants results in fewer hours per week worked and more sick days.[102] In the United Kingdom, it has been calculated that meeting the WHO air quality guidelines would result in a gain of 3 million working days and £1.6 billion (AUD$ 3.2 billion) in economic benefit, per year.[145] Similarly, in Spain, over a 10 year period, improved ambient air quality reduced worker absence by an estimated 5.5 million days.[146] In New Zealand, air pollution resulted in an estimated 1.75 million restricted activity days and a societal cost of NZ$ 15.6 billion.[147]

Small increases in air pollution are also associated with school absences in children.[148-151] School absenteeism reduces academic performance, affecting later employment opportunities, leading to economic difficulty in early adulthood.[152-154] School absenteeism also means parents and caregivers miss work and this too has an economic cost.

With an ageing population,[109] the public health risks and economic costs attributable to air pollution will likely rise in Australia. Older people (>65 years) are more susceptible to the health effects of air pollution[106-108] and air pollution has disproportionately higher health costs among older people compared to younger age groups.[155] Despite accounting for just over 10% of the global population, older populations contributed approximately 60% of the total economic cost attributed to ambient $PM_{2.5}$ between 2000 and 2016.[155] This cost doubled during the same period.[155]

Return on Investment

Return on investment of policies for safer air in Australia have not been characterised in detail, however there are several estimates of the economic burden relating to premature mortality as described in the above paragraph (**Table 1**).

In the United States, a cost-benefit analysis of the Clean Air Act showed that the benefits ($2 trillion) of improved air quality far outweighed the costs ($65 billion) in a ratio of 30:1; meaning that for every $1 invested in air pollution control and mitigation, a $30 benefit is received in reduced health care costs and economic productivity.[156] At the higher end of the range, the estimated benefits are approximately 90 times the cost.[156] A more recent analysis found that economic benefits could range from 2 to 90 times the cost, depending on the chosen policy option.[157]

In Europe, the Organisation for Economic Co-operation and Development (OECD) estimated that reducing $PM_{2.5}$ concentration by 1μg/m^3 would boost Gross Domestic Product (GDP) by 0.8%.[158] Modelling suggests that attaining ambient air quality targets set by the European Union would increase GDP by 1.25%, and up to 3% in the most polluted European countries. Further, reducing $PM_{2.5}$ by 25% across Europe would cost €1.2 billion annually but the economic benefit would be at least two orders of magnitude greater.[158]

Best-buy Interventions

Detailed economic assessments are clearly required for specific interventions. One relatively simple way to achieve rapid and substantial improvements in air quality is to address the problem of pollution generated by domestic wood heaters. Average long-term population exposure to $PM_{2.5}$ in Australia is approximately 7 μg/m^3.[4] About 10% of this (0.7 μg/m^3) is on average attributable to wood heater emissions although this varies considerably by location.[31]

The Centre for Safe Air estimated that a hypothetical intervention to replace 50% of the existing stock of wood heaters with non-combustion heating such as electricity would have large benefits for health and the environment (**Table 2**).[31] It could reduce the annual average pollution burden by a modest 5% yet provide an annual economic benefit of $1.64 billion every year, through reduced mortality alone (**Table 2**).[31] Thus, a relatively small improvement has large potential benefits..

Some jurisdictions are already moving in this direction. Recently, the Australian Capital Territory state government announced the phase out of wood heaters in residential areas by 2045.[159]

Table 1:
Australian studies demonstrating the health-related economic costs of various air pollutants.

Author (year)	Region	Pollutant(s)	Outcome	Economic cost per annum
Hanigan et al., (2020)[4]	Australia	$PM_{2.5}$	Mortality	$6.2 billion (2019 dollars)
Department of Environment and Conservation NSW(2005)[160]	Greater metropolitan Sydney	PM_{10}	Mortality, hospital admissions (respiratory, cardiac), asthma, bronchitis, lost productivity	$4.7 billion (midpoint) (2003 dollars)
Department of Planning and Environment NSW (2023)[161]	Greater metropolitan NSW	$PM_{2.5}$	Mortality and years of life lost.	$4.8 billion (2021 dollars)
VIC Department of Environment, Land, Water and Planning (2019)[162]	Victoria	SO_2, NOx, $PM_{2.5}$ and PM_{10}	Mortality, morbidity.	$1.08 billion to $2.1 billion (2018 dollars)
Johnston et al., (2020)[123]	Australia	Black Summer Bushfire $PM_{2.5}$	All-cause mortality, asthma ED visits, cardiovascular and respiratory hospitalisations	$1.95 billion (2018 dollars)

Table 2:
Estimated national benefit (per year) of replacing 50% of wood heaters with electric heaters powered by renewable sources.

Population average exposure to $PM_{2.5}$ from all sources	*Population average $PM_{2.5}$ reduction from intervention*	*Estimated reduced annual mortality (N)*	**Estimated annual benefit*
7.0 µg/m^3	0.4 µg/m^3	364 deaths	$1.639 billion

*Estimates based on national modelling of air pollution from all sources, air pollution from wood heaters, established estimates of the association with mortality and value of a statistical life.[31]

Key Messages

- The health-related economic costs of air pollution in Australia are substantial. The most recent Australian estimate is $6.2 billion annually.
- As Australia's population ages, the health-related economic costs of air pollution will grow.
- Costs are likely to be underestimated as they typically account for particulate matter to the exclusion of other important air pollutants, and do not include non-health related costs such as labour, productivity, and educational impacts.
- More frequent severe pollution events like large bushfires will result in higher costs.
- International evidence shows that the return on investment is high. Every dollar spent on action on air pollution could return between $2 to $90.

5. SMALL IMPROVEMENTS HAVE LARGE BENEFITS

Air pollution negatively affects health at concentrations well below Australia's Air Quality National Environmental Protection Measure (NEPM) standards. Multiple studies have shown exposure to ambient air pollution in the concentration range experienced in Australia, results in increased premature mortality due to heart and lung disease[57, 163-170] and hospitalisation due to heart, lung, vascular, neurological, and metabolic conditions like diabetes.[164, 166, 171] These deaths and hospitalisations are potentially avoidable with more stringent policies for cleaner air.

Indeed, interventions that target lower levels of air pollution produce some of the most significant health benefits. The health effects of air pollution are not linear but differ substantially at different points in the 'concentration-response curve'. Concentration-response curves are used to calculate the risk of specific health outcomes associated with differing levels of exposure. For some air pollutants (PM particularly), the shape of this curve is described as a 'decelerating concentration-response relationship' (**Figure 3**).[1, 172-175] Counterintuitively, this means that at low levels of pollution, adverse health outcomes increase sharply, but this rate slows or plateaus at higher levels.

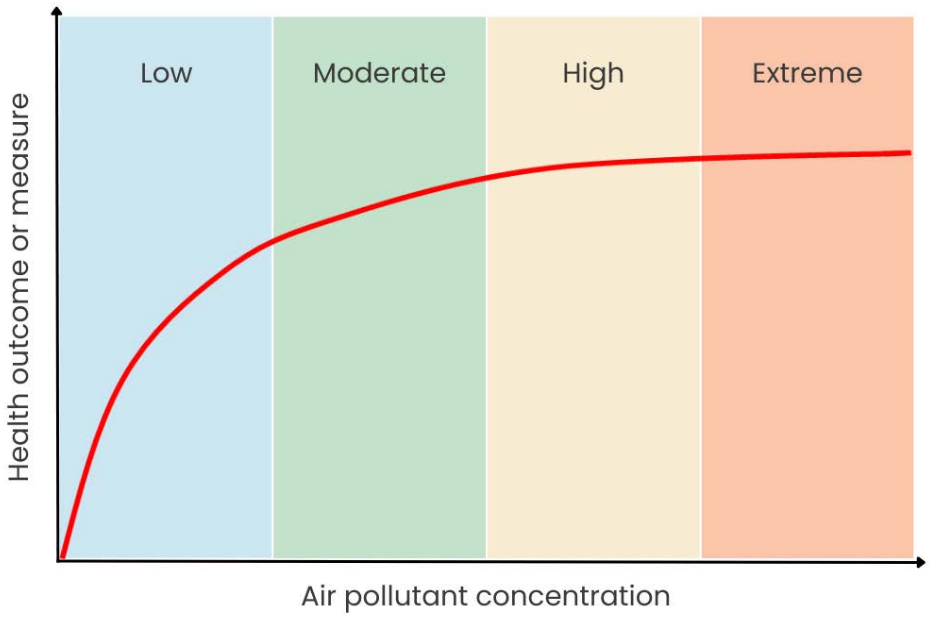

Figure 3: Illustration of the general shape of concentration-response relationships for particulate air (PM) pollution. The steepest increase in health impacts occurs with increments above minimal background pollution levels (the blue section). The rate of increase for many health outcomes tapers off at high to extreme concentrations (yellow and red sections). This means there are substantial health benefits to be gained by reducing air pollution in Australia. Image based on referenced sources, including the WHO.[1, 172-175]

Most exposure to air pollution in Australia occurs at levels in the steeper part of the curve. Current estimated average Australian population exposure to $PM_{2.5}$ is around 7 $\mu g/m^3$ per year on average,[4] higher than the WHO guideline of 5 $\mu g/m^3$.[1] This is of importance as it indicates that there are significant health gains to be made from relatively small pollution reductions.

Some NEPM pollutant maximal accepted concentrations are more than double WHO guidelines (**Table 3**). The Australian NEPM standards for ambient air quality should reflect the most recent health evidence. The current NEPM threshold-based approach should be complemented with an increased focus on continuous improvement in air quality, regardless of source. This would involve setting targets for continuous air pollution reduction over time to significantly improve health outcomes related to air pollution and prevent future ill health.

Key Messages

- Evidence does not support the assumption that there is a ‘safe’ lower threshold for air pollutants, nor a regulatory approach based solely on this assumption.
- Air pollution negatively affects human health at levels below current Australian standards.
- There remains great potential to further improve the health and wellbeing of Australians through better air quality. Even small reductions in air pollution will have substantial health benefits.
- Australian policy should continue the move towards continuous improvement in air quality rather than relying solely on threshold-based approaches for air quality regulation.

Table 3:

Maximum concentration standard and averaging period for National Environmental Protection Measure (NEPM) ambient air quality standards[176] and World Health Organization (WHO) guidelines.[177] Values highlighted in green are the WHO guideline maximum concentration standards to compare with those highlighted in orange, which are the NEPM values that exceed the WHO guidelines.

Pollutant	*Averaging period*	*NEPM maximum concentration standard*	*WHO maximum concentration standard*
$PM_{2.5}$ (μg/m^3) *	Annual	**8**	**5**
	24-hour	**25**	**15**
PM_{10} (μg/m^3)	Annual	**25**	**15**
	24-hour	**50**	**45**
O_3 (μg/m^3)	Peak season	-	**60**
	8-hour	**127**	**100**
NO_2 (μg/m^3)	Annual	**28**	**10**
	24-hour	-	**25**
	1-hour	**150**	**200**
SO_2 (μg/m^3)	24-hour	**52**	**40**
	1-hour	**262**	-
	10-minute	-	**500**
CO (mg/m^3) **	24-hour	-	**4**
	8-hour	**10.35**	**10.0**
	1-hour	**-**	**30**
Lead #	Annual	**0.50**	**-**

CO = carbon monoxide, NO_2 = nitrogen dioxide, O_3 = ozone, SO_2 = sulphur dioxide, $PM_{2.5}$ = particulate matter less than 2.5μm diameter, PM_{10} = particulate matter less than 10 μm diameter.

* μg/m^3 = micrograms per cubic metre

** mg/m^3 = milligrams per cubic metre

Note that lead may soon be removed from the Air Quality NEPM

Conversion to WHO units were calculated using conversion factors (at 25 °C) sourced from NSW Department of Planning and Environment.[178]


SAFER AIR, HEALTHIER COMMUNITIES

6. WAYS FORWARD

Air pollution and the associated adverse health effects are linked to how we generate energy, how we heat our homes, our transport systems, and our climate. No single policy will adequately tackle the problem of air pollution therefore effective policy measures and regulation need to consider and address the diverse sources, settings, and susceptible populations impacted more seriously by air pollution (**Figure 4)**.

The multi-faceted nature of air pollution requires a comprehensive and holistic policy response such as the 'health in all policies' approach. This type of approach combines and leverages synergies between policies to improve air quality including climate change mitigation, fuel efficiency standards, housing insulation standards, and industrial, transport and domestic energy sources.

Currently, air quality and safety falls between the health and environmental portfolios. Monitoring and management interventions are often needed in the environment, planning and transport sectors where health expertise and input is limited, whereas public health impacts and responses to air pollution largely reside in the health sector. Moreover, expertise outside the health and environment sectors is needed to effectively respond to air quality challenges. Action and advice are required from infrastructure and transport; agriculture and forestry; industry, science and resources; employment and workplace relations; and statewide fire and emergency services. A unified and coordinated approach will ensure that policies to mitigate air pollution are streamlined, consistent and easier to implement.

Emerging government initiatives such as the Centre for Disease Control, the Net Zero Authority, and the National Health, Sustainability and Climate Unit point to increased inter-departmental coordination that could each assist in the management of air quality. National leadership, with trans-departmental governance arrangements and diverse expertise will represent the best path forward. However, further structural changes in governance are needed to ensure air pollution policy drivers are not lost between portfolios. This will be crucial in addressing the complex and interrelated policy options needed (**Figure 4**) to address the key requirements for achieving the benefits of safer air.

Key Messages

- Air pollution is a multifaceted problem requiring a multi-pronged but holistic approach that leverages synergies between health, climate, fuel efficiency, housing, industrial, transport and domestic energy policies.
- A unified approach that incorporates health and environmental portfolios for integrated management, monitoring, and regulation, of airborne hazards and health impacts will enable effective policy solutions with a high return on investment.
- Strong leadership, structural changes in governance, and national oversight are crucial for coordinated policies across the three key axes: sources, settings, and susceptible populations.

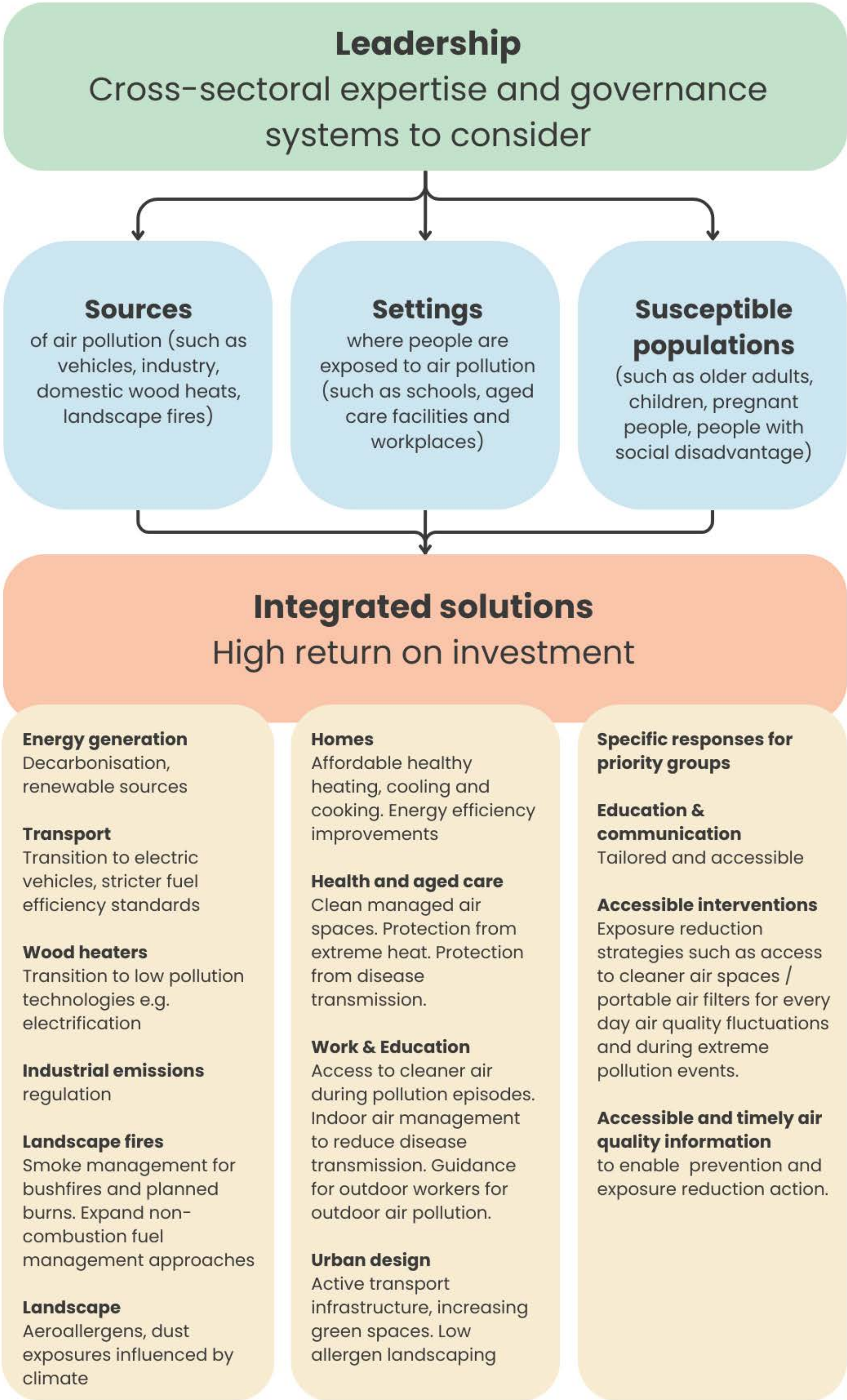

Figure 4: Conceptual diagram illustrating the intersecting policy connections for action on safer air.

CONCLUSION

Air pollution is a major and increasing threat to human health and wellbeing. Coordinated action to manage air quality represents one of the best investments for improving and protecting health in Australia.

While air pollution ranks alongside unhealthy diets, inadequate physical activity, and tobacco smoking, as a major risk factor for mortality, improved air quality does not require extensive health literacy and behaviour change for people to experience the benefits. Small improvements in Australian air quality will:

- have a large benefit at a population level.
- reduce the development, progression, and exacerbation of non-communicable diseases.
- reduce the impacts of epidemics such as influenza and COVID-19.
- raise the health outcomes of vulnerable populations in our community.
- reduce health inequities faced by socially disadvantaged populations, and Aboriginal and Torres Strait Islander people.

Emerging challenges like population growth and ageing, urbanisation, and increasing transport and energy demands pose additional risks for air quality, accelerating climate change and population health. The health costs of air pollution are substantial – at least $6.2 billion in Australia annually. These costs (as well as the burden of disease) are likely underestimated as they typically only account for PM, some rather than all health outcomes, and do not include non-health related costs such as labour, productivity, cognitive and educational losses.

There is much to be gained by acting on air pollution. To reap the benefits, we need comprehensive, integrated management approaches and funding for air, just as we do for other essentials for life like food and water. There aren't many interventions that will equitably benefit the health of all Australians, mitigate climate change, and simultaneously save billions in health and non-health costs. Accessing these benefits will require evidence-informed policy, strong leadership, structural changes in governance and funding; including national oversight through a trans-departmental body.

Air is a shared resources and its quality affects everybody. The Centre for Safe Air will work together with all stakeholders to support cost-effective, practical and evidence-informed action, to the ultimate benefit of all Australians.

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APPENDIX

Appendix A: Glossary

Acute	Referring to conditions or illnesses that generally develop suddenly and last a short time (hours to weeks).
Aeroallergen	Any of various airborne substances, such as pollen or spores, that can cause an allergic response.
Ambient air pollution	A term used to describe air pollution in outdoor environments.
Anthropogenic	Caused by humans or their activities.
Antibiotic resistance	When microorganisms (particularly bacteria and fungi) develop the ability to defeat the medicines designed to kill them.
Carcinogen	A substance, organism, or agent capable of causing cancer.
Cardiac	Referring to the heart.
Cardiovascular	Referring to the heart and blood vessels.
Chronic	Referring to conditions or illnesses that generally develop slowly and may worsen over a long period of time (months to years)
Chronic obstructive pulmonary disease	A chronic and progressive lung condition that causes obstructed airflow from the lungs.
Communicable disease	A disease that is spread from a person or animal to another, either directly or indirectly. Often used synonymously with the term 'infectious disease'.
Concentration-response curve	A type of graph showing how a health outcome is affected by the concentration of an air pollutant.
Earth system event	An event that triggers or influences interactions between the various spheres of Earth (biosphere, cryosphere, hydrosphere, atmosphere, geosphere) resulting in changes in one of more of these spheres.
Fine particulate matter	Synonym for particulate matter less than 2.5μm in diameter ($PM_{2.5}$).
Gestational diabetes	A condition of pregnancy characterised by higher-than-normal blood glucose (sugar) levels.
Hypertension	Medical term for high blood pressure.

La Niña	A climatic pattern that describes the cooling of surface ocean water in the central and eastern tropical Pacific Ocean that brings heavy rainfall and cooler temperatures across much of Australia.
Metabolic	Referring to the metabolic syndrome – a group of conditions often occurring together that increases the risk of heart disease, stroke, and type 2 diabetes.
Morbidity	A measure of being symptomatic or unhealthy for a disease or condition
Mortality	A measure of the frequency of occurrence of death in a defined population during a specified period of time.
Neonatal	Relating to newborn babies.
Non-communicable disease	A disease that is not spread from person to person and is typically the result of behavioural or lifestyle factors coupled with genetic predisposition.
Particulate matter	Airborne particles made from solids or liquids, of any size, from any source.
Physiological	Relating to the normal or healthy functioning of the human body.
Pre-eclampsia	A serious condition in pregnancy characterised by high blood pressure, high levels of protein in the urine, and swelling.
Risk factor	Attributes, characteristics or exposures that increase the likelihood of a person developing a disease or health disorder.
Respiratory	Referring to the airways and lungs.
Stratospheric	Referring to the second layer of Earth's atmosphere from the ground. It is located above the troposphere but below the mesosphere.

Appendix B: Abbreviations

AIHW	Australian Institute of Health and Welfare
CO	carbon monoxide
COPD	chronic obstructive pulmonary disease
CSA	Centre for Safe Air
GDP	Gross Domestic Product
IARC	International Agency for Research on Cancer
$\mu g/m^3$	micrograms per cubic metre
mg/m^3	milligrams per cubic metre
NEPC	National Environment Protection Council
NEPM	National Environmental Protection (Ambient Air Quality) Measure
NO_2	nitrogen dioxide
O_3	ozone
OECD	Organisation for Economic Co-operation and Development
PAHs	polyaromatic hydrocarbons
PM	particulate matter
$PM_{2.5}$	particulate matter less than 2.5 micrometres in diameter (fine particulate matter)
PM_{10}	particulate matter less than 10 micrometres in diameter
ppm	parts per million (by volume)
SO_2	sulphur dioxide
VOCs	volatile organic compounds
WHO	World Health Organization

Appendix C: Table 1

Evidence and level of certainty of the effects of air pollution on various health conditions

Health conditions by body system	*Author (year)*	*Certainty of Evidence* (well-established, emerging, inadequately characterised)*
All-cause mortality		
	Chen et al., (2020)[57] Di et al., (2017)[179] Walter et al., (2021)[180] Christidis et al., (2019)[167] Liu et al., (2019)[165] Sanyal et al., (2018)[181] Achilleos et al., (2017)[182] Atkinson et al., (2015)[183] Dominski et al., (2021)[184] Dwivedi et al., (2022)[56] Bu et al., (2021)[185]	Well-established
Cardiovascular		
Cardiovascular disease mortality	Liu et al., (2019)[165] Sanyal et al., (2018)[181] Achilleos et al., (2017)[182] Fajersztajn et al., (2017)[186] Zhao et al., (2017)[187] Atkinson et al., (2015)[183] Dwivedi et al., (2022)[56] Schraufnagel et al., (2019)[6] Bu et al., (2021)[185] de Bont et al., (2022)[55] Chen et al., (2021)[18] Manisalidis et al., (2020)[188] Thurston et al., (2017)[189] Konduracka et al., (2022)[54]	Well-established
Cardiovascular disease morbidity	Makar et al., (2017)[190] Brook et al., (2010)[63] Dwivedi et al., (2022)[56] Schraufnagel et al., (2019)[6] Wei et al., (2019)[171] de Bont et al., (2022)[55] Manisalidis et al., (2020)[188] Thurston et al., (2017)[189]	Well-established
Cardiac arrest	Dwivedi et al., (2022)[56] Dennekamp et al., (2015)[126]	Emerging
Atherosclerosis	Thurston et al., (2017)[189] Konduracka et al., (2022)[54]	Inadequately characterised
Ischaemic heart disease	Danesh et al., (2022)[191] Brook et al., (2010)[63] Dwivedi et al., (2022)[56] Schraufnagel et al., (2019)[6] de Bont et al., (2022)[55] Thurston et al., (2017)[189]	Well-established

Arrhythmia	Brook et al., (2010)[63] de Bont et al., (2022)[55]	Inadequately characterised
Congestive heart failure	Brook et al., (2010)[63] Dwivedi et al., (2022)[56] Jia et al., (2023)[192] Zhang et al., (2023)[193] de Bont et al., (2022)[55] Konduracka et al., (2022)[54]	Emerging
Changes in heart rate variability	Brook et al., (2010)[63] Schraufnagel et al., (2019)[6] Thurston et al., (2017)[189]	Emerging
Hypertension	Brook et al., (2010)[63] Schraufnagel et al., (2019)[6] de Bont et al., (2022)[55] Thurston et al., (2017)[189] Konduracka et al., (2022)[54]	Emerging
Peripheral vascular disease	Brook et al., (2010)[63]	Inadequately characterised
Deep vein thrombosis	Brook et al., (2010)[63]	Inadequately characterised
Carotid intima-media thickness	Thurston et al., (2017)[189]	Inadequately characterised
Carotid artery stenosis	Thurston et al., (2017)[189]	Inadequately characterised
Endothelial dysfunction	Brook et al., (2010)[63] Schraufnagel et al., (2019)[6] Thurston et al., (2017)[189]	Inadequately characterised
Increased blood coagulation	Brook et al., (2010)[63] Schraufnagel et al., (2019)[6]	Inadequately characterised
Raised LDL cholesterol	Zhang et al., (2021)[58]	Inadequately characterised
Impaired HDL cholesterol function	Ossoli et al., (2022)[194]	Inadequately characterised
Phlebitis / thrombophlebitis	Wei et al., (2019)[171]	Inadequately characterised
Dermatological		
Skin ageing	Schraufnagel et al., (2019)[6] Dijkhoff et al., (2020)[195]	Inadequately characterised
Atopic skin disease	Ngoc et al., (2017)[196] Schraufnagel et al., (2019)[6] Dijkhoff et al., (2020)[195]	Inadequately characterised
Urticaria	Schraufnagel et al., (2019)[6]	Inadequately characterised
Acne	Schraufnagel et al., (2019)[6]	Inadequately characterised
Endocrine		
Insulin resistance	Schraufnagel et al., (2019)[6] Dang et al., (2018)[197] Thurston et al., (2017)[189]	Inadequately characterised

Type 2 diabetes	Schraufnagel et al., (2019)[6] Bu et al., (2021)[185] Wei et al., (2019)[171] Thurston et al., (2017)[189]	Well-established
Type 1 diabetes	Mozafarian et al., (2022)[198]	Inadequately characterised
Metabolic syndrome	Schraufnagel et al., (2019)[6] Ning et al., (2021)[199]	Inadequately characterised
Obesity	Schraufnagel et al., (2019)[6]	Inadequately characterised
Eyes and Nose		
Eye irritation	Schraufnagel et al., (2019)[6]	Inadequately characterised
Allergic rhinitis	Schraufnagel et al., (2019)[6] Li et al., (2022)[61]	Inadequately characterised
Conjunctivitis	Schraufnagel et al., (2019)[6]	Inadequately characterised
Nasopharyngitis	Zhang et al., (2019)[200]	Inadequately characterised
Allergies	Schraufnagel et al., (2019)[6] Bowatte et al., (2017)[62] Bowatte et al., (2015)[201]	Inadequately characterised
Allergic sensitisation	Melen et al., (2021)[202] (pollen)	Inadequately characterised
Blepharitis	Schraufnagel et al., (2019)[6]	Inadequately characterised
Dry eye disease	Schraufnagel et al., (2019)[6]	Inadequately characterised
Cataracts	Schraufnagel et al., (2019)[6]	Inadequately characterised
Gastrointestinal		
Inflammatory bowel disease	Schraufnagel et al., (2019)[6] Adami et al., (2022)[9]	Inadequately characterised
Crohn's disease	Schraufnagel et al., (2019)[6]	Inadequately characterised
Appendicitis	Schraufnagel et al., (2019)[6]	Inadequately characterised
Gastric and colorectal cancer	Schraufnagel et al., (2019)[6]	Inadequately characterised
Gastric ulcer disease	Schraufnagel et al., (2019)[6]	Inadequately characterised
Hepatic steatosis	Schraufnagel et al., (2019)[6] Guo et al., (2022)[203]	Inadequately characterised
Hepatocellular carcinoma	Schraufnagel et al., (2019)[6]	Inadequately characterised
Haematological		
Anaemia	Schraufnagel et al., (2019)[6] Fongsodsri et al., (2021)[64]	Inadequately characterised

Leukaemia	Schraufnagel et al., (2019)[6] Fongsodsri et al., (2021) [64]	Inadequately characterised
Thrombosis	Schraufnagel et al., (2019)[6] Brook et al., (2010)[63]	Inadequately characterised
Venous thromboembolism	Fongsodsri et al., (2021) [64]	Inadequately characterised
Sickle cell pain crisis	Schraufnagel et al., (2019)[6]	Inadequately characterised
Immunological		
Systemic inflammation	Glencross et al., (2020)[8] Loaiza-Ceballos et al., (2022)[19] Ossoli et al., (2022)[194] Brook et al., (2010)[63] Xu et al., (2022)[204]	Emerging
Autoimmune diseases	Schraufnagel et al., (2019)[6] Adami et al., (2022)[9]	Inadequately characterised
Rheumatoid arthritis	Adami et al., (2022)[9]	Inadequately characterised
Connective tissue disease	Adami et al., (2022)[9]	Inadequately characterised
Microbiological		
Septicaemia	Wei et al., (2019)[171]	Inadequately characterised
Microbial dysbiosis	Mousavi et al., (2022)[205]	Inadequately characterised
Viral respiratory infections	Loaiza et al., (2022)[19]	Emerging
Musculoskeletal		
Osteoporosis	Mousavibaygei et al., (2023)[14] Pang et al., (2021)[15] Schraufnagel et al., (2019)[6]	Inadequately characterised
Osteoporotic fractures	Mousavibaygei et al., (2023)[14] Pang et al., (2021)[15]	Inadequately characterised
Low bone mineral density	Prada et al., (2023)[16] Schraufnagel et al., (2019)[6]	Inadequately characterised
Neurological		
Ischaemic stroke	Brook et al., (2010)[63] Dwivedi et al., (2022)[56] Schraufnagel et al., (2019)[6] Bu et al., (2021)[185] Dirgawati et al., (2019) [206] de Bont et al., (2022)[55]	Well-established

Cognitive impairment	Schraufnagel et al., (2019)[6] Aguilar-Gomez et al., (2022)[102] Chandra et al., (2022)[101] Claesen et al., (2021)[103] Clifford et al., (2016)[25] Sakhvidi et al., (2022)[207] Guxens et al., (2018)[92]	Emerging
Dementia	Trevenen et al., (2022)[208] Chandra et al., (2022)[101] Clifford et al., (2016)[25] Thurston et al., (2017)[189]	Emerging
Neurodevelopmental delay	Clifford et al., (2016)[25]	Inadequately characterised
Parkinson's disease	Wei et al., (2019)[171]	Inadequately characterised
Headache	Schraufnagel et al., (2019)[6]	Inadequately characterised
Mental health	Bhui et al., (2023)[60] King et al., (2022)[59] Thurston et al., (2017)[189]	Inadequately characterised
Paediatric		
Air pollution and child health	WHO (2018)[24] European Environment Agency (2023)[23]	Various certainties of evidence
Congenital abnormalities	Thurston et al., (2017)[189]	Inadequately characterised
Congenital heart disease	Ma et al., (2021)[209] Wan et al., (2023)[210] Liu et al., (2017)[13]	Inadequately characterised
Neuropsychological development	Peterson et al., (2015)[94] Suades-Gonzales et al., (2015)[95] Thurston et al., (2017)[189]	Inadequately characterised
Cognitive development	Thurston et al., (2017)[189] Health Effects Institute (2022)[211]	Inadequately characterised
Paediatric education	Margolis et al., (2021)[96]	Inadequately characterised
Reproductive and Pregnancy		
Impaired fertility	Carre et al., (2017)[71] Siegel et al., (2023)[72]	Inadequately characterised
Pregnancy loss	Nyadanu et al., (2022)[65] (spontaneous abortion) Siddika et al., (2016)[12] (stillbirth) Thurston et al., (2017)[189] (stillbirth)	Emerging
Intrauterine growth restriction	Pederson et al., (2013)[67] Melody et al., (2019)[11]	Emerging

Low birth weight	Pederson et al., (2013)[67] Ghosh et al., (2021)[10] Nyadanu et al., (2022)[65] Bekkar et al., (2020)[68] Stieb et al., (2012) Li et al., (2020)[69] Thurston et al., (2017)[189] Stieb et al., (2012)[222]	Emerging
Pre-term birth	Ghosh et al., (2021)[10] Melody et al., (2019)[11] Pereira et al., (2022)[66] Bekkar et al., (2020)[68] Klepac et al., (2018)[70] Thurston et al., (2017)[189]	Well-established
Pregnancy-induced hypertension	van den Hooven (2011)[83] Pedersen et al., (2014)[85] Pedersen et al., (2017)[84]	Inadequately characterised
Pre-eclampsia	Pereira et al., (2013)[81] Melody et al., (2020)[82] Pedersen et al., (2017)[84]	Inadequately characterised
Small for gestational age	Pun et al., (2021)[212] Nyadanu et al., (2022)[65] Health Effects Institute (2022)[211]	Emerging
Respiratory		
Respiratory disease mortality	Chen et al., (2021)[18] Liu et al., (2019)[165] Sanyal et al., (2018)[181] Achilleos et al., (2017)[182] Fajersztajn et al., (2017)[186] Ren et al., (2017)[213] Atkinson et al., (2015)[183] Schraufnagel et al., (2019)[6] Bu et al., (2021)[185] Ko et al., (2022)[21] Thurston et al., (2017)[189]	Well-established
Respiratory disease morbidity	Wei et al., (2019)[171] Ko et al., (2022)[21]	Well-established
Lung cancer	IARC (2016)[5] Schraufnagel et al., (2019)[6] Bu et al., (2021)[185] Ko et al., (2022)[21] Babatola et al., (2018)[214] Chen et al., (2021)[18] Manisalidis et al., (2020)[188]	Well-established
Asthma	Schraufnagel et al., (2019)[6] Ko et al., (2022)[21] Manisalidis et al., (2020)[188] Bowatte et al., (2017)[62] Thurston et al., (2017)[189]	Well-established

Asthma (childhood)	Khreis et al., (2017)[97] Sbihi et al., (2016)[89] Wang et al., (2020)[88] Wright et al., (2021)[90] Thurston et al., (2017)[189] Health Effects Institute (2022)[211]	Well-established
COPD	Schraufnagel et al., (2019)[6] Bu et al., (2021)[185] Ko et al., (2022)[21] Manisalidis et al., (2020)[188] Thurston et al., (2017)[189]	Well-established
Respiratory tract infections	Bu et al., (2021)[185] Health Effects Institute (2022)[211] Ko et al., (2022)[21]	Well-established
Upper and lower respiratory symptoms	Schraufnagel et al., (2019)[6]	Well-established
Airway inflammation	Schraufnagel et al., (2019)[6]	Well-established
Decreased lung function	Schraufnagel et al., (2019)[6] Schultz et al., (2016)[215] Milanzi et al., (2021)[216]	Emerging
Decreased lung growth	Voynow et al., (2015)[217] Zhebin et al., (2023)[218] Schultz et al., (2016)[215] Gauderman et al., (2007)[219] Urman et al., (2020)[220]	Emerging
Urological		
Chronic kidney disease	An et al., (2021)[221]	Inadequately characterised
Renal failure	Wei et al., (2019)[171]	Inadequately characterised
Bladder cancer	Schraufnagel et al., (2019)[6] IARC (2016)[5]	Inadequately characterised
Renal cancer	Schraufnagel et al., (2019)[6]	Inadequately characterised
Other		
Fluid and electrolyte disorders	Wei et al., (2019)[171]	Inadequately characterised
Epigenetic alterations	Thurston et al., (2017)[189]	Inadequately characterised

This list is non-exhaustive based on rapid review of the available literature.
***Well-established** – many studies with high level of evidence demonstrating strong associations between air pollution and health outcome.
Emerging – some studies with high levels of evidence demonstrating associations between air pollution and health outcome.
Inadequately characterised – few studies or studies with low levels of evidence demonstrating associations between air pollution and health outcome.

Our partners:

University of Tasmania

Menzies Institute for Medical Research, University of Tasmania

Curtin University

Monash University

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