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स्वास्थ्य एवं
परिवार कल्याण मंत्रालय
MINISTRY OF
HEALTH AND
FAMILY WELFARE

सत्यमेव जयते

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Investment case study for air pollution reduction in Amritsar and Gurugram, India

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List of abbreviations

2DRT	two-dimensional radiotherapy
3DRT	three-dimensional radiotherapy
AAP	ambient air pollution
ALRI	acute lower respiratory tract infection
CABG	coronary artery bypass graft
CaDCQoL	National Cancer Database for Cost and Quality of Life
CAQM	Commission for Air Quality Management
CHC	Community Health Centre
CHSI	Cost of Health Services in India
CEMS	Continuous Emission Monitoring Systems
CNG	compressed natural gas
COPD	chronic obstructive pulmonary disease
CPCB	Central Pollution Control Board
DFU	diabetic foot ulcer
DH	District Hospital
ESRD	end-stage renal disease
GBD	Global Burden of Disease
GDP	Gross Domestic Product
GMDA	Gurugram Metropolitan Development Authority
HSPCB	Haryana State Pollution Control Board
IER	Integrated Exposure Response
IGRT	image-guided radiation therapy
IHD	ischemic heart disease
INR	Indian national rupee
LC	lung cancer (as per GBD definition – tracheal, bronchus and lung cancer)
MI	myocardial infarction
NAAQS	National Ambient Air Quality Standards
NAMP	National Ambient Air Quality Monitoring
NCD	non-communicable diseases
NCR	national capital region
NGT	National Green Tribunal
NPDR	nonproliferative diabetic retinopathy
NSCLC	non-small cell lung cancer
OOPE	out-of-pocket expenditure
PAF	population attributable fraction
PDR	proliferative diabetic retinopathy

PHC	Primary Health Centre
$PM_{2.5}$	particulate matter with diameter < 2.5μm
PNG	piped natural gas
PPCB	Punjab Pollution Control Board
PTCA	percutaneous transluminal coronary angioplasty
QALY	quality adjusted life years
ROI	return on investment
RR	risk ratio
SBRT	stereotactic body radiation therapy
SPCB	State Pollution Control Board
TTO	time trade-off
VSL	value of statistical life
WHO	World Health Organization
WTP	willingness to pay

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Executive summary

Air pollution accelerates climate change and damages all aspects of planetary health, including food systems and human health. Air pollution is linked to stroke, heart disease, respiratory diseases, lung cancer, adverse pregnancy outcomes and poor cognitive development. Preventable deaths and illness from diseases attributable to air pollution impose a significant economic burden on society. Ambient air pollution (AAP) is of particular concern in India, with pollution exceeding recommended levels.

This report summarizes the findings from a comprehensive assessment of the health and economic impacts of ambient air pollution in the Indian cities of Amritsar and Gurugram through ill-health, premature mortality, and reduced workplace productivity. The analysis includes the impact of air pollution exceeding the National Ambient Air Quality Standards (NAAQS) levels of 40µg/m^3 on the six following diseases: acute lower respiratory infections (ALRI), lung cancer, chronic obstructive pulmonary disease (COPD), type-2 diabetes mellitus, stroke, and ischemic heart disease (IHD). It is composed of an institutional and context analysis (ICA) as well as two economic modelling components – a health and economic burden analysis as well as a return-on-investment analysis, which estimates the costs and benefits of relevant interventions to combat air pollution and its negative impacts on health and the economy.

Making the case for air pollution interventions

Air quality management in Indian cities is largely dependent on the development of city-level air action plans, conducting source apportionment studies and identifying proposed interventions based on these studies. Evaluation of such interventions based on their cost of implementation and the health and economic gains they should generate are valuable to city administrators with limited resources. The main output of the report is an estimation of the expected health benefits from air pollution mitigation measures, and an economic valuation of these, in terms of averted future health spending and averted decreases in the quantity and productivity of human capital. We examine the implementation of nine interventions in total: three in the transport sector, two in the industrial sector, three for mitigating road dust, and one related to the agricultural sector. We model the lifetime benefits of sustained implementation of these interventions over a five-year period.

This investment case examines air pollution interventions independently, making a strong advocacy case for air pollution control and offering valuable insights for selecting effective interventions and scaling up efforts to address air pollution. To achieve sustainable improvements in these cities' air quality, it is important to shift from short-term fixes to long-term transitions, concentrating on comprehensive strategies that address the underlying causes of pollution.

Burdens

Excess air pollution beyond NAAQS-recommended levels is causing a significant health burden across the two cities.

Health burden of excess air pollution

Excess deaths and diseases

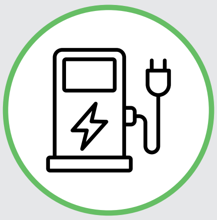
Excess air pollution beyond NAAQS-recommended levels is causing a significant health burden across the two cities. Amritsar experiences **150 excess deaths** and over **6,000 excess diseases** incidents, and Gurugram **340 deaths** and over **19,000 diseases** incidents every year due to exceeding NAAQS standards.

Economic burden of AAP

The annual burden of ambient air pollution was estimated at **695.4 million Indian rupees (INR) (US$8.4 million)** for Gurugram and **INR 241.2 million (US$2.9 million)** for Amritsar. The per-capita costs due to these diseases amount to INR 610 (US$7.4) per year for Gurugram and INR 164 (US$2.1) for Amritsar.

Benefits

By acting now, India can reduce the national health and economic burden from air pollution. The investment case findings demonstrate that implementing air pollution control interventions would reduce costs and save lives. Over the next ten years...



Electric power

Converting two-wheelers and three-wheelers to electric power can save 143 lives and prevent 7,015 incident cases of AAP-related disease in Amritsar, as well as save 50 lives and 4,434 disease incident cases in Gurugram. Additionally, the intervention can avert INR 384 million and INR 121 million in economic losses in Amritsar and Gurugram, respectively.

Clean fuel

Transitioning industries to cleaner fuel can save 785 lives and prevent more than 37,200 new cases in Amritsar, as well as 223 lives and 18,650 new cases in Gurugram. Moreover, the intervention has the potential to avert INR 2,125 million and INR 560 million in economic losses in Amritsar and Gurugram, respectively.

Emission control measures

Enforcing stricter industrial emission control measures, including the deployment of air pollution control devices and continuous emissions monitoring systems is estimated to avert 369 deaths and 18,000 incident cases in Amritsar, as well as avert 160 deaths and 13,749 incident cases in Gurugram. This intervention can prevent INR 996 million and INR 399 million in economic losses in Amritsar and Gurugram respectively.

Roadside greenbelts

Establishing roadside greenbelts can avert 875 deaths and 41,299 incident cases in Amritsar, as well as avert 477 deaths and 36,309 incident cases in Gurugram. The intervention can prevent INR 2.4 billion and INR 1.2 billion in economic losses in Amritsar and Gurugram respectively.

Recommendations

The results of this analysis and the following recommendations can be used by national stakeholders to enhance the rationale for strengthened action that can allow India to reduce the burden of air pollution in the country:

1. Invest in the intervention modeled under this investment case.
2. Raise awareness of the dangers of air pollution and the benefits of its reduction, including more sustainable transport.
3. Strengthen whole-of-government and whole-of-society approach to tackling air pollution.
4. Implement monitoring and enforcement measures to strengthen compliance.
5. Support the development and uptake of sustainable and environmentally friendly transport.

1

Introduction

1. Introduction

Air pollution is the largest single environmental health risk linked to illness and early death (before 70 years of age). Nearly 99 percent of the world's population lives in areas where fine particle levels exceed global air quality guidelines [1]. According to the World Health Organization, 6.7 million premature deaths globally are attributable to air pollution [2]. Yet, as of March 2024, only one percent of international development aid is allocated to clean air interventions [3].

Air pollution damages the environment, accelerates climate change, affects food systems and contributes to serious health outcomes including stroke, heart disease, respiratory diseases, lung cancer and adverse pregnancy outcomes [4]. In children specifically, air pollution has been linked to adverse effects on brain development and lung function, obesity, asthma and cancers [5], as well as decreased cognitive function and academic performance [6]. In addition, air pollution is linked to higher mortality rates, especially among the most vulnerable, including children, the elderly as well as individuals and households with low income [7] . Two major sources of air pollution can be distinguished: ambient air pollution (AAP), also referred to as outdoor air pollution, and household air pollution (HAP), referred to as indoor air pollution. Pollution is measured in particulate matter (PM), which describes any substance in the air which is not gas. Among these, fine particulate matter ($PM_{2.5}$) poses the greatest risk to health globally [8].

Ambient air pollution is caused by emissions from vehicles, industry, and other sources [2]. It is one of the most pronounced global environmental hazards posing a major threat to economic development [9]. Although there is no truly safe level of $PM_{2.5}$ exposure [8], the WHO's Air Quality Guidelines recently reduced the recommended maximum exposure level from an annual average of 10 $\mu g/m^3$ to an annual average of 5 $\mu g/m^3$ to minimize AAP-attributable diseases [2], [10]. While in the period from 1990 until 2019 some regions such as North America and Western Europe (19 to 11.6 $PM_{2.5}$) have managed to significantly decrease outdoor air pollution (from 10 to 5 $PM_{2.5}$ and 19 to 11.6 $PM_{2.5}$ $\mu g/m^3$, respectively), other regions, such as South America and the African region, have made little progress (from 30 to 27 $PM_{2.5}$ and 43 to 44 $PM_{2.5}$ $\mu g/m^3$, respectively) [11], [12].

Ambient air pollution is of particular concern in India. A study conducted in 2019 found that lost output from premature deaths and morbidity attributable to air pollution in India accounted for economic losses of US$28.8 billion (21.4–37.4) and US$8.0 billion (5.9–10.3), respectively, equivalent to 1.36 percent of India's gross domestic product (GDP) [13]. Among state specific estimates, Delhi had the highest per-capita economic loss due to air pollution, followed by Haryana [13].

Given the alarming burden of air pollution in the country, UNDP and partners, with funding from the European Union, initiated a four-year project to support the governments of India, Mongolia and Ethiopia in addressing pollution as a key environmental determinant of NCDs and as part of broader efforts to respond to environmental degradation and the changing climate. In addition to developing national air pollution investment cases, the project supports the development of global ambient air pollution investment case methods; a methodology to conduct legal environment assessments for health and pollution; three national legal environment assessment on pollution and health; as well as technical support to three project countries to create national multisectoral action plans on pollution and health, along with establishing multisectoral coordination mechanisms for health and pollution. Lastly, the project aims to share the methods and the results with a larger set of countries, advocating for their use for policy change.

The investment case quantifies the health, economic, environmental and social burden of AAP in India. The investment case pilots UNDP's novel ambient air pollution investment case methodology in the selected study cities of Gurugram and Amritsar and will serve as a protype for future work in other cities. Gurugram, situated in the state of Haryana, borders the capital city and is commonly regarded as part of the National Capital Region (NCR), sharing its airshed. Amritsar, located in Punjab, lies to the north of both Delhi and Haryana (**Figure 1**). The cities in the project were selected based on the outcomes of a UN mission in 2019. The cities considered in the study, Amritsar and Gurugram, are currently experiencing rapid economic and infrastructural development and subsequent increases in ambient air pollution.

Assessing the health and economic impact of air pollution is essential to inform and advocate for evidence-based policymaking and intervention strategies. The results of this analysis can be used by national stakeholders to strengthen the rationale for bold action that can begin to transition households and the economy towards cleaner and more efficient technologies. This work aligns with India's commitment to achieving the SDGs as well as the objectives of the Paris Agreement and alleviating the burden of NCDs [14]. By investing in energy infrastructure, India can accelerate its development and generate substantial health, economic, social, and environmental benefits.

Objectives

This investment case for air pollution mitigation is based on UNDP's methodology for AAP, which was piloted in Amritsar and Gurugram [15]. The economic analysis estimates the health and economic benefits from scaling up AAP interventions and the return on investment of implementing such measures. The objectives of the investment case are as follows:

To propose potential interventions aimed at mitigating ambient $PM_{2.5}$ in Amritsar and Gurugram through a structured methodology:

1) Scoping of city-level source apportionment studies and city level action plans
2) Interviewing stakeholders to pinpoint pertinent interventions.

Adapting existing ROI tools to:

1) Estimate the costs and impacts of identified interventions.
2) Quantify of the health and economic benefits attributable to ambient air pollution in "intervention" and "no intervention" scenarios.
3) Determine the return on investment for the identified interventions to facilitate the prioritization of future actions.

2

Air pollution in India: status and context

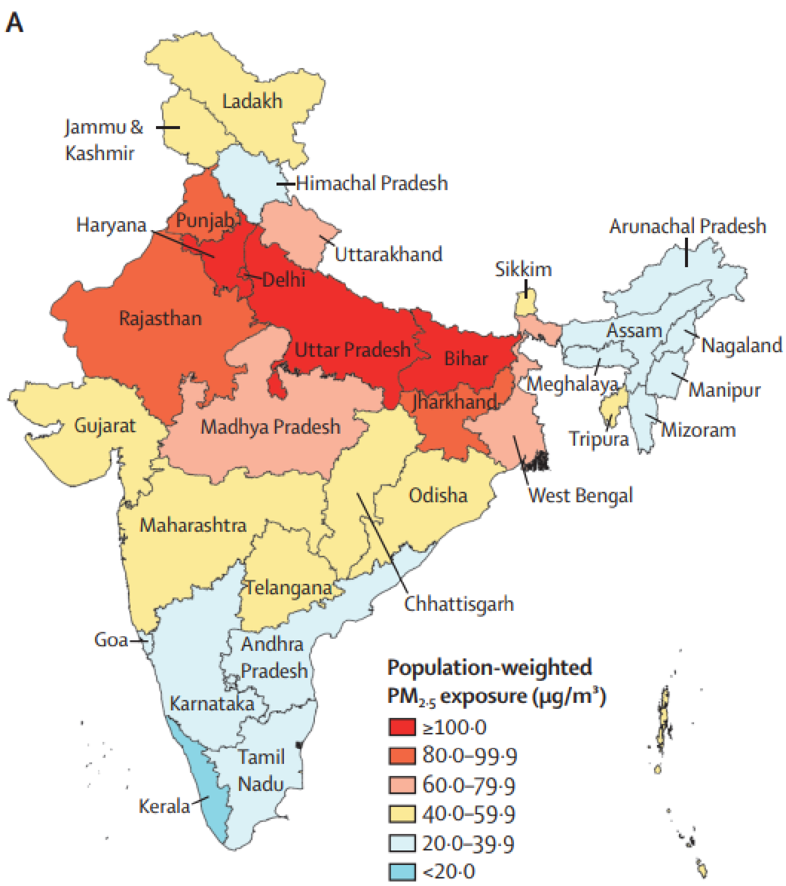
2. Air pollution in India: status and context

Ambient air pollution (AAP) in India exceeds recommended levels and is of major concern. Key contributors to AAP include coal-based power plants and other industries, construction activities, traffic-related exhaust, biomass and waste burning, agricultural practices, and residential heating. AAP is also exacerbated by industrialization, rapid urbanization, and an increase in vehicle ownership and automobile traffic [16].

Amritsar experiences annual ambient $PM_{2.5}$ exposures ranging between 80–99.9 µg/m^3 and Gurugram has exposures beyond 100 µg/m^3. This is 50 times above the WHO air quality guideline level of 5 µg/m^3 for annual averages [10].

Figure 1 below shows the population-weighted annual average $PM_{2.5}$ exposure levels for India in 2019 [1].

Figure 1: Population weighted annual average $PM_{2.5}$ exposure levels in India [1]



Box 1: Gender and air pollution in India

Cultural, socio-economic and physiological factors mean that women and girls face unique risks from air pollution and its negative impacts. Women tend to have a higher accumulation of inhaled particles in their lungs [17], and they are disproportionately exposed to more pollutant emissions from their environment, with additional indoor air pollution from household toxins, than men [18]. In India, women and girls are significantly impacted by the dual exposure from outdoor and indoor air pollution, particularly those living in low-income rural areas where the use of biofuels such as wood and crops for cooking is common, and cooking hours for women are long [19]. Household air pollution from such cooking fuels places rural Indian women at a much higher risk of experiencing cognitive impairment [20] and chronic obstructive pulmonary disease in the long term [19] compared to other household members. Due to cost, women in India, particularly those with low income, are more likely to walk than men and use the informal transport system such as rickshaws, further increasing their exposure to air pollution. Walking is associated with a 40 percent higher exposure to $PM_{2.5}$ and travelling in a rickshaw with a 30 percent higher exposure [21].

Box 2: The impact of air pollution on child and maternal health in India

Air pollution poses a significant threat to pregnant women and their children. Exposure to air pollution increases the risk of preterm births, low birth weight, fetal development problems and adverse neonatal outcomes [22], [23]. Pregnant women exposed to air pollution also face an increased risk of developing pregnancy-induced hypertensive disorders, postpartum depression, pregnancy loss, miscarriage and stillbirth [24]. Moreover, the effects of exposure to air pollution during pregnancy continue to affect the health of the infant later in life, increasing the likelihood of developing high blood pressure, type 2 diabetes and cardiovascular disease in adulthood [22]. India has the highest rate of stillbirths caused by air pollution, with 217,000 stillbirths occurring annually (out of 25 million live births) [25]. Particularly, oxidative stress in pregnant women and low birth weights are commonly observed in Indian industrial and traffic pollution areas, while these measures are lower in cleaner ambient areas in the country [26].

2.1 National legislation, strategy, and coordination

Air pollution is governed by several key legal frameworks in India, including the Air (Prevention and Control of Pollution) Act, the Environment (Protection) Act, the National Green Tribunal Act, and the Commission for Air Quality Management in National Capital Region and Adjoining Areas Act. These laws empower governmental bodies to regulate air quality, monitor emissions, and suspend activities harmful to health and the environment.

In 1981, India passed the Air Act, which empowers the Central Pollution Control Board (CPCB) and State Pollution Control Boards (SPCBs). CPCB started the National Ambient Air Quality Monitoring Programme (NAMP) Network to assess the air quality across the country, now covering around 398 cities with a total of 931 stations [27]. The coverage of the network varies geographically, with higher representation in urban areas but more sparse monitoring in rural areas. Guided by the directives from the CPCB, SPCBs and urban local bodies are mandated to monitor compliance with standards and to act in cases of violation, with their jurisdictional control restricted to city or state boundaries. For various reasons, the Act has, over time, fallen short in ensuring enforcement and implementation. In 1986, India enacted the Environment (Protection) Act to address pollution across multiple domains, including air, water, land and the relationships among these elements. Acting as an "umbrella" legislation, it empowers the central government to coordinate activities of various authorities created under previous environmental laws, such as the Air Act and Water Act [28].

In 2010, the National Green Tribunal Act established the National Green Tribunal (NGT) as a specialized body for handling environmental disputes efficiently. The Tribunal is empowered to address cases related to environmental protection, forest conservation, and natural resources management. With jurisdiction over key statutes including the Air Act and the Environmental (Protection) Act, the NGT plays a crucial role in addressing air pollution and related environmental issues across India [29].

In 2021, the Commission for Air Quality Management in National Capital Region and Adjoining Areas Act was introduced to address air pollution in the National Capital Region (NCR) and surrounding states. The Act established the Commission for Air Quality Management (CAQM), which monitors and manages air quality in the NCR and coordinates efforts across different states and agencies. CAQM has the authority to set policies, enforce pollution control measures, and take stringent actions, include issuing fines or imprisonment. Appeals against its decisions are heard by the NGT, ensuring an integrated judicial oversight mechanism. CAQM holds overriding authority in case conflicts with other bodies, including the state government and CPCB [30].

In addition to legal frameworks, India launched the National Clean Air Programme (NACP) in 2019, a nation-wide programme with targets to reduce particulate matter (PM) pollution levels by 20-30 percent by 2024. This target was later extended to a 40 percent reduction by 2026. The NCAP covers 131 non-attainment cities, which are areas that fail to meet national air quality standards [31]. The programme primarily focuses on implementing the mitigation measures, expanding air quality monitoring networks, and enhancing public awareness. Unfortunately, the 2024 progress report found that many projects including the expansion of monitoring stations and the set-up of air pollution forecasting systems have been delayed due to administrative and logistical barriers [32].

India's commitment to tackling air pollution is driven by its pledge to reduce emissions intensity by 45 percent by 2030 and achieve net-zero by 2070, as outlined at COP26. India aims to source 50 percent of its electricity from non-fossil fuel by 2030 and increase forest cover to absorb more CO_2. However, the anticipated rise in coal consumption and India's decision not to join global methane reduction agreements pose significant challenges to achieving these goals and reducing the burden of air pollution [33].

2.2 Financing

India has allocated increasing funds to tackle air pollution in recent years. In 2020, the Government announced funds of US$1.7 billion dedicated to tackling air pollution over the next 5 years, specifically for the 42 cities with a population of more than one million if they meet targets to reduce air pollution by 15 percent each year [34]. The National Clean Air Programme releases additional funds including for "Non-Attainment Cities" which are failing to meet air pollution standards. According to analysis, funds released as part of the National Clean Air Programme are primarily being used to address road dust (64 percent), followed by biomass burning (14.5 percent) and vehicles (12.6 percent). Just 6 percent of funds are used for capacity building and less than 1 percent (0.7 percent) on public outreach, which has raised concerns about the level of importance associated with enhancing skills and resources for stronger air pollution regulations and engaging and informing the public [32].

Analysis of funding and air quality initiatives across the cities also shows a severe underutilization of funds, particularly among non-attainment cities. Of the total allocation to 82 non-attainment cities analysed, just 40 percent was utilised as of November 2023, while among the 49 'million plus' cities, 62 percent of funding allocations were utilised [32].

2.3 Challenges

Addressing the growing burden of air pollution in India requires sustained focus and collaboration across all levels of government. While India has implemented a variety of policies and programmes such as its National Clean Air Program in recent years, significant challenges remain, and air pollution continues to pose a major risk to the wellbeing of both the population and economy of India.

India's dependency on coal to meet its energy needs remains a major hurdle for addressing air pollution. Coal is the largest source of energy production in the country and accounts for 49 percent of India's energy mix according to the Ministry of Power [35]. Transitioning India's power mix towards renewable sources of energy is a vital step towards tackling the growing burden of air pollution in the country. The Prime Minister has announced ambitious targets, including installing 500 gigawatts of renewable energy capacity by 2030 [36]. Transitioning energy to renewable sources will be increasingly important, as energy demand is expected to grow significantly as temperatures increase. Major and prolonged heat waves in India over the last few years have increased energy consumption by approximately 11 percent and with temperatures predicted to rise by a further 1.8 degrees Celsius by 2050, this figure will increase dramatically [37].

As a result of increased industrialization, economic opportunities, and development, India's urban areas are growing rapidly, leading to substantial increases in transport-related air pollution. According to the World Bank, India's population has doubled since 1960, and 36 percent of Indians now live in urban areas. With an urbanization rate of 1.3 percent annually, India's urban centers are expected to continue to grow exponentially [38], [39]. These increasingly large urban populations have and continue to put pressure on the transportation network. While the government has invested heavily in expanding transportation networks and railways, the transport system has struggled to keep up with this growth. Current road infrastructure is not suitable for the growing number of vehicles and insufficient public transportation capacity results in major congestion and further pollution [40]. The Government of India has recently been pursuing the electrification of transportation as part of efforts to reduce transport-related emissions [41]. India is the world's 4th largest producer of electric vehicles (EV) and has set a target of 30 percent of all vehicles in India being electric by 2030, the equivalent of 100 million green vehicles [41]. However, the cost of EV vehicles remains an issue for accessibility for the wider population.

The lack of robust enforcement mechanisms also presents a challenge to tackling the air pollution burden. While emission standards exist, there are limited measures to penalize those who exceed them. Enforcement is particularly lacking within the energy production industries, and clean coal and low carbon policies are regularly not followed [42]. Whilst the Ministry of Environment, Forest and Climate Change issued strict emissions standards for thermal power plants in 2015, reports suggest low compliance and emissions continuing to reach record highs [43], [44], [45]. According to estimates, weak enforcement could result in up to 59,000 excess air pollution related deaths [42]. Insufficient staffing and expansion of mandates of State Pollution Control Boards have been cited as contributing factors to enforcement challenges [46].

2.4 The need for an investment case

Air quality management in Indian cities has largely depended on the development of city-level air action plans, conducting source apportionment studies and proposals for air pollution control interventions based on the studies. Evaluation of such interventions based on their cost of implementation and health gains will help inform decision making for city administrators with limited resources.

As cities and states have overlapping strategies within the National Clean Air Programme (NCAP), at different stages of implementation, it is imperative to align actions with source apportionment studies and evidence-based resource allocation. An investment case for ambient air pollution abatement provides a structured argument for funding and support, outlining the urgency in addressing environmental and public health concerns. It lays forth specific goals, such as lowering emissions and raising air quality, decreasing incidence of disease and in turn reducing APP-attributable healthcare costs and preventing productivity losses. The advantages include improved public health and wellbeing, improved economic growth, and environmental sustainability. The investment case justifies the needs-based allocation of limited resources for efficient air pollution control and acts as a strategic road map, bringing stakeholders together.[1]

1 As part of the same project, this investment case is complemented by a legal environment assessment and multi-sectoral action plan to put the findings and recommendations of the legal and policy assessments into action.


Photo: © UNDP

3

Methodology

3. Methodology

This study assesses the health and economic burden of air pollution and models the costs and benefits of implementing selected air pollution interventions in the cities of Amritsar and Gurugram.

3.1 Estimating the health and economic burden of AAP

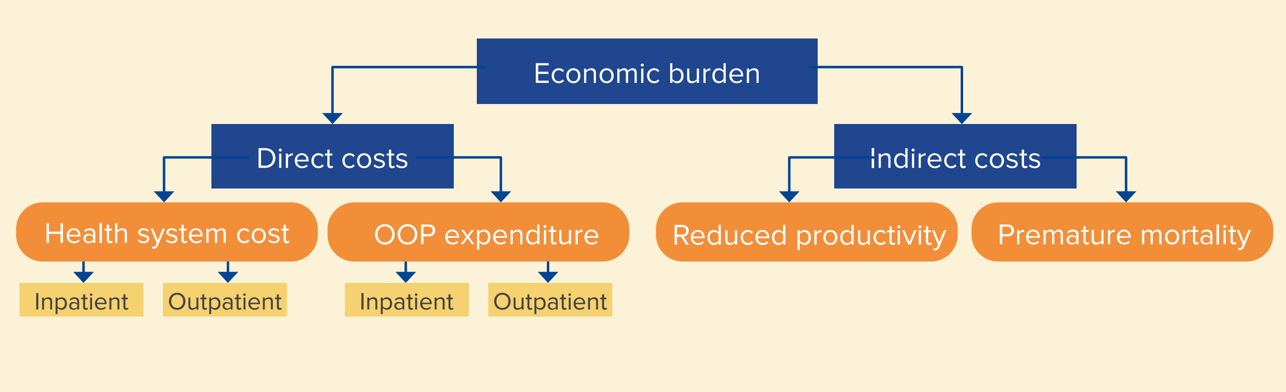
This study adapted the *Cost of Illness (COI)* model developed by UNDP, RTI International, and Centre for Chronic Disease Control to estimate the health and economic burden of excess AAP in the Indian cities of Amritsar and Gurugram.

Briefly, the following aspects were assessed in the analysis:

1. Health burden analysis
    - Exposure assessment. The level of exposure to air pollution was assessed using $PM_{2.5}$ concentration data provided by the air pollution monitoring network within the two cities. Excess pollution levels were assessed as compared to two hypothetical lower levels of pollution: 40μg/m^3 (NAAQS guideline) [47] and 5 μg/m^3 (WHO guideline) [48].
    - Outcome assessment: Cause-attributable mortality data was acquired from medical certification of cause of death (MCCD) reports, and supplemented with mortality and incidence data modeled from GBD 2019 (using Integrated Exposure Response Mode).
2. Estimating AAP-attributable excess disease burden. Excess mortality and morbidity due to increased levels of pollution (relative to guidelines) related to air pollution was assessed for six diseases: ALRI, COPD, IHD, lung cancer, stroke and diabetes mellitus type 2.

3. Estimating AAP-attributable economic burden. The economic burden related to air pollution-attributed illnesses was assessed using two distinct components: direct costs and indirect costs. Direct costs encompassed the health system cost and Out-of-Pocket Expenditure (OOPE), while indirect costs quantify premature mortality and workplace productivity losses. Productivity losses include excess absenteeism (i.e., sick days missed at work due to an AAP-related illness) and excess presenteeism (i.e., lower on-the-job productivity while experiencing an AAP-related illness) (**Figure 2**).

Figure 2: Cost components of the economic burden analysis



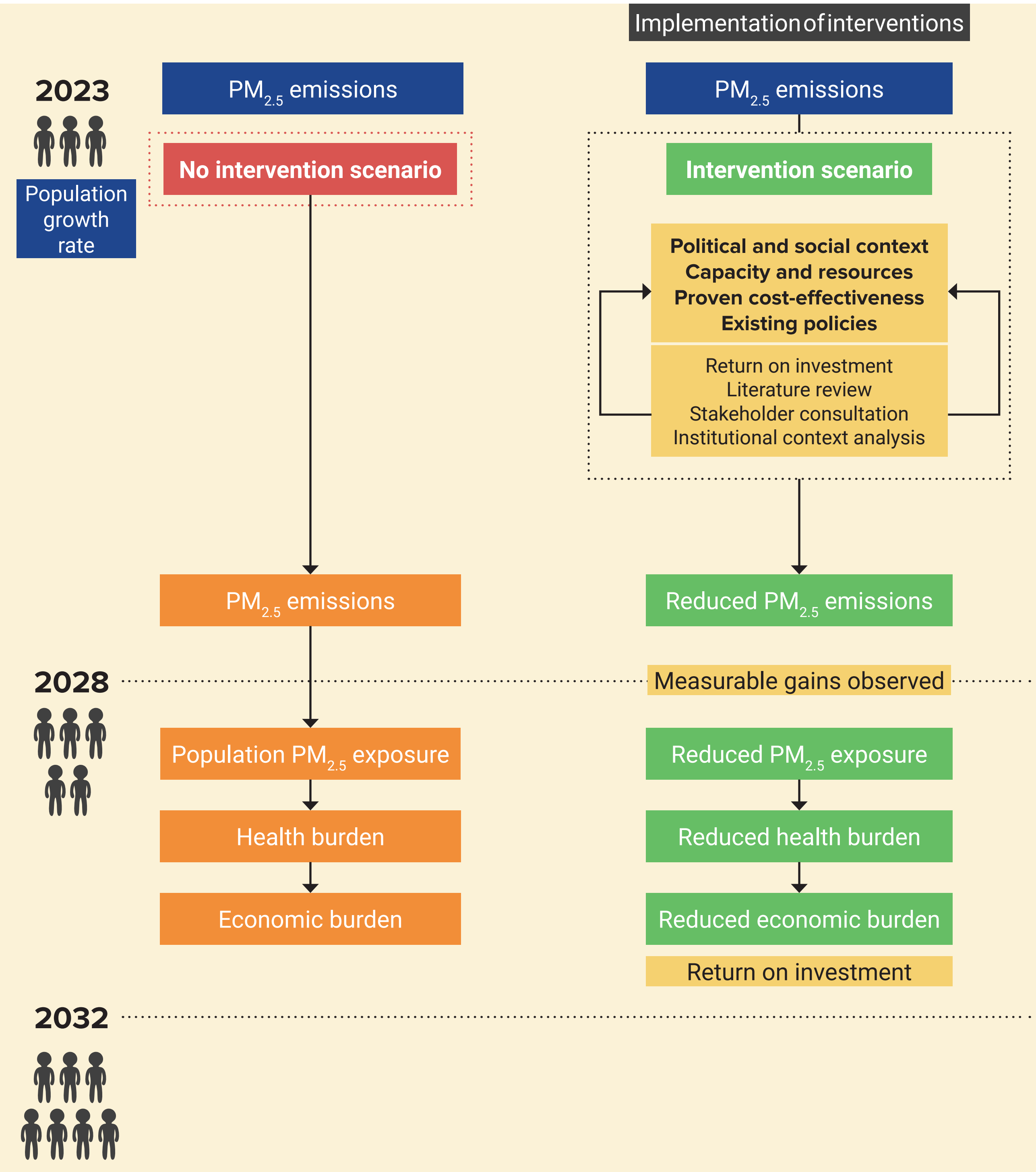
The different components and data sources used in calculating the ambient air pollution-attributable health and economic burden are described in the **Methodology annex**. More details and input data are available as Supplementary Material upon request.

Photo: © World Bank

3.2 Investment case framework

The comprehensive strategy depicted in Figure 3 forms the basis for developing an investment case for reducing air pollution. We examined two different scenarios over a period of 10 years.

Figure 3: Overall Conceptual Framework for the Investment Case



The first scenario, termed "**Business as Usual – BAU**", depicts the status quo and models events based on no additional interventions. This scenario accounts for population growth, economic growth rates within sectors and the implementation of ongoing plans.

The second scenario ("**Intervention**") models immediate implementation of targeted, cost effective measures starting in 2023. We hypothesise that the proposed interventions will lead to measurable reductions in air pollution over time with optimum effectiveness after five years, i.e. by 2028. Long-term benefits, such as more pronounced health and economic results, are anticipated from this focused approach after 2028. The analytical focus of the study is the quantitative valuation of health improvements, which allows for the estimation of the ROI of addressing ambient air pollution.

Selection of air pollution mitigation interventions for implementation should broadly rely on four components highlighted as yellow diamonds in **Figure 3**:

1. Proven cost-effectiveness of interventions
2. Political and social context in which the interventions are intended to be implemented
3. Human resources and financial capacity of the relevant stakeholders
4. Scaling up existing policies, particularly linked to National Clean Air Programme

Our study uses all these criteria to assess the potential impact and feasibility of interventions, which serves as a guide to a suggested prioritisation of interventions (see recommendations). We adopted several methodologies such as literature review, ROI analysis, stakeholder consultations and institutional context analysis to understand the components mentioned above and provide evidence to support the potential implementation of the proposed interventions. An overview of the investment case approach is provided in **Figure 4**.

Figure 4: Stepwise approach to conduct the investment case for air pollution

The next section details the steps of identifying potential interventions and selecting relevant ones using source apportionment studies and stakeholder consultations. Our research applied UNDP's Global Methodology[2] to craft an Investment Case tailored to address Ambient Air Pollution in the Indian context.

Details on the identification of and assumptions for interventions, as well as estimating costs and impacts of interventions are available in the Methodology annex. Modeled interventions are shown in **Figure 5**.

Figure 5: List of selected interventions in the study

Transport
Buses on electricity
2W and 3W on electricity
Modal shift of private vehicles to electric buses

Industries
Shift of industries to cleaner fuel
Enforcement of APCD and stricter control of emission

Road dust
Mechanized cleaning of roads
Pavement of arterial roads
Road greenbelt development

Agriculture
Integrated agriculture residue management

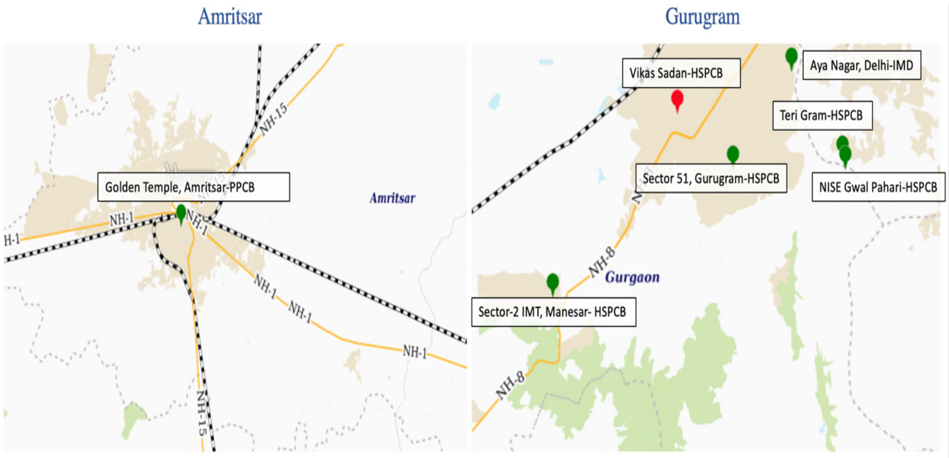
2 To be published

3.3 Disease burden modelling

Exposure assessment

We estimated the average annual $PM_{2.5}$ exposure in the cities using ground monitoring data for the monitoring stations managed by Punjab Pollution Control Board (PPCB) and Haryana State Pollution Control Board (HSPCB) as depicted in **Figure 6**. The city of Amritsar has one monitoring station which is located at the Golden Temple. Gurugram has two monitors in the heart of the city (Vikas Sadan and Sector 51) and two monitors situated at the outskirts (NISE Gwal Pahari and TERI Gram). We considered the exposure levels from the monitors which are located within the city.

Figure 6: Continuous air pollution monitoring locations in Amritsar and Gurugram [20]



We downloaded the freely available daily average data for the period of 1 January 2022 to 31 December 2022 from the CPCB website [49] for relevant monitors. The data at Vikas Sadan had missing values for all days of July, August and September and some days of June and October. Therefore, we computed the average exposure at Sector-51 station across the year to arrive at the final annual exposure. Since the study focuses on annual ambient exposure levels, it is reasonable to assume that the ground monitoring data in the cities are representative of the population exposures of ambient air pollution levels in the long-term.

Exposure in Scenario 1 (business-as-usual)

In the absence of implementation of selected additional interventions, we assume the PM levels will remain the same as in 2022.

Annual average ambient $PM_{2.5}$ concentration for Gurugram: 100 μg/m^3
Annual average ambient $PM_{2.5}$ concentration for Amritsar: 51 μg/m^3

Exposure in Scenario 2 (intervention)

The exposure reduction due to each intervention is calculated using the effectiveness estimates in Table A3.

Reduction in $PM_{2.5}$ levels in city *i* due to intervention *n* was calculated as follows:

$$PM_{red} = PM_{2.5}\ conc - \frac{Eff_n}{100} \times PM_{2.5}\ conc$$

Where,
PM_{red} – Reduction in $PM_{2.5}$ levels in city i due to intervention n
n – Serial number for Intervention from Table 1 (n ranges from 1 to 9)
Eff_n – Effectiveness for intervention n from Table 1
$PM_{2.5}$ conc – Annual average ambient $PM_{2.5}$ levels in 2022

Cause- and age-specific mortality and morbidity

We downloaded cause-specific mortality and incidence data for the following age groups for India from the GBD website [50]:

- ≥25 years for lung cancer, COPD, IHD, type 2 diabetes mellitus, and stroke in 5-years age intervals
- All ages for ALRI in 5-year age intervals (0-5 years to 95 and above)

City-specific estimates were derived by calculating the proportion of deaths based on relative population sizes of the cities in comparison to the country based on projected 2021 population levels [51]. For extrapolating the data, we used the urban annual growth rate from the World Bank as both cities are likely to grow at a greater rate than the national average [52]. We assumed that the age distribution remains unchanged from 2019 GBD estimates.

Exposure-response model

After carefully considering the limitations of both Integrated Exposure Response Mode (IER) and GEMM (Global Exposure Mortality Model) exposure-response (E-R) model, this study used the IER from GBD 2019 [53], [54]. In the GBD-IER, models for stroke and IHD are stratified by age, allowing for use of risk estimates for the most relevant age group (after considering the age distribution of the population and disease aetiology). In the case of COPD, lung cancer, ALRI and diabetes, only a single exposure-response curve for all age groups was available. The IER provides the specific risk of disease mortality or incidence associated with each concentration of $PM_{2.5}$ intervention. Two risk ratios are derived for each:

RR1 indicates the cause-specific relative risk (RR) of the outcome for each city under a BAU scenario. This entails the risk of disease at 2022 levels of $PM_{2.5}$ i.e. 100 $\mu g/m^3$ and 51 $\mu g/m^3$ for Gurugram and Amritsar, respectively. This remains the same for comparing interventions.

RR2 represents the cause-specific relative risk of the outcome for each city under the intervention scenario. This ratio is specific to each intervention and is influenced by the intervention's effectiveness in reducing the concentration of pollutants. For instance, if an intervention has an effectiveness of two percent, it will lower Gurugram's exposure from 100 $\mu g/m^3$ to 98 $\mu g/m^3$.

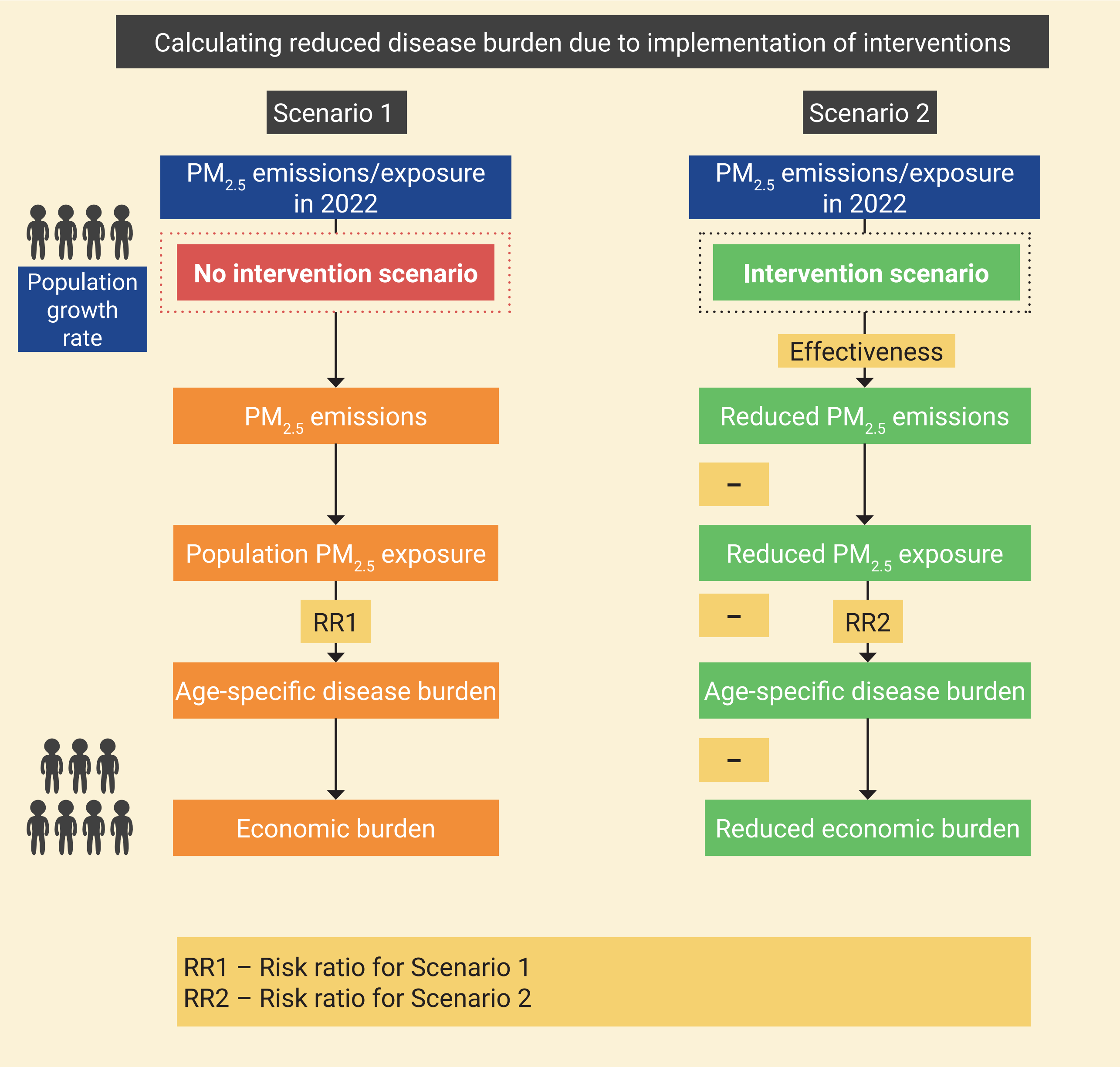
Given that the risk curves exclusively feature whole numbers, we rounded up all interventions in Gurugram to a minimum of one percent and up to two percent in Amritsar. It was not feasible to detect risk differences less than 1 $\mu g/m^3$.

Estimating attributable excess diseases burden

The overall health burden analysis calculates the city-level excess mortality and incidence of diseases associated with $PM_{2.5}$ exposure in the intervention to the BAU scenario (**Figure 7**). All the estimates in the study are calculated based on Amritsar and Gurugram city (urban), which is geographically different from their "district".[3] Given the concentration of monitoring stations and the execution of pollution control measures in the cities, they serve as focal points for assessing the efficacy of interventions and understanding the dynamics of air quality management.

3 Districts is a larger administrative unit which often includes a mix of urban, semi-urban, and rural areas, each with its unique socio-economic dynamics, infrastructure, and demographic composition.

Figure 7: Conceptual Framework of health burden analysis



Note: Figure 7 describes the overall approach used in the study to understand disease and economic burden in intervention and business as usual scenarios. In Scenario 1, we assume the exposures to remain same as in 2022. In Scenario 2, the exposure reducing for each intervention based on its effectiveness and reduced the risk of developing disease (RR1 > RR2).

The total number of baseline deaths and incidences was calculated for each disease within five-year age categories using baseline deaths from GBD, population projections and proportion of population in the cities (see Methodology annex). We then calculated city level population attributable fraction (PAF) for the six different diseases for 2028 to 2032 for BAU and each intervention The PAF depicts the proportion of mortality and incidence of an illness in the population that is attributable to exposure levels of $PM_{2.5}$ compared to counterfactual exposure level at which there is no risk. We computed the excess cause-specific mortality and incidence for Gurugram and Amritsar for the year 2028 by calculating the number of cause-specific baseline deaths and incident cases in the city that was attributable to ambient $PM_{2.5}$ exposure alone. Finally, we subtracted the disease burden (death or incidence) of the reference scenario from the intervention scenario to obtain the excess or averted deaths and incidences because of implementation of the interventions on disease burden.

3.4 Economic modelling

Development of Markov models

Following the health impact assessment, the study delved into the development of individual Markov models for each of the six diseases. The models were designed for specific diseases as a series of discrete time intervals or cycles. Each Markov model comprised of different health states, which were mutually exclusive and exhaustive, and simulated the natural history of the diseases. Patients were modeled to move (‘transition’) between disease states as their condition changed over time. These movements from one disease state to another (in the subsequent time period) were represented through transition probabilities. These probabilities were based on epidemiological data in the literature. Time spent in each disease state for a single model cycle (and transitions between states) was associated with cost and health outcome. Thereafter, costs and health outcomes were aggregated for a modeled cohort of patients over successive cycles to provide a summary of the cohort experience. We used a societal perspective that included health system costs, out-of-pocket expenditures, and indirect costs. A lifetime horizon and a discount rate of three percent was used to model the costs and consequences in different intervention scenarios.

The models were simulated for various ages, starting at 25 years, then 30 years, and continuing in 5-year intervals up to 95 years for diabetes, stroke, ischaemic heart disease, chronic obstructive pulmonary disease, and lung cancer. The model of acute lower respiratory infections was simulated from age 0 in 5-year intervals, up to 95 years. The models helped to ascertain lifetime QALYs per patient as well as direct and indirect costs per patient for the considered disease conditions.

Model specifications

Perspective

In the context of this investment case, we chose to adopt a societal perspective. This decision was grounded in the understanding that the economic benefits derived from proposed interventions, which avert health expenditures and productivity losses, have a broader impact on society, rather than benefiting a specific provider entity (e.g., government, donors, or the private sector).

Lag time to benefits

The "lag time to benefits" for air pollution control interventions refers to the time delay between the implementation of measures to reduce air pollution and the realization of the associated health and environmental benefits. We considered no lag time to realize the complete benefits from the reduction in $PM_{2.5}$ levels and considered the benefits for five years (2028–2032), in line with city-level policy cycles. We further acknowledge that there might be different lag time between reduction in emissions attributed to different interventions and their impact on health through reduced mortality and morbidity. However, due to limited evidence, we assumed no lag time to benefits for all the pollution control interventions.

Time horizon for economic modelling of diseases

We modeled the diseases for lifetime of the cohort, based on disease progression probabilities. Therefore, our investment case is structured to provide a comprehensive view in terms of lifetime health expenditure incurred on treatment and benefits associated with averted morbidities [55].

Discount factor

The discount factor is a crucial component when calculating the return on investment (ROI) for air pollution control interventions. It accounts for the time value of money, reflecting the principle that a sum of money received or spent in the future is worth less than the same amount received or spent today. The discount rate of 3 percent was applied to both costs and the benefits, in lines with the guidelines from the reference case for conducting economic evaluations in India [56].

Calculation and monetization of NET QALY gain

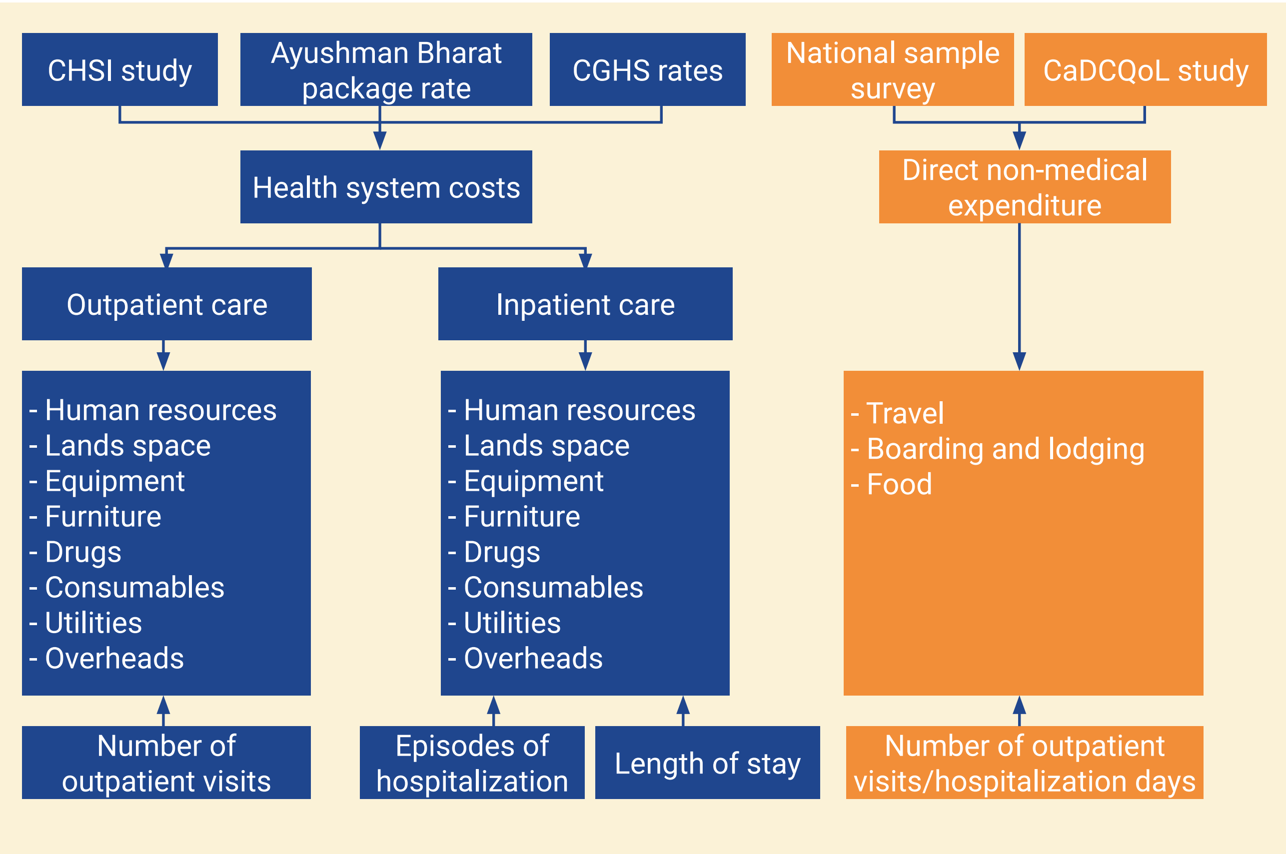
To calculate the gain in QALYs, an additional model was developed to estimate QALY per person with no disease. This model was also simulated for different age group starting from 0 years, 5 years, and so on till 95 years to estimate QALYs per person without any morbidity. The utility value of 0.848 was used for each person that did not develop a disease, as derived from the EQ-5D-5L population-based study in India [29]. The QALY gain per person was estimated as a difference of QALYs in intervention and business-as-usual scenario for each disease. This difference was further multiplied with the net reduction in incidence of diseases that can be attributed to air pollution mitigation interventions to determine the net QALY gains. The QALY gains were monetized by using the willingness-to-pay (WTP) equivalent to (GDP per capita) of India, in line with the reference case for conducting economic evaluations in India [56].

Determination of lifetime direct and indirect costs

The direct medical as well as non-medical lifetime treatment costs were estimated for patients with the selected diseases using standardized data sources from India. The standard treatment pathways as well as care seeking pattern were simulated using published data sources. There were two primary types of sources used to determine patient-level treatment costs (**Figure 8**).

First, the provider payment rates from insurance schemes as central government health services rates and *Pradhan Mantri Jan Arogya Yojana* were used [57]. Second, in cases where such rates were unavailable, the estimates for health system costs were calculated using the primary data of Cost of Health Services in India (CHSI) study [58].

Figure 8: Components of disease specific direct expenditure



The direct non-medical expenditure included expenditure on transportation, boarding/ lodging and food. The disease-specific estimates for these components were derived from the data collected as part of 71st/ 75th round of National Sample Survey [59]. Expenditure for lung cancer was derived from the National Cancer Database for Cost and Quality of Life (CaDCQoL) study, which involved data collection on out-of-pocket expenditure (OOPE) from 12,148 patients of cancer in India [60].

The calculation of indirect costs involved assessing the economic impact of premature mortality, using a human capital approach [61]. The computations were based on the discounted value of earnings foregone due to premature mortality associated with the burden of the selected diseases in business-as-usual scenario.

The estimation of indirect costs was conducted until 70 years of age, considering the typical productive life years of individual in India. We used the employment rate and wage rate for Indian population from the report of International Labour Organization [62]. The indirect costs were estimated as a product of reduction in life years due to disease, wage rate, employment rate, and number of disease-specific deaths attributable to air pollution [59].

Further, we also estimated indirect costs using the friction cost method and the value of a statistical life (VSL) approach, as part of a sensitivity analysis. In the friction cost approach, a friction period of three months was considered [63]. The indirect costs using this approach were estimated as a product of reduction in life years due to disease, wage rate, employment rate, friction period, and number of disease-specific deaths attributable to air pollution.

The VSL approach [64] assigns a monetary value to the reduction in the risk of premature death, reflecting individuals' willingness to pay for risk reduction, and thus also valuing the preservation of life itself. The VSL value was acquired from a study by Viscusi et al (2017) [65].

Estimation of total benefits attributable to interventions

The fourth step was to determine the total benefits attributable to the air pollution mitigation strategies. These benefits were calculated by summing the monetized QALY gains attributed to the interventions, the averted direct and indirect costs, and additional benefits of implementation the interventions, such as savings in fuel costs, scrap value of equipment etc.

Estimation of economic value of air pollution control interventions

The final step of the analysis was the measurement of the economic value of the air pollution control interventions. This was done based on the calculated net benefits and costs. The ROI for all interventions were computed to depict the relationship between the relative costs and benefits of the proposed interventions, expressed in monetary terms. An ROI greater than 1 implies that the pollution control strategy is economically advantageous.

4

Results and discussion

4. Results and discussion

4.1 Health and economic burden of air pollution

We first sought to assess the health and economic burden due to stroke, IHD, COPD, lung cancer, type 2 diabetes, and ALRI that is attributable to excess $PM_{2.5}$ exposure in Amritsar and Gurugram.

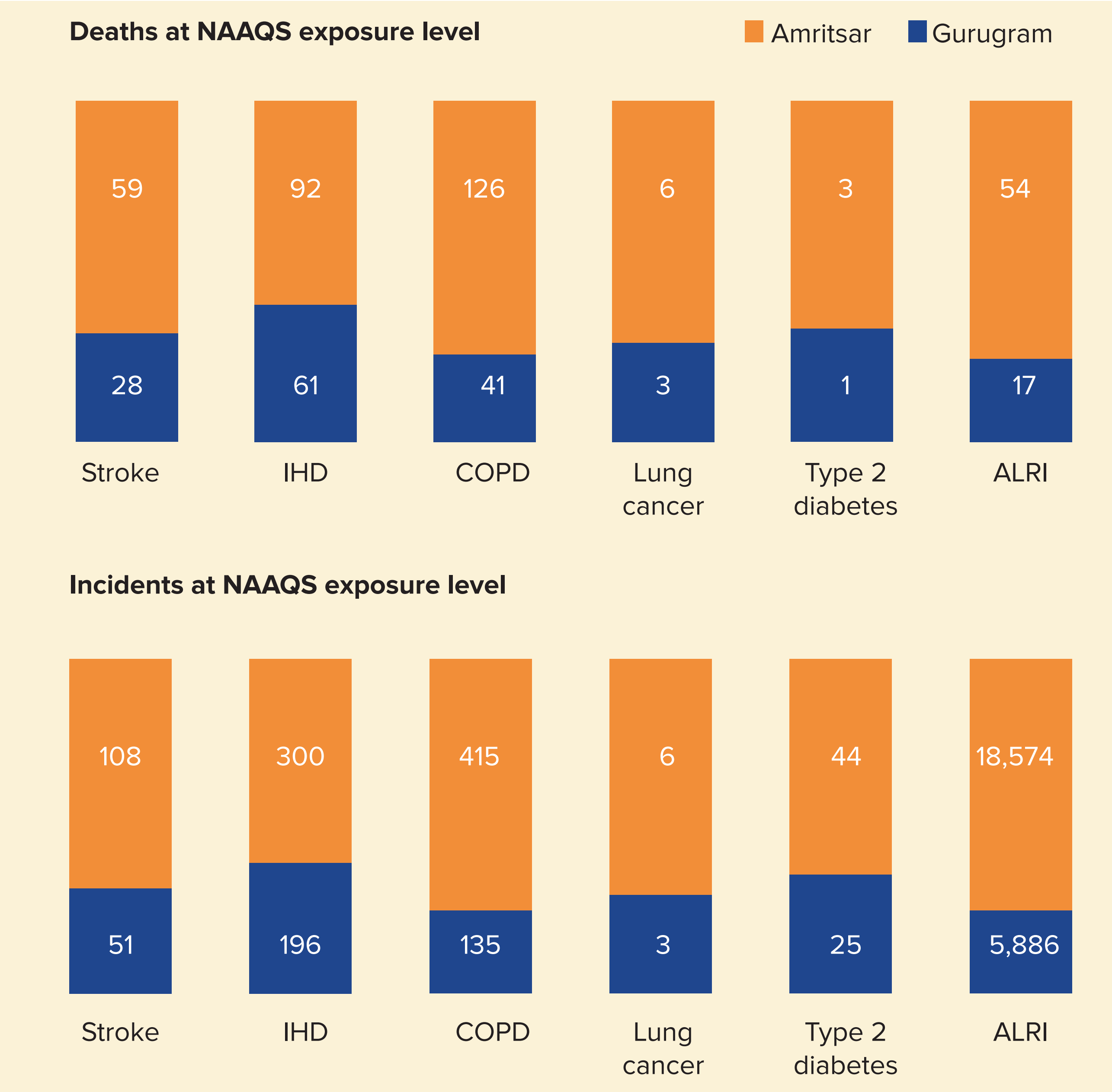
Table 1 provides the average number of deaths and incidences of selected diseases due to excess air pollution beyond NAAQS or WHO-recommended levels in Amritsar and Gurugram in 2021. For the city of Amritsar, if $PM_{2.5}$ exposure had adhered to the NAAQS guideline of 40µg/m3, an average of 150 deaths and 6,295 incident cases could have been prevented. Adhering to the WHO recommended level of 5µg/m^3 could have prevented an average of 1,075 deaths and 36,743 incident cases in Amritsar. In Gurugram, adherence to NAAQS guidelines could have prevented 340 deaths and 19,447 incident cases. Notably, although Amritsar has a larger population compared to Gurugram, the difference between current exposure levels and NAAQS guidelines is higher in Gurugram, resulting in a greater burden of diseases.

As the costs and benefits of interventions were based on NAAQS levels, the rest of this report will focus on excess mortality and morbidity using this measure. A breakdown of disease incidence and death by cause due to pollution exceeding NAAQS levels is provided in **Figure 9**.

Table 1: Mortality and morbidity due to excess air pollution in Amritsar and Gurugram

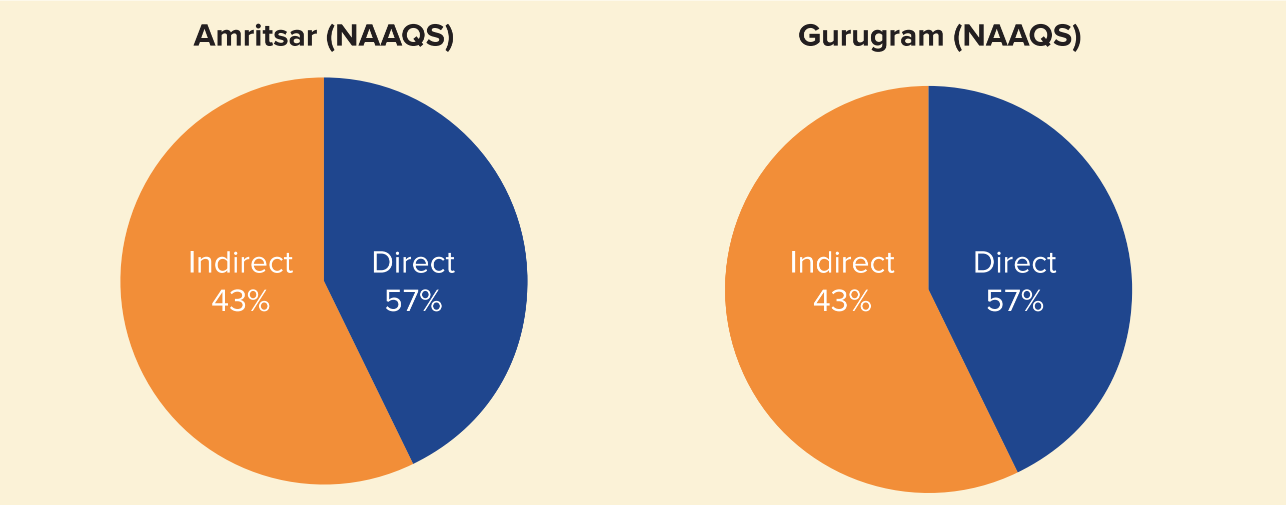
Measure	NAAQS level (40ug/m^3)		WHO level (5ug/m^3)	
	Amritsar	Gurugram	Amritsar	Gurugram
Total deaths	150	340	1,075	1,013
Total incidence	6,295	19,447	33,200	42,885

Figure 9: Cause-specific deaths and due to pollution exceeding NAAQS levels



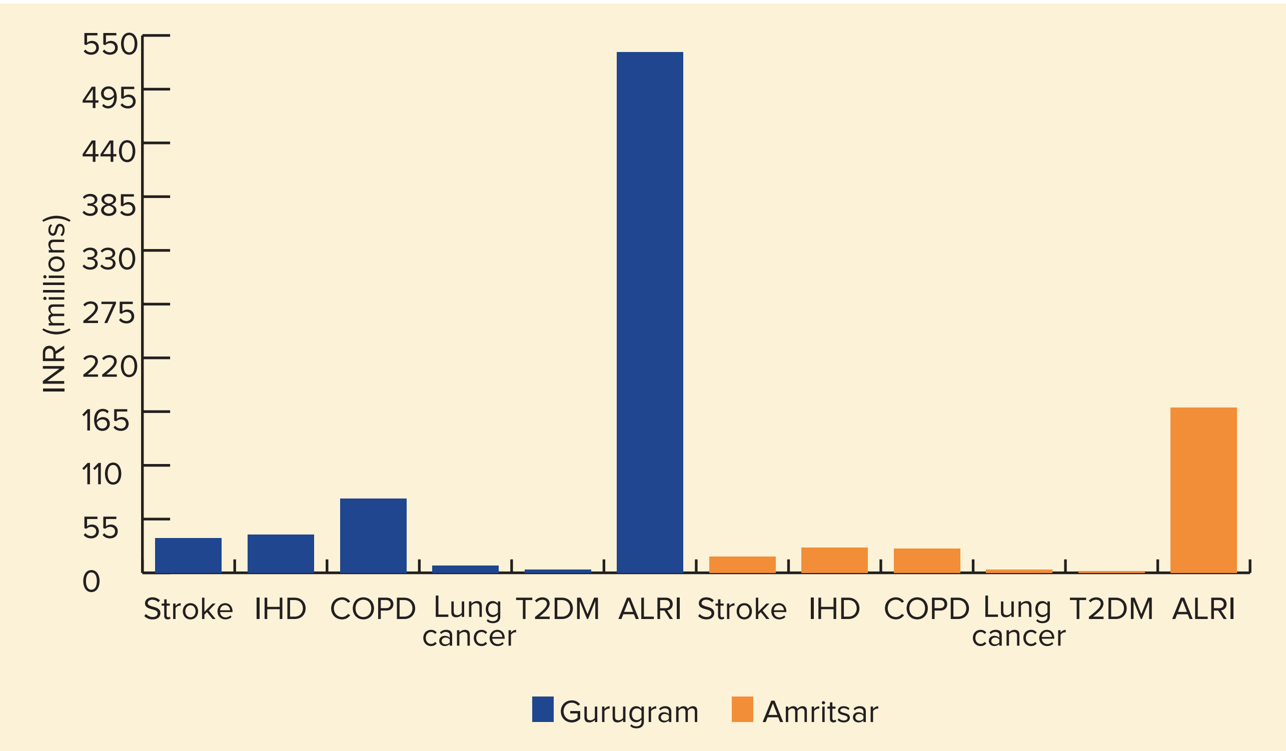
To emphasize the magnitude of the disease burden, we further calculate the economic burden that these cities could have averted if the air pollution levels were at NAAQS reference levels. The total burden of pollution-related NCDs was estimated at INR 695.4 million (US$8.4 million) for Gurugram which is higher than Amritsar (INR 241.2 million, US$2.9 million). Direct costs contribute similarly higher proportion in both the cities- Amritsar and Gurugram (57 percent) compared to indirect costs (43 percent) (**Figure 10**). The per capita cost of specified diseases was INR 610 (US$7.4) and INR 164 (US$2.1) for Gurugram and Amritsar, respectively.

Figure 10: Economic burden of air pollution in Amritsar and Gurugram



In terms of disease categories, ALRI (INR 533 million, US$6.4 million) contributes the highest economic burden for Gurugram, followed by COPD (INR 76.14 million, US$0.9 million), IHD (INR 39.26 million, US$0.5 million), stroke (INR 35.55 million, US$0.4 million), lung cancer (INR 7.61 million, US$92,000) and T2DM (INR 3.25 million, US$39,000). Similarly for Amritsar, ALRI (INR 169.23 million, US$2.1 million) contributes the highest economic burden, followed by IHD (INR 25.74 million, US$0.31 million), COPD (INR 24.67 million, US$0.3 million), stroke (INR 16.62 million, US$0.2 million), lung cancer (INR 3.16 million, US$38,000), and T2DM (INR 1.80 million, US$21,000) (**Figure 11**).

Figure 11: Economic burden of air pollution in Gurugram and Amritsar by disease



It is valuable to delve into the reasons why certain diseases exert a more substantial economic impact than others. Firstly, when comparing the number of incident cases and deaths attributable to ambient air pollution-related lung cancer with other diseases under consideration, it becomes evident that the former exhibits a considerably lower figure. Consequently, the economic impact directly associated with ambient air pollution-related lung cancer is correspondingly less. Furthermore, although the mortality rate stemming from ALRI may be relatively low, the sheer magnitude of incident cases is remarkably high. This prevalence contributes significantly to ALRI's larger share in the overall economic burden, despite its lower fatality rate. Likewise, in the case of COPD, the costs associated with medical care surpass those of other illnesses. This disparity arises due to an increased number of days necessitating inpatient care within the COPD care pathway. The prolonged and intensive nature of COPD management contributes to its relatively higher economic burden in comparison to other diseases. Exploring these factors sheds light on the varying economic impacts of different diseases, considering factors such as incidence rates, mortality rates, and the specific care requirements associated with each condition.

4.2 Cost of interventions

Our research initially identified appropriate interventions for the two cities through source apportionment and stakeholder consultation. To ensure relevance, we aligned these interventions with on-the-ground city-level action plans and excluded outdated interventions in the study areas. In total, we identified three interventions in the transport sector, two in the industrial sector, three for mitigating road dust, and one related to the agricultural sector. The effectiveness of these interventions was examined in the literature, particularly within the studied settings. In addition to selecting interventions and extracting their effectiveness data from the literature, we gathered primary data on the cost of implementation and maintenance of each intervention from relevant departments. The results detailing the cost of implementation for each intervention are given in the section below.

The final cost borne by the government and individuals for each intervention in the two cities is provided in **Table 2.**

Table 2: Estimated cost of interventions (in INR millions)

Intervention		Amritsar		Gurugram	
		Government	Individual/ Industry	Government	Individual/ Industry
Integrated residue management		232.3	235.9	171.78	157.7
Buses on electricity		134.9	0	253.3	0
2W and 3W on electricity	2W	105.4	- 691.3	234.6	- 1445
	3W	4.62	- 53	172.1	- 1719.5
Modal shift of private vehicles to buses	Cars	843.5	- 221.4	281.2	- 79.8
	2W	288	- 113.9	240	95
Shift of industries to cleaner fuel			248.6		- 44.6
Enforcement of APCD and stricter control of emission		46.3	104.9	81	198
Mechanized cleaning of roads		43.2	0	44.7	0
Pavement of arterial roads		149.5	0	202.5	0
Road greenbelt development		375.5	0	1036.6	0

Note: Positive values indicate expenses to be incurred for the implementation of the intervention and negative values indicate savings

Agriculture: The ex-situ component of this intervention costed INR 223.5 million in Amritsar and INR 166.5 million in Gurugram to the government. The primary costs included the capital cost of the machines and storage and transportation costs of the agricultural residues. Farmers gained a benefit by earning income for every acre of agricultural residue. The societal cost borne for the in-situ component was a combination of the farmers collectives costs of procurement of happy/super seeders and individual farmer rental and labour costs. The government costs here mainly comprised of subsidies.

Transport sector: The cost of conversion to e-buses was double in Gurugram compared to Amritsar as the conversion target was 50 percent in Gurugram compared to 25 percent in Amritsar. Amritsar is in the process of rolling out electric vehicle interventions from 2023, therefore a lower target is more feasible. Additionally, all buses currently in use in Gurugram were CNG-based, in comparison to the petrol driven fleet in Amritsar. This resulted in a higher scrap value due to the higher purchase price of the vehicle. The scrap value lowered the net cost of implementation considerably.

The government expenditure for the intervention to convert three-wheelers to electric was considerably higher in Gurugram as the subsidy cost for Gurugram was for conversion of 5,738 3Ws. The net government subsidy expenditure was INR 4.62 million in Amritsar for a fleet of 154 three-wheelers.

The cost of the modal shift of private cars to public buses was INR 843.5 million in Amritsar compared to INR 281.2 million in Gurugram. This was due to a greater number of private cars in Amritsar as compared to Gurugram (due to the absence of metro rail facilities in Amritsar).

Industries: The intervention to shift industries to cleaner fuel was cost-saving in Gurugram. Since all industries in Gurugram were running on liquid fuel, the cost of conversion primarily involved the cost for Industries to retrofit instead of procuring new gas fired equipment. The enforcement of CEMS was an expense for both the government and industry. While the government expenditure entailed costs of additional personnel recruitment, sensitization, and awareness costs as well as subsidies, the installation, operations, and maintenance expenses fell under industry cost heads.

Road and construction dust: The pavement of arterial roads costed the government INR 149.5 million in Amritsar and INR 202.5 million in Gurugram. The mechanized cleaning of roads costed nearly INR 45 million in both the cities. The intervention aimed at increasing roadside green belt is costlier in Gurugram as the arterial road length was greater, resulting in a larger area of 276 km to be covered.

4.3 Net QALY gains attributed to the interventions

We next assessed how these interventions might reduce population exposure to air pollution, thus lowering the risk of disease and death from AAP-related NCDs in the two cities. This analysis assumes sustained implementation over five years after reaching the target coverage. Implementation of interventions would save 2,674 lives in Amritsar and 1,127 lives in Gurugram over a five-year period (**Table 3**). In both cities, roadside greenbelt development and shifting industries to cleaner would save the most lives.

Table 3: Lives saved due to implementation of AAP interventions

Intervention	Amritsar	Gurugram
Integrated agriculture residue management	216	140
Buses on electricity	72	32
2W and 3W on electricity	143	50
Modal shift of private vehicles to buses	72	15
Shift of industries to cleaner fuel	785	223
Enforcement of APCD and stricter control of emission	369	160
Mechanized cleaning of roads	72	15
Pavement of side roads	72	15
Roadside greenbelt development	875	477
Total	**2,675**	**1,127**

The gain in Quality Adjusted Life Years (QALYs) was calculated to measure the impact of interventions on life expectancy and quality of life based on the reduced mortality and morbidity burden of the six diseases in the intervention scenario compared to the BAU scenario.

The implementation of the 'roadside greenbelt development' intervention resulted in the greatest number of QALYs gained (3,159 QALYs in Gurugram and 6,646 QALYs in Amritsar), followed by "shift of industries to cleaner fuel" (1,412 QALYs in Gurugram and 5,953 QALYs in Amritsar) (**Table 4**). The QALY gains were monetized using the willingness to pay method, with one QALY gained being valued as being equal to GDP per capita for 2022–2023 [66]. For both cities, the monetized QALY gain was highest for "roadside greenbelt development" (INR 1.3 billion in Amritsar and INR 622 million in Gurugram), followed by "shift of industries to cleaner fuel" (INR 1.2 billion for Amritsar and INR 278 million for Gurugram) (Table 4).

Table 4: Monetized value of QALY gain attributable to AAP interventions (in INR millions)

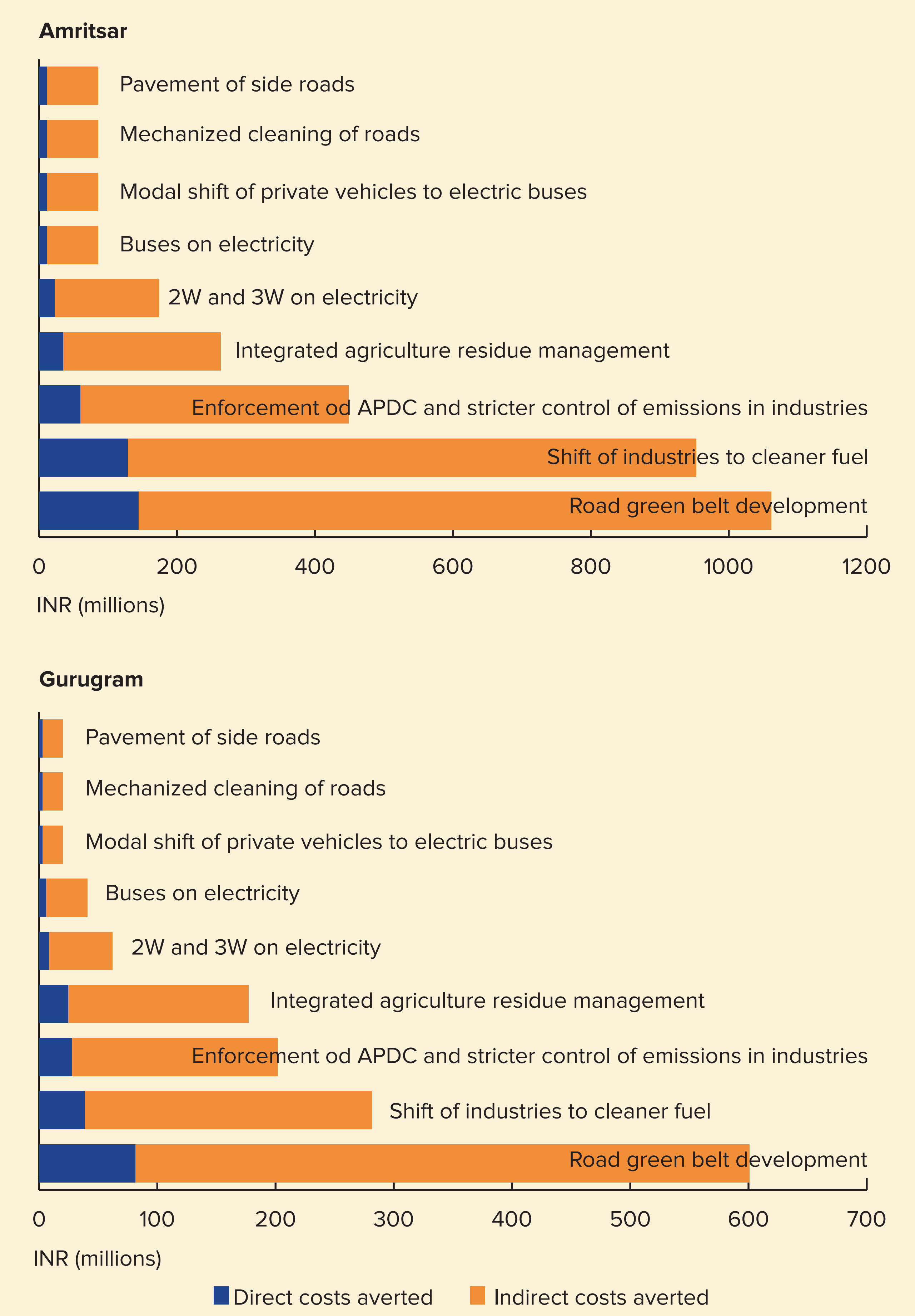
Intervention	Amritsar		Gurugram	
	QALY gain (years)	Monetized QALY gain (millions INR)	QALY gain (years)	Monetized QALY gain (millions INR)
Integrated agriculture residue management	1,625	320	872	172
Buses on electricity	528	104	197	39
2W and 3W on electricity	1,070	211	301	59
Modal shift of private vehicles to buses	528	104	97	19
Shift of industries to cleaner fuel	5,953	1,173	1,412	278
Enforcement of APCD and stricter control of emission	2,778	547	999	197
Mechanized cleaning of roads	528	104	97	19
Pavement of side roads	528	104	97	19
Roadside greenbelt development	6,646	1,309	3,159	622

4.4 Total direct and indirect costs averted

We next determined averted direct and indirect costs from implementing air pollution interventions. The most costs were averted for the following interventions: "roadside greenbelt development" (INR 1.06 billion in Amritsar and INR 600.88 million in Gurugram), "shift of industries to cleaner fuel" (INR 952.81 million in Amritsar and INR 281.54 million in Gurugram) and 'stricter control of emissions in industries' (INR 448.52 million in Amritsar and INR 202.10 million in Gurugram) (**Figure 12**).


Photo: © World Bank

Figure 12: Lifetime direct and indirect costs saved in Amritsar and Gurugram (in millions INR)



The direct costs saved due to the air pollution mitigation strategies ranged by intervention from INR 2.88 million to INR 81.42 million, and INR 11.40 million to INR 144.03 million, in Gurugram and Amritsar, respectively. The indirect costs averted through scaled-up air pollution mitigation strategies ranged from INR 17.41 million to INR 519.45 million in Gurugram, and INR 74.36 million to INR 917.53 million in Amritsar.

4.5 Return on investment

We evaluated the implementation cost and anticipated health benefits (return on investment, ROI) for these interventions over a five-year period (2028–2032), following an initial five years of intervention rollout (2023–2027). The analysis assumes that after reaching target coverage (by 2027), the interventions are sustained for the modelling period. The ROI varied across the cities as well as the interventions (**Table 5**).

Table 5: Return on investment ratios (ROI)

Interventions	Amritsar	Gurugram
Integrated agriculture residue management	1.23	1.06
Buses on electricity	1.34	0.47
2W and 3W on electricity	3.28	2.70
Modal shift of private vehicles to buses	0.46	0.40
Shift of industries to cleaner fuel	8.55	9.99
Stricter control of emissions in industries	6.58	1.43
Mechanized cleaning of roads	4.34	0.88
Pavement of side roads	1.26	0.19
Road greenbelt development	6.31	1.17

Note: The bold number in green colour present the ROIs >1. ROIs >1 imply that the intervention has a positive return on investment. The number in red colour represent a negative ROI, i.e., <1.

Industrial interventions: The "shift of industries to cleaner fuel" was found to yield the highest economic returns — INR 9.99 and INR 8.55 for every rupee spent on the intervention in Gurugram and Amritsar, respectively. Similarly, the 'stricter control of emissions in industries' yielded a high benefit-cost ratio, with Amritsar benefiting more than Gurugram. This disparity could be due to fewer industries within the Gurugram airshed. Overall, reducing emissions from the industrial sector proved to be the most beneficial investment.

Transport interventions: Industrial sector interventions were followed by the electric transition in the transport sector. The "conversion of two- and three-wheelers on electricity" was found to yield the highest economic returns within this group of interventions – INR 2.7 and INR 3.3 for every rupee spent on the intervention in Gurugram and Amritsar, respectively. While the intervention "buses on electricity" proves to be beneficial in Amritsar but not in Gurugram due to similar effectiveness coupled with a higher target coverage requirement in Gurugram, necessitating the purchase of a greater number of buses to meet the target. Electric buses are in their early stages of adoption in Amritsar; hence a conservative 25 percent target coverage was initially set. In Gurugram, despite its ambitious target, it promises long-term benefits. While the "modal shift of private vehicles to buses" intervention did not show a positive ROI over five years (ROI of 0.46 in Amritsar and 0.40 in Gurugram), it is important to consider health benefits and potential longer-term benefits from this intervention. A more substantial reduction in the number of on-road private two- and four-wheelers is necessary, ideally over an extended period, to significantly mitigate pollution. Furthermore, a considerable portion of the costs of this intervention overlaps with the implementation of electric buses, which, upon introduction, can reduce the overall intervention costs.

Agricultural intervention: "Integrated residue management" yielded marginal benefits in both cities. It represented a complex intervention requiring careful consideration of various stakeholder perspectives. Balancing *in situ* and *ex situ* management approaches is essential for successful implementation. Moreover, creating a robust system and infrastructure for residue management is imperative to ensure its success.

Road and construction dust: The "roadside greenbelt development" proved highly beneficial in Amritsar, with an ROI of 6.31. While still advantageous in Gurugram, the benefits were less pronounced, reflected in a ROI of 1.17. This difference is attributed to Gurugram's significantly larger road network compared to Amritsar. The interventions related to road and construction sector — "mechanized cleaning of roads", "pavement of arterial roads" generated value for money only in Amritsar. This could be because target coverage for road dust interventions in Gurugram is notably high (80–100 percent) compared to Amritsar (25 percent), resulting in lower intervention costs in the latter. The overall effectiveness of "mechanized cleaning of roads", "pavement of arterial roads" was limited in both cities (1–2 percent reduction of $PM_{2.5}$ concentration).

Our study noted a more substantial improvement in health outcomes in Amritsar compared to Gurugram, despite Gurugram experiencing higher levels of air pollution. This discrepancy can be attributed to the non-linear nature of the exposure-response curve for particulate matter and its association with various diseases. The curve exhibits a plateauing effect, characterized by flatter curves beyond a certain pollution concentration threshold. The exposure in Gurugram lies in the plateaued region, while Amritsar is positioned on a more linear segment of the curve, indicating that efforts to reduce air pollution in this range can yield more significant health benefits. Therefore, in Gurugram, implementing a combination of interventions targeting diverse pollution sources may be essential to realize more significant health improvements. Importantly, the challenge extends beyond city borders for both cities, highlighting the need for a comprehensive, airshed-level approach involving consistent efforts in the national capital region.

5

Limitations

5. Limitations

This study has several key limitations that should be considered when interpreting the findings and for future research.

First, the evidence on the impact of AAP on various health outcomes is continuously evolving, and our understanding of these impacts remains incomplete. Assessing the effectiveness of interventions is inherently more complex than for many other health areas, as it requires precise data on AAP exposure levels and involves multiple pollutants, each with unique parameters affecting their production and health impacts. Consequently, accurately estimating both the economic burden and the return on investment for addressing AAP is particularly challenging, as it hinges on the precision of numerous parameters. This complexity increases the likelihood of relying on standardized or default values, which can lead to potential inaccuracies in the results.

The economic model also exclusively addresses $PM_{2.5}$ and its precursor pollutants, excluding greenhouse gases such as CO_2 and CH_4. While $PM_{2.5}$ is a short-lived climate pollutant, and reducing it yields primarily economic benefits through reduced morbidity and mortality, the broader economic impacts of mitigating short-lived climate pollutants are still not well understood. As a result, these broader benefits are not fully captured in the analysis, which may lead to underestimation of the overall impact. Some interventions could yield additional health benefits not reflected in the calculated economic gains due to this exclusion.

Additionally, secondary $PM_{2.5}$ formation is influenced by a range of geographic, environmental, and seasonal factors [67]. The relationship between precursor gas emissions and the formation of secondary $PM_{2.5}$ is non-linear, and estimating secondary $PM_{2.5}$ production with higher accuracy would require sophisticated chemical transport modelling or atmospheric simulations, which were beyond the scope of this study.

Finally, this study does not evaluate the combined impact of implementing all interventions simultaneously. However, scaling up as many interventions as feasible would likely maximize synergies and amplify overall benefits.

6

Conclusion and recommendations

6. Conclusion and recommendations

The widespread national economic and health burden of ambient air pollution (AAP) illustrates the need to invest in ambient air quality control efforts. Each year, AAP costs Gurugram INR 695.4 million (US$8.4 million) and Amritsar INR 241.2 million (US$2.9 million) in economic costs.

However, the investment case demonstrates the health and economic benefits of investing in air pollution interventions in Amritsar and Gurugram. AAP abatement measures will require a cross-sectoral effort to identify, implement, and enforce the best air quality control policies aligned with India's priorities. Investing in air quality control initiatives will enable India to reduce its health and economic losses in the short-term while paving the way for long-term sustainable growth.

Recommendations

To address air pollution, the Government of India is recommended to take the following actions based on the findings of this investment case:

1. Invest in the intervention modeled under this investment case.

The investment case findings demonstrate that by investing in and implementing air pollution control interventions, India can reduce costs and save lives.

The modelling demonstrates, over the next five years:

- **Converting of two-wheelers and three-wheelers to electric power** can save 143 lives and prevent 7,015 incident cases of AAP-related disease in Amritsar, as well as save 50 lives and 4,434 disease incident cases in Gurugram. Additionally, the intervention can avert INR 384 million and INR 121 million in economic losses in Amritsar and Gurugram, respectively.

Transitioning industries to cleaner fuel can save 785 lives and prevent more than 37,200 new cases in Amritsar, as well as 223 lives and 18,650 new cases in Gurugram. Moreover, the intervention has the potential to avert INR 2,125 million and INR 560 million in economic losses in Amritsar and Gurugram, respectively.

- **Enforcing stricter industrial emission control measures**, including the deployment of air pollution control devices and continuous emissions monitoring systems is estimated to avert 369 deaths and 18,000 incident cases in Amritsar, as well as avert 160 deaths and 13,749 incident cases in Gurugram. This intervention can prevent INR 996 million and INR 399 million in economic losses in Amritsar and Gurugram respectively.

- **Establishing roadside greenbelts** can avert 875 deaths and 41,299 incident cases in Amritsar, as well as avert 477 deaths and 36,309 incident cases in Gurugram. The intervention can prevent INR 2.4 billion and INR 1.2 billion in economic losses in Amritsar and Gurugram respectively.

While some interventions, such as the modal shift of private vehicles to buses did not show a positive ROI over five years, it is important to consider the additional potential health and longer-term benefits from these interventions which are not included in the modelling. For instance, shifting from private vehicles to buses would support both cities to significantly mitigate pollution, while simultaneously tackling congestion and road traffic crashes.

Additionally, while the modelling focuses on a scenario adhering to the national guideline of 40 ug/m^3 air pollution, this remains above WHO-recommended levels of 5 ug/m^3. India may therefore consider implementing additional measures to further reduce air pollution in line with WHO recommendations to protect its population and avert additional health and economic losses.

India can also look to other countries and regions that have recently made progress on policies tackling emissions. For example, in 2023 the European Union passed stricter CO_2 emission standards for cars and vans while creating more low emission zones that restrict the use of high-emitting vehicles. Similarly, Australia passed a New Vehicle Energy Efficiency Standard which sets a maximum annual average level of carbon emissions for all new cars sold by manufacturers [68].

2. Raise awareness of the dangers of air pollution and the benefits of its reduction, including more sustainable transport.

India would benefit from increasing public awareness about air pollution in the country. Campaigns can include the key causes of air pollution in the country and associated health risks, in addition to ways to reduce air pollution and their benefits. This can include highlighting the benefits of some of the key interventions modeled in this investment case, including switching to electric vehicles. Public awareness campaigns on the benefits of more sustainable transport such as walking, cycling and public transport can also encourage uptake.

It is often most effective to communicate through a variety of media outlets, including TV, public transport, and social media. India can also consider using events such as the International Day of Clean Air to further raise public awareness surrounding air pollution.

3. Strengthen whole-of-government and whole-of-society approach to tackling air pollution.

As the causes and effects of air pollution are far-reaching, improving air quality requires political commitment across different sectors. India has made commendable efforts in encouraging a whole-of-government approach to air pollution, including through the establishment of the National Clean Air Programme (NCAP), which has collaborative and multisectoral coordination at the core of its approach. However, India can benefit from taking additional measures to further strengthen its whole-of-government and whole-of-society approach, including:

- Strengthening collaboration with industrial associations and officials from the National Clean Air Program (NCAP) to raise awareness about air pollution mitigation and its health and economic gains.
- Strengthen coordination and collaboration between State Pollution Control Broads and urban local bodies to support implementation of action plans.
- Building capacity among relevant stakeholders to prioritize and implement city-specific air quality management interventions.
- Considering air pollution within urban planning for example, integrating greenbelts and using native plants for sustainability and ecological benefits.
- Encourage industries to adopt cleaner technologies and best practices to reduce emissions while strictly adhering to environmental regulations.
- Ensure funding allocations as part of NCAP are being fully utilized by all cities to improve air pollution and reduce its burden.

4. Implement monitoring and enforcement measures to strengthen compliance.

India should enhance air pollution monitoring efforts, with a particular focus on expanding monitoring capabilities in Amritsar. This could also involve developing other local air quality monitoring systems and public reporting, thus empowering communities and civil society to hold stakeholders accountable. Increased monitoring will also provide valuable data for targeted pollution control measures. India can also consider increasing its use of gender-disaggregated data, as reliable gender-disaggregated data is essential for gender-sensitive planning, monitoring and implementation of air pollution management.

While India has made progress in regulation and legislation surrounding air quality, implementation and enforcement remains a challenge. India can consider implementing additional measures to drive compliance. This can include addressing critical staffing challenges in governmental bodies to bolster the effective implementation of air quality regulations. India can also consider establishing robust coordination mechanisms for airshed management among states (especially in Indo-Gangetic region), ensuring a cohesive approach to ambient air pollution control measures.

5. Support the development and uptake of sustainable and environmentally friendly transport.

India's growing urban populations are increasingly putting pressure on transport networks which have struggled to keep up with this rapid growth. Insufficient current transport networks result in major congestion and increased air pollution, in addition to accidents causing further risks to population health and wellbeing and economic burden.

The Government of India has recently been pursuing the electrification of transportation and has set a target of 30 percent of all vehicles in India being electric by 2030, the equivalent of 100 million green vehicles [41]. To help achieve this target, the Government can increase investment in comprehensive infrastructure needed to effectively support electric vehicles (EV). The Government can also consider fiscal measures such as subsidies to incentivize widespread public adoption of EVs in both cities.

More broadly, the Government of India can also promote and support the use of more sustainable and environmentally modes of transport including walking, cycling and public transportation. This should include ensuring that there is sufficient infrastructure for the public to travel by walking, cycling and public transport, and that routes are safe and accessible. These measures can also include educating the public on the health benefits, both at the individual and wider community level.

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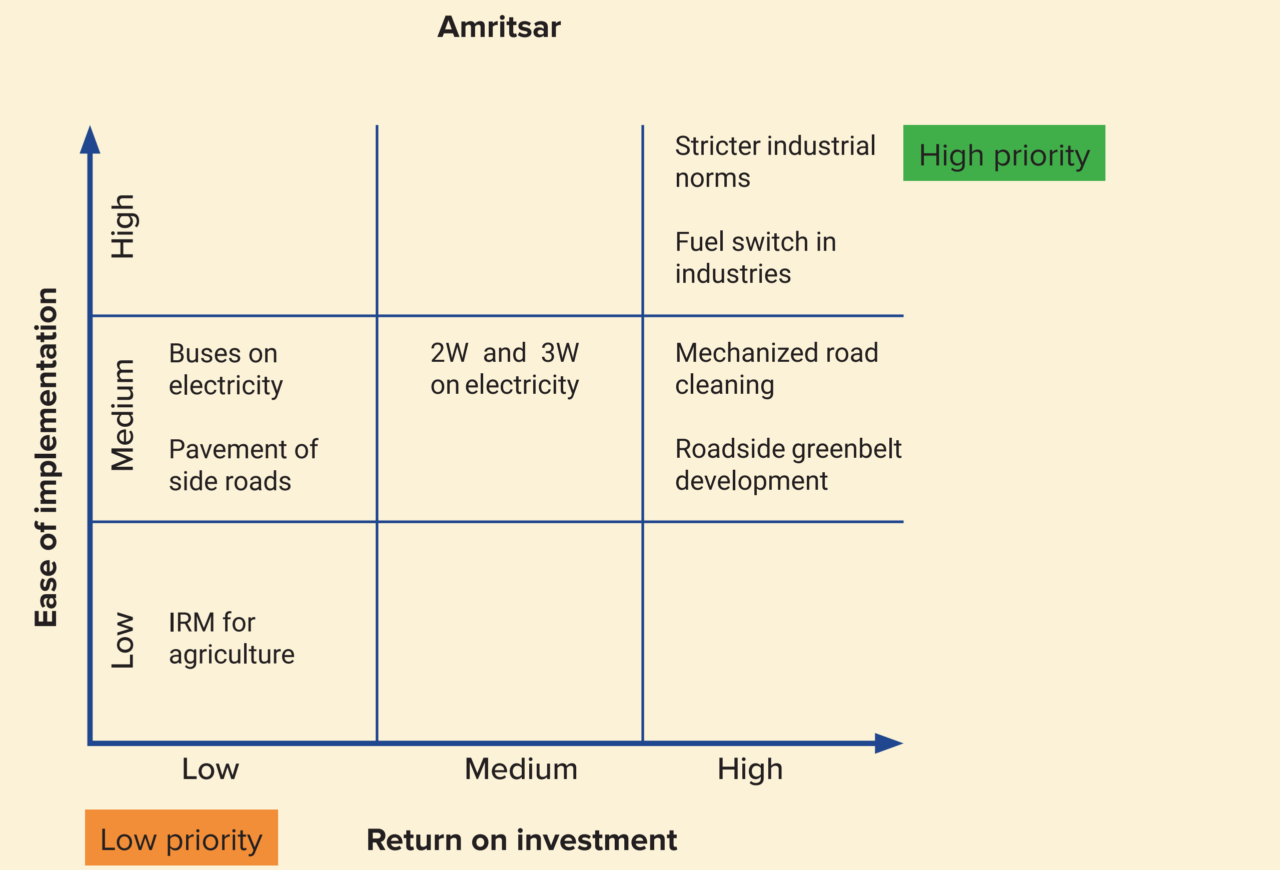
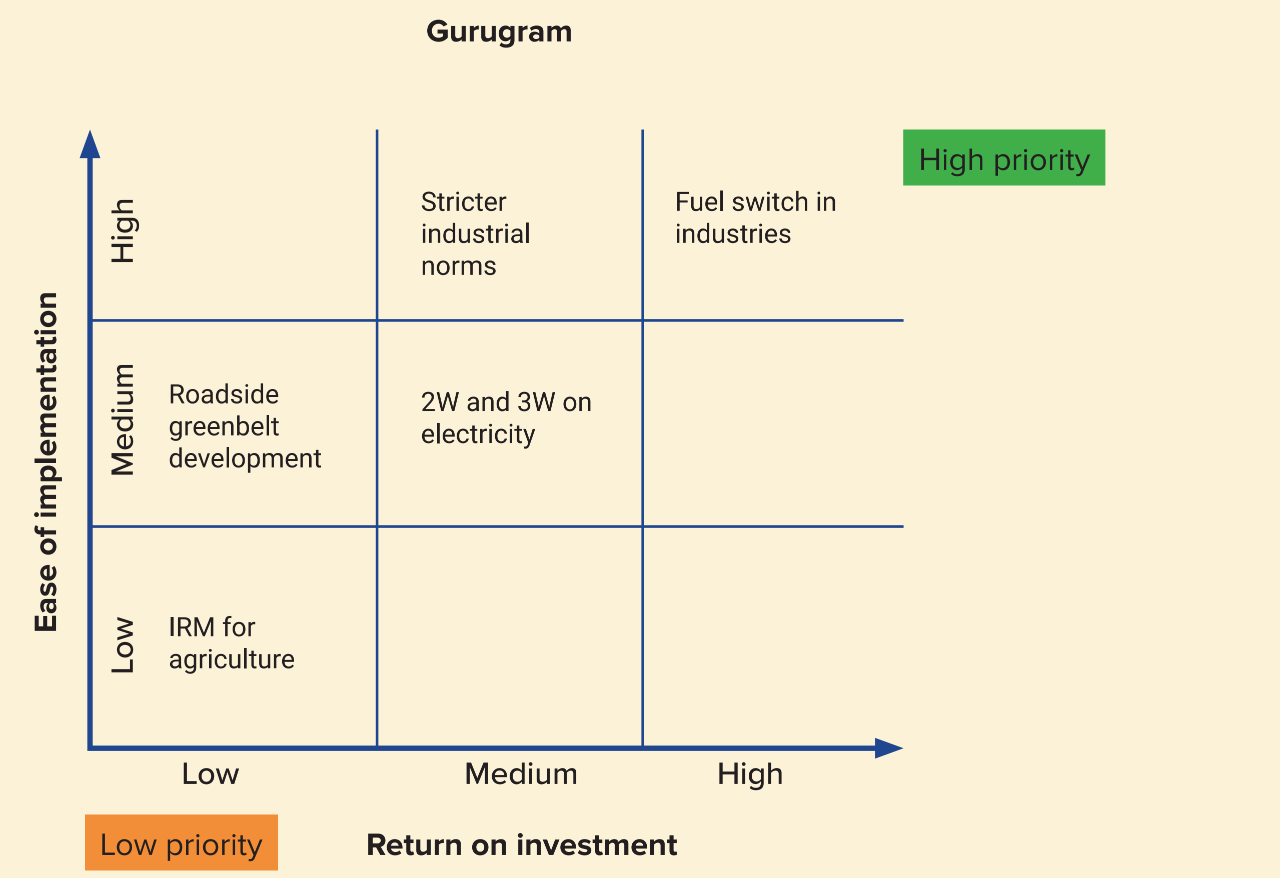
Annex

In the process of understanding what interventions to promote, we recognize the importance of considering not only their economic returns, but also the ease of their implementation. Thus, our approach involves plotting interventions with positive ROIs on a graph, where interventions in the upper right-hand corner are not only economically beneficial but also easily implementable. Conversely, interventions in the lower left-hand corner, although are economically beneficial, may present some challenges that need to be addressed before proceeding with the implementation. **Figure A1** serves as a visual representation of this prioritization strategy for economical strategies (we did not consider interventions with ROIs below 1 in this section). Based on the anticipated challenges, we categorized the interventions as “Low”, “Med” and “High” ease of implementation with “High” meaning easy to implement. We categorized ROIs (**Table A2**) in the same categories.

Photo: © World Bank

Figure A1: Prioritizing implementations based on their economic-returns and ease of implementation





Highlighting the significance of targeting industrial emissions in both cities, which can be deemed as ‘low-hanging fruits’ due to their very high economic returns, **Figure A1** emphasizes that these interventions are easier and less resource intensive for implementation. Execution can be facilitated by leveraging the manpower of regulatory bodies or through initial investments from industrial entities. Government incentives, such as the regulation of prices for Piped Natural Gas (PNG) and subsidies for technology transitions, have the potential to expedite this shift. Sensitizing the industries on fuel switching and transparency of CEMS data is also needed.

The transport sector, particularly the conversion of buses, two-wheelers, and three-wheelers to electric alternatives, emerges as a second priority. Given Amritsar’s notable pollution concerns related to two and three-wheelers, we recommend prioritizing this sector for intervention. This would require developing charging infrastructure for electric vehicles and providing subsidies for purchase. Investments in strengthening the public transport systems are also favourable in the long run, especially for Gurugram, where the presence of a rapid metro adds strategic value. Moreover, transitioning towards a comprehensive public transportation system not only addresses air quality concerns but also reduces traffic congestion and travel time. Furthermore, modal shift to public transport can promote physical activity, potentially leading to greater health gains over time.

Interventions to address resuspended road dust such as green belt development, mechanized cleaning and pavement of side roads require consistent efforts, extensive planning, coordination, and manpower. Similarly, the agriculture sector requires sensitization and planning among multiple stakeholders and demands significant effort for successful implementation. However, if executed, these interventions have the potential to yield benefits in the long run. Greenbelt development can address the immediate concern of dust suppression. It also has comprehensive positive impacts on aesthetics, urban planning, recharging of ground water resources, and carbon capturing ability make it a compelling option for long-term considerations. Studies have also suggested a shift towards electric vehicles, eliminating diesel emissions and reducing crop burning can have climate co-benefits [69].

As the benefits of the interventions are modeled over a five year period, this may fail to accurately capture additional benefits which would accrue beyond this time period.

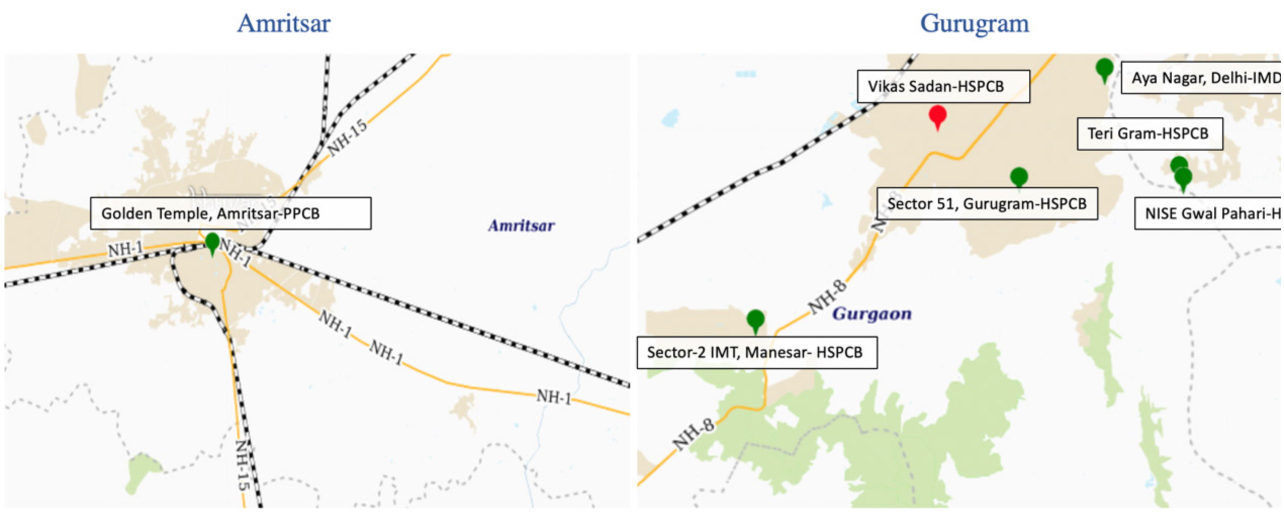
Methodology annex

Section 1: Components of health burden analysis

1.1 Exposure assessment

We estimated the average annual $PM_{2.5}$ exposure in the cities by acquiring the ground monitoring data for the monitoring stations managed by Punjab Pollution Control Board (PPCB) and Haryana State Pollution Control Board (HSPCB) (**Figure A2**). The city of Amritsar has one monitoring station which is located at the Golden Temple. Gurugram has two monitors in the heart of the city (Vikas Sadan and Sector 51) and two monitors situated at the outskirts (NISE Gwal Pahari and TERI Gram). We considered the exposure from the monitors which are located within the city. We downloaded the freely available daily average data for the period of 1st January 2021 to 31st December 2021 from CPCB [70] for relevant monitors and computed the average of the two stations across the year to arrive at the final annual exposure.

Figure A2: Continuous air pollution monitoring locations in Amritsar and Gurugram



Source: Central Pollution Control Board website [71]

1.2 Outcome assessment

Medical certification of cause of death (MCCD) reports provide cause-specific deaths at a district level in India, with the most recent published in 2020 [71]. However, in India not all deaths are recorded, especially in rural settings, and of the deaths recorded, only 20 percent are medically certified for the cause of death [72]. We also did not have cause-specific data on morbidity (incidence and prevalence) in the form of published reports. As this study requires cause-specific data on both mortality and incidence, we used modeled data from the Global Burden of Disease study (GBD 2019) for our purpose. This data was then extrapolated using urban population growth curves (2.3 percent per year).

The GBD derives incidence and mortality by integrating data from different sources for each country, including health surveys, vital registration systems, surveillance data and literature. Statistical techniques are used to analyse these inputs in the form of cause-specific mortality rates, population demographics, and risk factor exposure levels to arrive at cause-specific burden. Models also account for age, sex, geographic location and time trends to provide detailed insights into disease burden. We downloaded cause-specific mortality and incidence data for the following age groups from the GBD website, where it is freely available upon request [50]:

- ≥25 years for lung cancer, COPD, IHD and stroke in 5-years age intervals
- ≥15 years for type 2 diabetes mellitus in 5-years age intervals
- all ages for ALRI in 5-years age intervals (0 years to 95 and above)

City-specific estimates were derived by calculating the proportions of deaths based on relative population sizes of the cities in comparison to the country [73]. For extrapolating the 2019 data to the year 2021, we used the urban annual growth rates from the World Bank [74]. The total number of baseline deaths/incidence for 2021 was calculated as per the Step 1 below for each five-year age category:

Step 1

Number of baseline deaths/incidence for a specific cause for each city in 2021 (i) =

$$\frac{P_i}{P_{ns}} \times D_{ns} \times P_{grow}$$

Where,
Pi is the population of the city i (Gurugram or Amritsar)
Pns is the population of India
Dns is the total deaths/incidence in the country for a particular cause as per GBD 2019 estimates
Pgrow is the percent increase in population from 2019 to 2021

1.3 Exposure response model

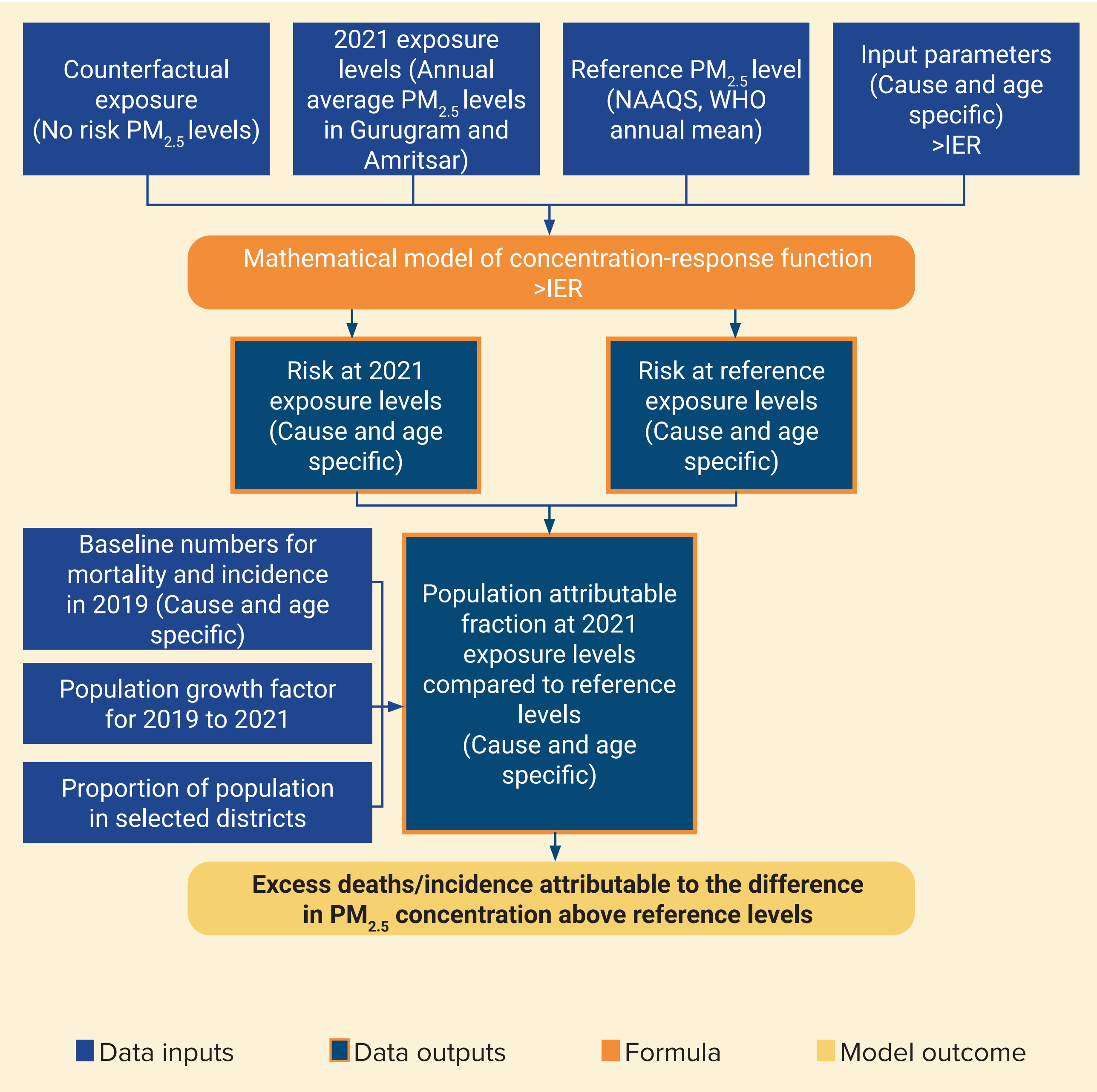
The study used the Integrated Exposure Response Mode (IER) from the GBD 2019 [75], [76] after carefully considering the limitations of both IER and GEMM (Global Exposure Mortality Model) [10] exposure-response (E-R) model. In the GBD-IER, Models for stroke and IHD are stratified by age, therefore, we used the risk estimates for most relevant age group (after taking into account the age distribution of the population and disease aetiology). In the cases of COPD, lung cancer, ALRI and diabetes, only a single exposure-response curve for all age groups was available. The IER model uses a counterfactual concentration of $PM_{2.5}$ to compute risk ratios. This is the concentration at which there is no additional risk of disease mortality/ incidence. The counterfactual concentration ranges between a minimum of 2.4 μg/m^3 and 5.9 μg/m^3, which is consistent with the lowest concentrations observed in long-term epidemiological studies.

Photo: © World Bank

Section 2: Estimating AAP attributable excess disease burden

The overall health burden analysis calculates the city-level excess mortality and incidence of diseases associated with $PM_{2.5}$ exposure at 2021 levels as compared to the scenario wherein the country's exposure levels would have met the NAAQS and WHO recommended levels. The reference level was based on India specific NAAQS guideline for annual average $PM_{2.5}$ concentration of 40µg/m^3 and the updated World Health Organization reference levels of 5µg/m^3. Excess deaths and incidences were estimated as per the framework provided in **Figure A3**.

Figure A3: Conceptual Framework of health burden analysis



The analysis continued with the below steps.

1. Calculate the country's **AAP population attributable fraction** (PAF) for the six diseases in 2021 (Step 2). The PAF depicts the proportion of mortality and incidence of an illness in the population that is attributable to exposure levels of $PM_{2.5}$ above the reference levels. To calculate the disease-specific PAF for each city (*i*), we extracted the disease-specific relative risk for mortality and incidence from the IER at current levels and reference levels (40 μg/m^3 and 5 μg/m^3). We calculated the PAF for both current levels and reference levels.

Step 2

$$\textit{Population Attributable Fraction (PAF) for AAP for city}_i = 1 - \frac{1}{RR_{(x/ref)}}$$

Where,

RRx – represents the cause-specific relative risk of the outcome at an exposure of x μg/m^3 in each subnational unit i compared to the counterfactual exposure

RRref – represents the cause-specific relative risk of the outcome at reference (NAAQS or WHO guidelines) concentration compared to the counterfactual exposure

2. Computing the difference in PAF (PAFx-ref) under exposure to current $PM_{2.5}$ levels as compared to reference levels (Step 3).

Step 3

PAFx-ref = **PAFx – PAFref**

Where,

PAFx – represents the cause-specific proportion of mortality/ morbidity that is attributable to an exposure concentration of x μg/m^3 (i.e., 2020 $PM_{2.5}$ levels)

PAFref – represents the proportion of mortality/ morbidity that is attributable to the reference exposure concentration of 40 or 5 μg/m^3

We computed the excess cause-specific mortality and incidence (Step 4) for Gurugram and Amritsar for the year 2021 by multiplying the difference in the PAF (PAF x-ref) by the corresponding number of cause-specific baseline number of deaths and incident cases in the city (i) calculated in Step 1.

Step 4

Number of excess cause-specific cases of mortality or incidence for city (i) =

$$PAF_{x\text{-}ref} \times i$$

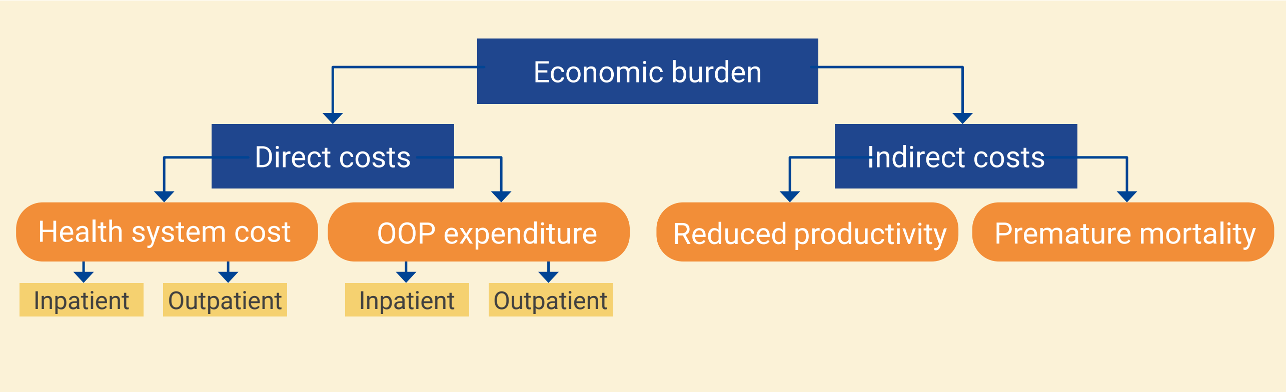
Where,
PAFx-ref – represents the cause-specific proportion of the outcome that is attributable to a exposure concentration difference between current concentration (x) and reference levels (ref)
i – represents the city's cause-specific baseline number of deaths and incidences in 2021 (calculated in Step 1)

Section 3: Estimating AAP Attributable economic burden

The assessment of the economic burden related to air pollution-attributed illnesses involved two distinct components: direct costs and indirect costs (**Figure A4**). Direct costs encompassed the health system cost (costs of providing care for specified diseases) and Out-of-Pocket Expenditure (OOPE). OOPE refers to the financial burden borne directly by the patients themselves to seek healthcare services. Both health system costs and OOPE could be incurred in outpatient and inpatient settings. The total outpatient cost was derived by considering factors such as human resources, capital investments, equipment, furniture, medications, consumables, and overhead utilities. Similarly, the total inpatient cost also incorporated these cost elements, but it was estimated by multiplying the average duration of hospitalization by the total number of inpatient days (per bed day).

Indirect costs result from the diseases' effect on reduced productivity (such as excess absenteeism and presenteeism). If a patient's life was prematurely cut short due to the selected disease, the productive output that would have been generated over the remaining expected lifespan was also forfeited, constituting a component of indirect cost.

Figure A4: Cost components of the economic burden

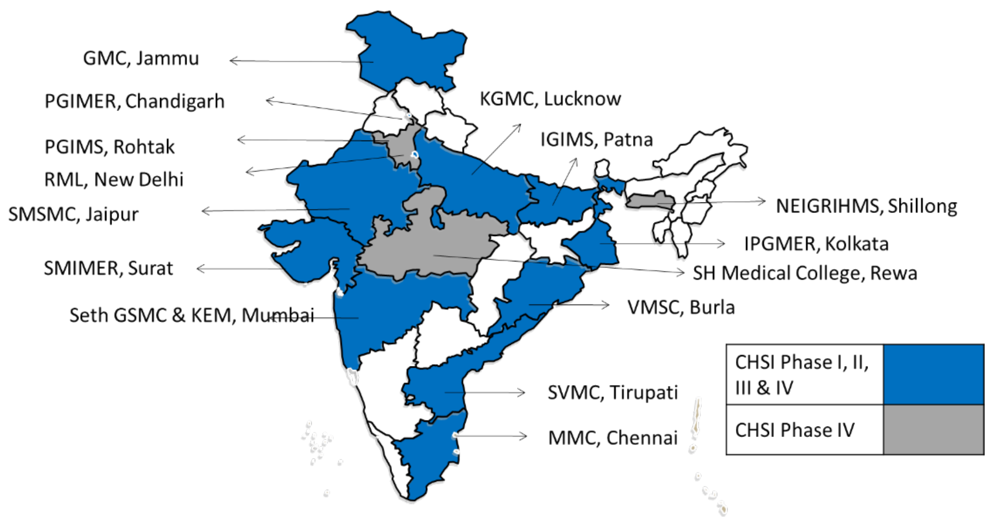


3.1 Direct cost

Health system cost

The estimates for health system cost were derived using the primary data of the "National Health System Cost database" and estimates of "Cost of Health Services in India (CHSI) study" [77], [78]. A multi-stage stratified sampling method was used to select health facilities. Multiple states were selected to represent the heterogeneity based on geography, human development index (HDI), gross state domestic product (GSDP) and health workforce density. Within each state, a public tertiary level teaching hospital was selected (**Figure A5**) [78].

Figure A5: Cost data collection sites



Source: *Costing of Health Services in India (CHSI) study: A report of tertiary public hospitals from 11 Indian states* [79]

Health system cost was assessed following the concept of economic costing and bottom-up approach. Under this approach, the first step involves identification and classification of cost centres in terms of those directly involved in the treatment process (out-patient clinic, operation theatre, in-patient ward, etc.) and those acting as supportive or indirect cost centres (laboratory, pharmacy, dietetics, laundry, etc.). After identification of respective cost centres, data on the quantity of various inputs i.e., both capital and recurrent resources spent on the delivery of service output was collected for the reference year of the health system costing.

Costing data sources

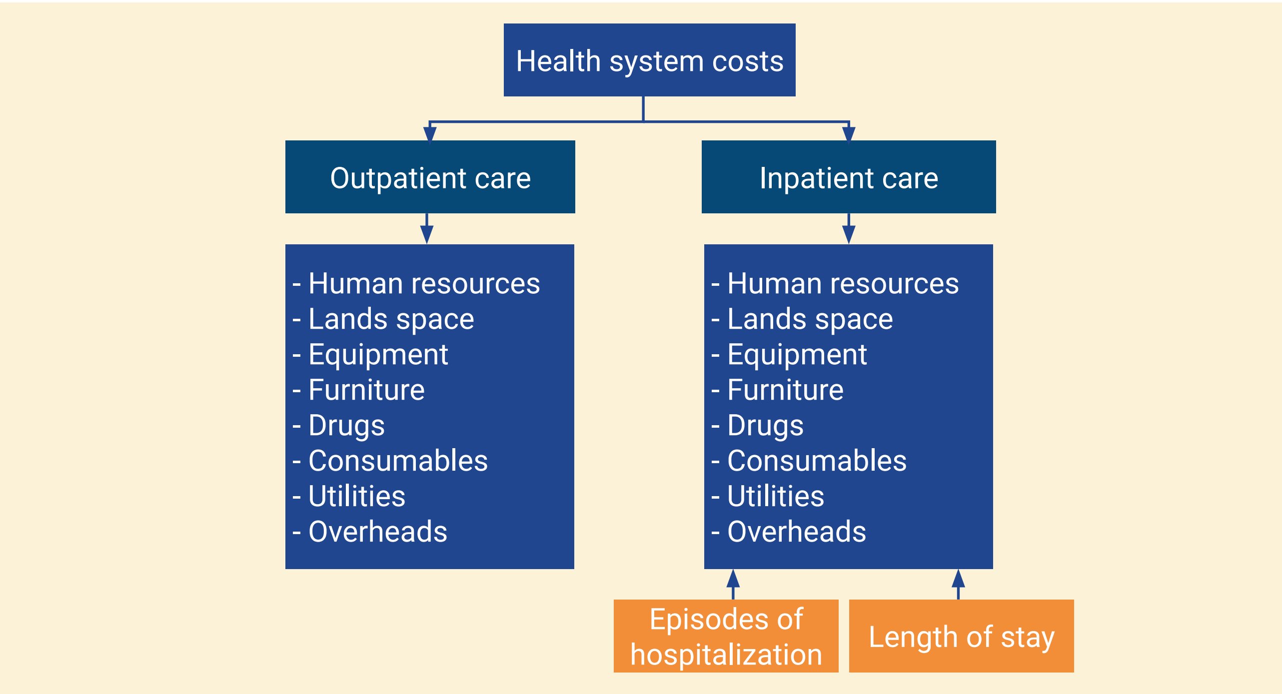
Facility maps were obtained from the Engineering department of the tertiary public hospitals from eleven Indian states which were included in CHSI study. These maps were reviewed for assessing the dimensions of the space and building (in square feet). Further, the non-consumable stock registers were reviewed for assessing the quantity of various medical/ non-medical equipment and furniture items available in the department. Similarly, recurrent resources in the form of drugs and consumables, surgical supplies and other sanitary/stationary items were estimated by reviewing the consumable stock registers, indents/vouchers and pharmacy records. Data on the salaries (inclusive of annual incentives) received by each of the staff members, both partly or completely involved in the treatment process, were assessed from payslips available from the accounts department of the institution. Patient files were assessed for details on the number of various diagnostic tests prescribed to the patients. Following identification of inputs, data on the service output produced by each of the cost centres (in the form of the number of out-patient consultations, in-patient admissions, surgeries, radiotherapy sessions, etc.) were assessed from the routine medical records of the respective department.

The next step involved assigning a monetary value to each of the inputs. For estimating space costs, the current market rental price of a similar space was used, based on an interview with the key informants. The actual procurement prices were obtained from the procurement department and central store of the study hospital, and used for pricing medical equipment, drugs and consumables (surgical, stationary and sanitary). In case of non-availability of procurement price data on any of the above-mentioned items, and particularly for furniture items, market prices were used. The expenses incurred on overheads like water, maintenance, laundry and dietetics were obtained from the respective departments of the institution. In addition, the annual expenditure incurred on electricity was based on an actual measurement of the total electricity load in kilowatt-hour (in each of the specific rooms of the department) by the electrical engineers.

Time allocation interviews were conducted with both the medical and the technical staff for assessing their time spent on the different activities related to the treatment of proportion of disease cases attributable to AAP. Specifically, medical staff members were asked for their time spent on activities done on a regular basis (outpatient consultation, inpatient care, operation theatre, etc.) and at a fixed interval (meetings, teaching/training, etc.). Similarly, technical staff specifically related to the treatment was interviewed for their time spent on planning activities, quality assurance and delivery of services. Alongside these interviews, observation-based data was also collected for per patient time spent on the procedures. The average life of the equipment was determined based on the interview with the staff members involved in using this equipment.

Capital expenditure was annualized to arrive at the equivalent annual cost taking into consideration the discount rate (time preference for money and inflation) and the lifespan of the capital equipment. A discount rate of three percent was used based on the recommended guidelines. Space cost was calculated by multiplying the estimates of floor size of the facility with the local commercial rental price of the similar space. The total cost of the recurrent resources (drugs and consumables) was estimated by multiplying the unit price with the quantity of respective resource consumed. The resources (both capital and recurrent) which are shared in nature and are used in multiple activities, was apportioned towards each of the respective activity using appropriate apportioning statistics. For example, the staff members (consultants, junior/senior residents) which are jointly involved in several activities (outpatient consultation, inpatient care, operation theatres, etc.), proportional time spent in each of these activities by the staff member was used as an apportioning statistic for allocating their salaries towards these activities. The unit health system incurred per patient on treatment modalities was estimated. The determination of the unit health system cost involved employing a weighted average methodology, considering diverse health states associated with a specific disease that encompassed varying levels of severity. The weighted average was derived by considering the case mix, i.e., the distribution of cases across different severity levels of the selected diseases, as observed within the study hospitals. Furthermore, health system cost on an outpatient visit in the department was estimated along with the per-bed-day cost incurred on a patient in the inpatient ward (**Figure A6**).

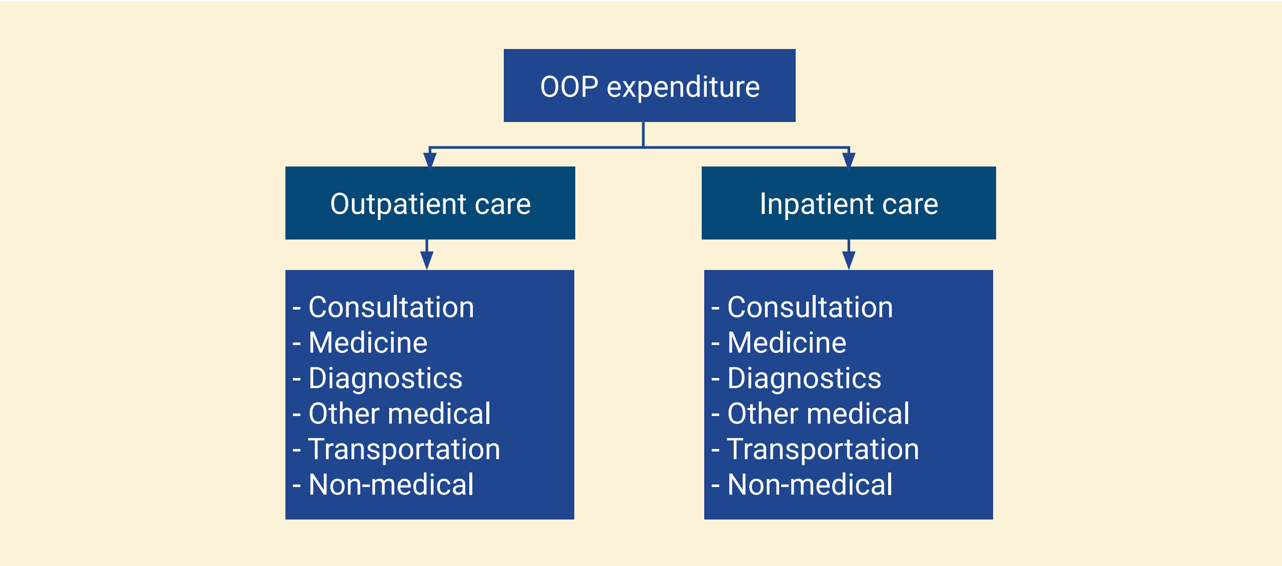
Figure A6: Components of the health system cost



3.2 Out-of-pocket (OOP) expenditure

A cost of illness approach was applied to classify OOP expenditure into direct (including both direct health care and direct non-health care expenditure) and indirect expenditure (**Figure A7**). Direct health expenditure includes expenses incurred on user fee/procedure fee, diagnosis, drugs and consumables and hospitalization. Further, the expenditure on transportation, boarding/lodging and food are considered under direct non-medical expenditure [80]. The disease-specific estimates for these components were derived from the data collected as part of the 75th round of the National Sample Survey [81].

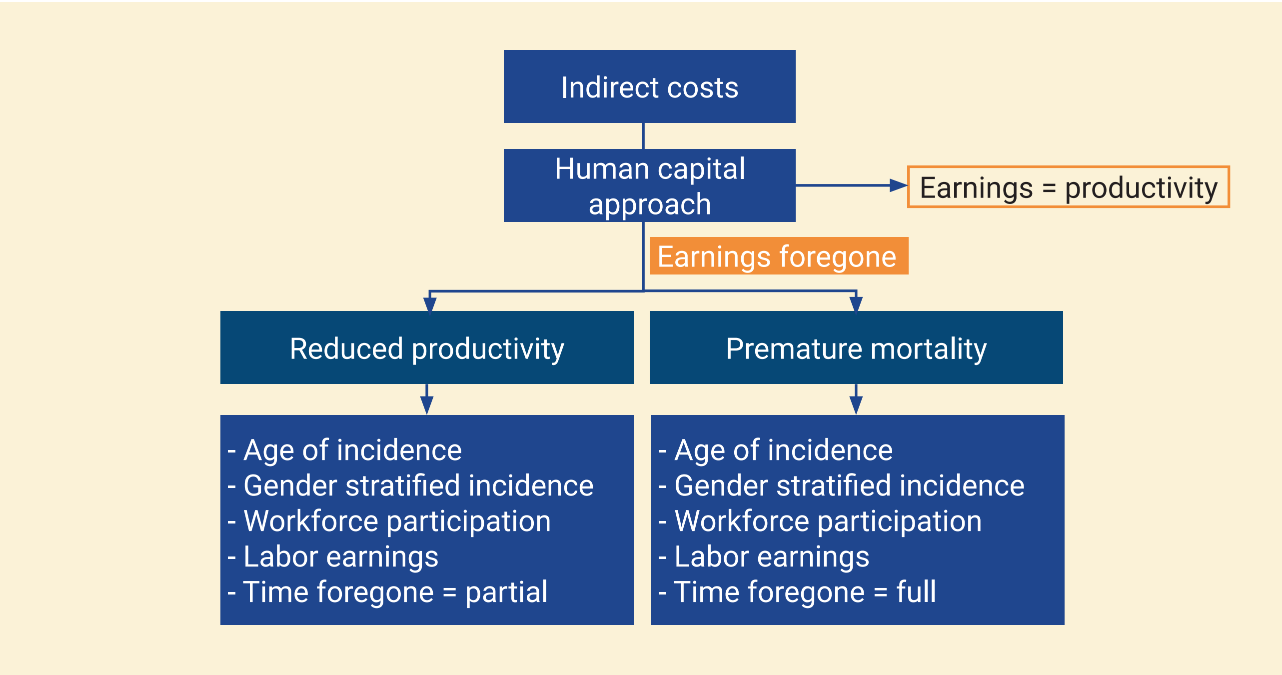
Figure A7: Components of the OOP expenditure



3.3 Indirect cost

Indirect costs were estimated from income losses due to the illness in terms of wage loss or the loss incurred due to premature mortality, using the human capital approach (**Figure A8**). The calculations were based on the discounted value of earnings forgone because of premature morbidity and mortality due to the AAP-attributed burden of the selected diseases. It was assumed that the worth to society of an individual's life is measured by the production potential, which in a competitive labor market is calculated as the present discounted value of expected labor earnings. In order to estimate the indirect costs, it was assumed that an individual produces a stream of output over their lifetime and generates labour earnings that reflect productive capacity. Thereby, the human capital valuation rests on the assumption that earnings reflect productivity. For estimation of indirect cost, we applied the wage rate to time forgone from productive activity. This approach used the reported time of forgone activities while seeking treatment and tending to the patient. For calculating the indirect cost, total hours forgone by patients were converted into workdays and relevant standardized wage rates provided in the National Sample Survey 2011–2016 (68th round) on Household Consumer Expenditure and Employment and Unemployment, and these were applied to estimate the loss of productivity. The wage rates were stratified by gender and consider an ideal workday to be of eight hours. The data for Amritsar and Gurugram regarding these parameters were extracted from the census reports [82], [83], [84]. Only the population in the age group of 18–65 years of both genders was considered for calculating productivity loss. Indirect cost was then calculated as the product of daily wage rates (calculated using the criteria mentioned above) and the total number of workdays (total hours forgone in a month divided by ideal work hours per day).

Figure A8: Components of the indirect cost



Section 4: Data analysis

We estimated the direct and indirect cost of the health burden due to air pollution exposure, where direct costs included costs incurred by both the patient (OOP) and the health system. Indirect costs were assessed using the human capital approach. Loss of working days were recorded, that is the days that a person missed or remained absent from his/her work due to hospital stay [85]–[88]. For those actively employed in the labour workforce, per-day income was used for calculations. For individuals not part of the workforce, an average minimum daily wage rate for India specific to gender and area of residence (rural/urban) was calculated. Years of life lost due to premature mortality in a respective year was calculated as a product of the number of deaths due to an AAP-attributable disease and the difference between average life expectancy at birth and average age of dying due to that disease. Reduced productivity due to a disease was derived using the decrease in health-related quality of life (HRQoL) of a person living with that particular disease. These estimates were derived from the Indian HRQoL value-set [89]. Total productive life years lost due to a disease represent the sum of years lost due to premature mortality and reduced productivity.

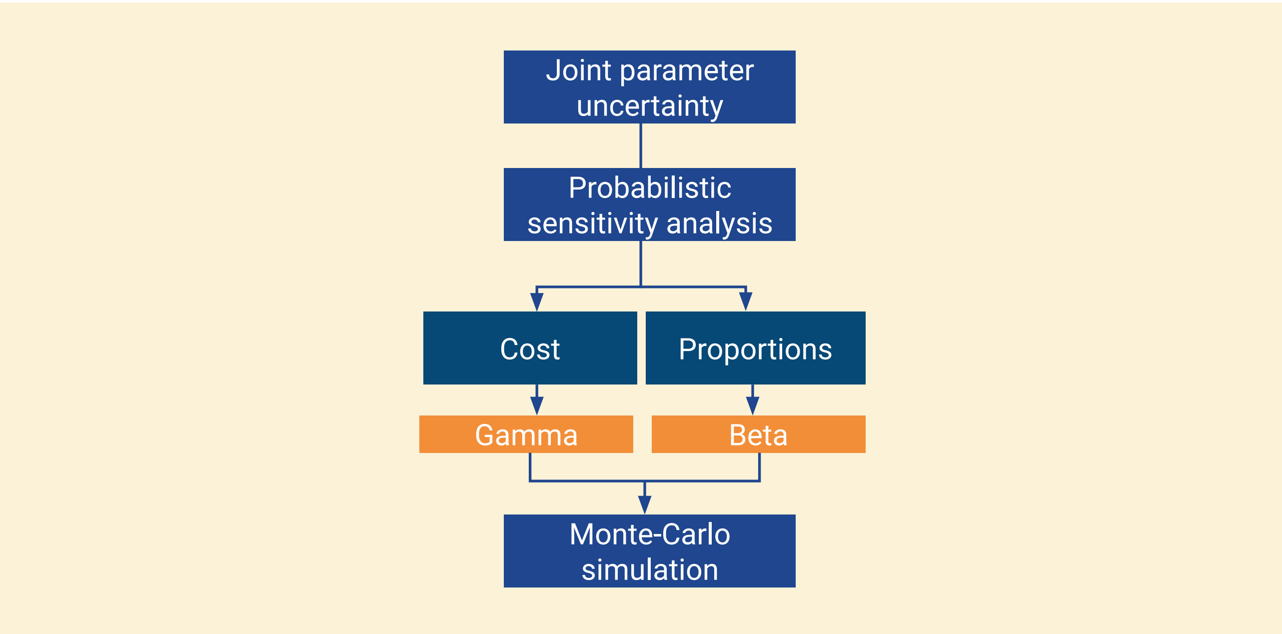
4.1 Model overview

A cost of illness model was developed in MS-Excel for comparing the health and economic burden of selected diseases attributable to current levels of $PM_{2.5}$ with a hypothetical lower pollution level of 40μg/m³ (country-specific guideline) and 5 μg/m³ (WHO guideline). We applied a societal perspective that included health system costs, patient level out of pocket expenditures, and indirect costs including productivity losses. We calculated the direct and indirect cost for each disease condition separately. Direct cost comprised health system cost of outpatient and inpatient cost. The total outpatient cost includes human resource, capital, equipment, furniture, drugs, consumables, and utility overheads. Similarly, the total inpatient cost also includes the same cost heads as direct cost but, is estimated by multiplying the mean duration of hospitalization and total inpatient (per bed day).

4.2 Sensitivity analysis

Multivariable probabilistic sensitivity analysis (PSA) was carried out to account for parameter uncertainty (**Figure A9**) [90]. Under the PSA, gamma distributions were applied for cost parameters and beta distributions for epidemiological rates or proportions and utility values [91]–[93].

Figure A9: Probabilistic sensitivity analysis for parameter uncertainty



Standard Error (SE), derived from literature, was used to generate a distribution around the point estimate of a parameter. After assigning both the distribution and range to each of the parameter values, 999 Monte Carlo simulations were run, from which a median value of incremental cost effectiveness ratio (ICER) along with 2.5th and 97.5th percentile were reported.

Section 5: Assumptions and limitations of burden calculations

For our analysis, we have chosen to include the cities of Amritsar and Gurugram rather than their respective districts. Districts are larger administrative units that may not accurately reflect the air pollution situation and may not align precisely with the geographical boundaries of the city clean air action plans. As the latest census data is yet to be published, the population estimates for calculating proportion of population residing in Amritsar and Gurugram were derived from the census 2011 data. We have assumed exposure experienced in other parts of the city is similar to what is experienced at the location of the ground monitors in Gurgaon and Amritsar. Our exposure assessment method does not capture seasonal and individual level variations. Incidence and deaths from the diseases was assumed to be proportional to the growth rate of the population. Due to the lack of an exposure response curve for prevalence, we faced difficulties in determining the current burden of the diseases caused by $PM_{2.5}$. This implies that our estimates are focused on the future burden of diseases, but it's important to note that the healthcare system will experience increased strain as more individuals with prevalent cases of these diseases will also require medical attention.

Due to differences in disease definitions (ICD coding) and the lack of cause-specific incidence and mortality data at a city level, we were unable to use latest data from national reports. Instead, modeled estimates from GBD provide the best available estimate of the disease burden. The exposure-response model developed by GBD has included only few studies from regions with high air pollution to develop the model, therefore, India/LMIC-specific risk estimates were not used. In line with GBD, we also considered very low risk of mortality and incidence of stroke, IHD, COPD and lung cancer in individuals <24 years of age and diabetes in individuals <15 years of age. We have also assumed that the age distribution of the population for Gurugram and Amritsar is the same as for India as a whole, and the relative proportion of population residing in these cities compared to the total population of the countryside is the same in 2021 as in 2011 (when the last census took place). We considered population increase in the cities at the national urban population growth rate, due to lack of city-specific population growth rates. Health system data has been obtained from other cities but applied to Amritsar and Gurugram. Additionally, only tertiary care hospitals, large public sector hospitals and private hospitals have been included due to the urban nature of the cities. OOP estimates have been extracted from nationally representative datasets and were applied to the local population of the two cities [71].

Section 6: Identifying potential interventions

Source apportionment studies

Source apportionment studies are focused on recognizing and measuring the contribution of different sectors to ambient air pollution within a defined geographic region. As a primary measure toward tackling the air quality challenges in Gurugram and Amritsar, we initially discerned the primary sectors responsible for $PM_{2.5}$ emissions within these cities. **Table A1** is sourced from a 2018 research collaboration between the Automative Research Association of India (ARAI) and The Energy and Resources Institute (TERI), conducted in the Delhi-National Capital Region (NCR) [94].

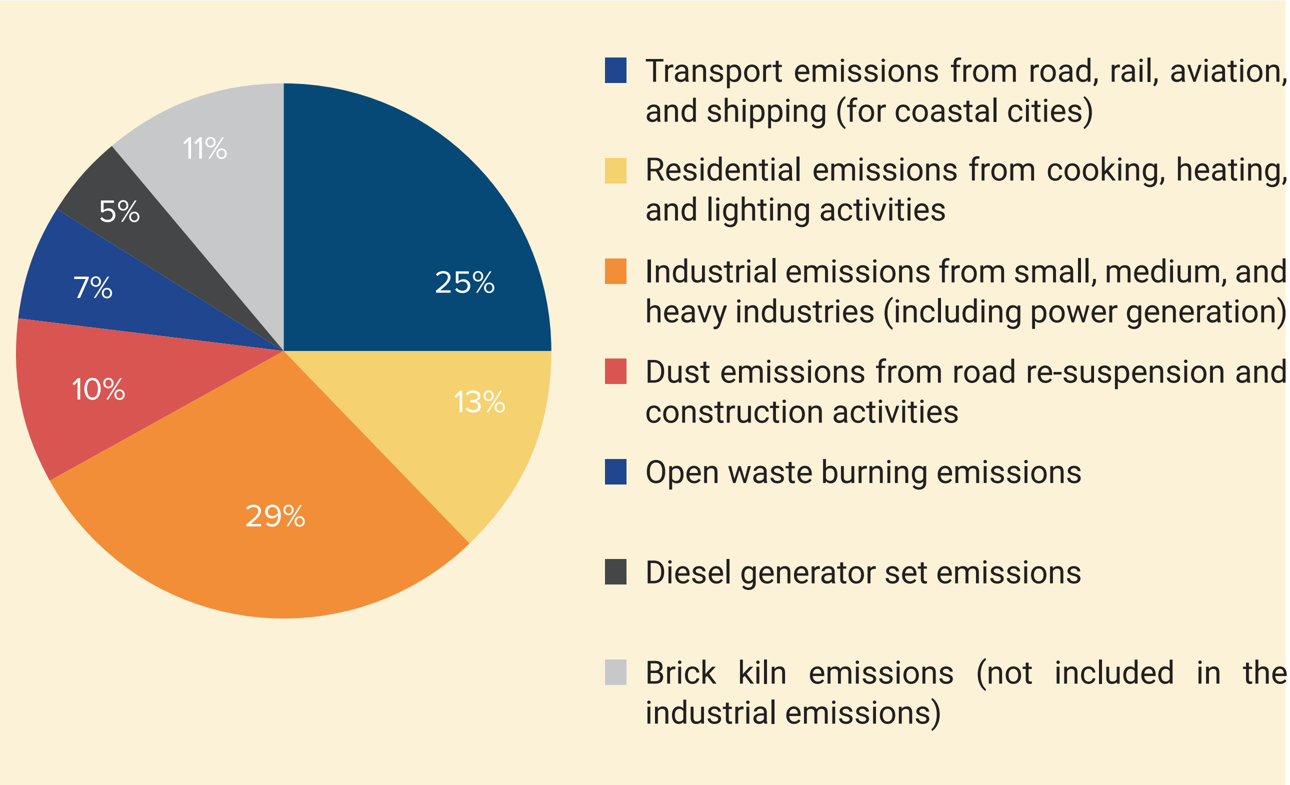
Table A1: Average Sectoral Contributions to total $PM_{2.5}$ in Delhi-NCR including Gurugram [94]

Source	Summer (% of total $PM_{2.5}$)	Winter (% of total $PM_{2.5}$)
Transport	16	27
Dust	49	20
Biomass	14	15
Industries	13	30
Others	8	8

Note: Industries includes power plants (stacks, fly ash ponds and coal handling units), brick manufacturing, stone crushers, and other industries. Others includes diesel generator sets, refuse burning, crematoria, airport, restaurants, incinerators, landfills, etc. Dust includes sources of natural and anthropogenic origin (soil, road dust re-suspension, and construction activities). Dust is also contributed by atmospheric transport from surrounding countries and areas.

In Gurugram, during the summer months, the primary contributors to ambient air pollution are road and construction dust, followed by vehicular emissions (Table A1). In contrast, during the winter season, industries are the leading contributor to air pollution, closely followed by the transport sector. Another significant source of pollution is biomass burning, which includes agricultural and residential burning.

Figure A10: Average sectoral contributions of $PM_{2.5}$ in Amritsar



For Amritsar, the primary sources of $PM_{2.5}$ include industrial activities, transportation, residential emissions from cooking, and dust (**Figure A10**).

Based on this identification of city-specific $PM_{2.5}$ emission sources from major sectors, we developed an initial catalogue of potential interventions aimed at mitigating PM levels. Given that the primary contributors to $PM_{2.5}$ pollution were present in both Gurugram and Amritsar, a similar set of interventions could be modeled in both cities with different target coverages.

Identifying interventions

A final list of interventions is presented in **Figure A11**.

Figure A11: List of selected interventions in the study

Transport
Buses on electricity
2W and 3W on electricity
Modal shift of private vehicles to electric buses

Industries
Shift of industries to cleaner fuel
Enforcement of APCD and stricter control of emission

Road dust
Mechanized cleaning of roads
Pavement of arterial roads
Road greenbelt development

Agriculture
Integrated agriculture residue management

Both Gurugram and Amritsar have developed Air Action Plans and the interventions examined in the study were already integrated into these [95], [96]. We modeled the interventions within this study either because they hadn't reached their maximum effectiveness, thus needed scaling-up, or because there were deficiencies in their enforcement or implementation.

Implementation timeframe and target coverage

Implementation time frame is the time taken for the intervention to be implemented or scaled up to reach target coverage. We assumed that during the period of 2023 to 2028, there would be an incremental uptake of the intervention to reach target coverage levels which mirrors the real-world scenario. **Table A2** details the timeframe for implementation of the proposed strategies and the target coverage required to achieve the potential effectiveness, based on the studies from which the impact sizes have been extracted.

Table A2: Proposed implementation time frame and target coverage of selected interventions

Intervention	Target Coverage	Description	Implementation Time
Integrated agriculture residue management	100%	Coverage of in situ and ex-situ management to ensure zero burning	5 years
Buses on electricity	Gurugram: 50% Amritsar: 25%	% of the buses in 2027 are electric.	5 years
2W and 3W on electricity	Gurugram: 40% 2W and 100% 3W Amritsar: 20% of 2W and 100% of 3W	% of two and three wheelers in 2027 are electric	5 years
Modal shift of private vehicles to buses	25%	% of 4W and 2W users shifting to public transport by 2027	5 years
Shift of Industries to cleaner fuel	100%	% of industries shift to gas by 2027	5 years
Enforcement of APCD and stricter control of emission	100%	% industries being monitored and have APCDs and CEMS in 2027	5 years
Mechanized cleaning of roads	Gurugram: 80% Amritsar: 25%	% roads to be covered	5 years
Pavement of arterial roads	Gurugram: 100% Amritsar: 25%	% roads to be paved	5 years
Road greenbelt development	40%	% of road layout covered with green belt	5 years

The choice to carry out interventions with a five-year implementation timeframe was the result of consideration of several important aspects. First, it was based on a careful examination of effectiveness estimates found in the literature [94], [97], supporting a five-year duration as an appropriate timeframe for substantial outcomes. This approach also recognizes the need to balance immediate and long-term outcomes to ensure noticeable advancement without compromising long-term advantages. It also fits well with the inclinations of policymakers for medium-term interventions, addressing their need for observable results in a reasonable amount of time, and conforming to public expectations and policy cycles. Furthermore, given the behavioural, infrastructural, and technical changes needed, it will take a considerable amount of time to plan, adopt gradually, and implement improvements due to the complexity of interventions spanning transportation, industry, road dust, and agriculture. The five-year period not only allows for these systemic adjustments, but it also guarantees a consistent effort to effectively reduce air pollution, recognizing the necessity of extensive, ongoing efforts across multiple sectors.

Section 7: Cost and effectiveness data

Data on effectiveness of interventions

The effectiveness of various interventions was assessed by reduced emissions (emanating from source) or the potential to reduce AAP concentration within a given time frame. To calculate the $PM_{2.5}$ (particulate matter) reduction potential of interventions, relevant data on historical $PM_{2.5}$ levels and intervention-related information is required. Once a baseline for $PM_{2.5}$ levels is established before the intervention, the expected reduction in PM emissions or concentrations after implementing the measure is calculated. The final values are represented as reduction in $PM_{2.5}$, expressed in units such as tons per year (emission reduction) or $\mu g/m^3$ per year (concentration reduction) within a specified geographic region, showcasing the intervention's potential to improve air quality and reduce environmental and health impacts. The comprehensive literature review regarding the costs and impact of these interventions is available upon request.

We based our concentration reduction estimates and target coverages on two studies conducted by TERI: one in the National Capital Region (NCR) [94] to derive effectiveness estimates for Gurugram and another in Ludhiana, Punjab, for Amritsar [97]. We relied on reports that modeled interventions in regions situated close to Amritsar and Gurugram. As roadside greenbelts were not explored as a potential intervention in these studies, we used impact sizes drawn from Guo et al., (2019) [98] the road is the most significant one among the five elements of the city image. The road greenspace have been suggested as one of the green infrastructures that could improve near-road air quality. The road greenbelt of the cross section layout is the core content of road green space planning and design. However, existing studies have primarily focused on the effect of different plants on atmospheric particulate matter. Modelling exercises conducted in these studies are designed to forecast intervention effects and integrate elements like land use, meteorological variables and sector-specific assumptions such as growth rates. The strength of these studies is that they use robust methodologies, modelling, and stakeholder consultation approaches to arrive at their estimates. They also incorporate growth rates for various industries and compare interventions with a business-as-usual (BAU) scenario and modelling interventions independent from each other, thereby avoiding overestimation of impacts or double counting. **Table A3** provides the effectiveness estimates utilized in this study based on the target coverages along with their respective data sources.

Table A3: $PM_{2.5}$ Reduction Potential of Interventions (effectiveness)

No.	Description	Target coverage (%)	% decrease in $PM_{2.5}$ concentration in Gurugram	% decrease in $PM_{2.5}$ concentration in Amritsar
1	**Integrated agriculture residue management**	100%	8.00 [94]	5.00 [97]
2	**Buses on electricity**	Gurugram: 50% Amritsar: 25%	2.00 [99]	2.00 [99]
3	**2W and 3W on electricity**	Gurugram: 40% 2W and 100% 3W Amritsar: 20% of 2W and 100% of 3W	3.00 [99]	4.00 [97]
4	**Modal shift of private vehicles to buses**	25%	1.00 [94]	2.00 [97]
5	**Shift of Industries to cleaner fuel**	100%	12.00 [94]	20.00 [97]
6	**Enforcement of APCD and stricter control of emission**	100%	9.00 [94]	9.00 [94]
7	**Mechanized cleaning of roads**	Gurugram: 80% Amritsar: 25%	1.00 [99]	2.00 [97]
8	**Pavement of arterial roads**	Gurugram: 80% Amritsar: 25%	1.00 [99]	2.00 [97]
9	**Greenbelt development**	40%	21.55 [98]	21.55 [98]

Assumptions and limitations: The TERI-Delhi-NCR study [94], which models reductions in $PM_{2.5}$ levels specifically during the winter season, presents a best-case scenario estimate of effectiveness. Our definition of green spaces aligns with the criteria used and suggested by the referenced study [98] the road is the most significant one among the five elements of the city image. The road greenspace have been suggested as one of the green infrastructures that could improve near-road air quality. The road greenbelt of the cross section layout is the core content of road green space planning and design. However, existing studies have primarily focused on the effect of different plants on atmospheric particulate matter. We operated on the assumption that the five-year timeframe for modelling effectiveness of the intervention mentioned in the TERI Report from 2019 is equivalent to the five years starting from 2023. Given the impact of COVID-19, we considered the possibility that the interventions mentioned in 2019, as reflected in the effectiveness estimates, might have been implemented later. We also assumed that the BAU scenarios remain valid. Additionally, we anticipated that the measurable reduction in $PM_{2.5}$ would be observable at the end of five years post-implementation of the intervention, reaching the target levels. Unfortunately, we encountered difficulty obtaining yearly incremental effectiveness data for the period between 2023 and 2028, when the implementation is underway. We also could not measure the total effectiveness if all or a set of interventions are implemented together.

Data on the cost of interventions

The cost elements associated with each intervention were initially identified through a thorough literature review and subsequent discussions with stakeholders. To ensure accurate and firsthand data collection, a field consultant with extensive experience and proficiency in the native language was recruited. Following a stakeholder mapping exercise, relevant government officials as well as other stakeholders in Amritsar and Gurugram were consulted on data collection for identified cost components. The overall approach and details of the cost components for each intervention are available as Supplementary Material upon request.

Once the list of necessary cost components was identified, the price for each cost was obtained via stakeholder consultations. This data was largely drawn from government records and, in the case of the fuel provisioning agency, records of technology providers. The total costs for each intervention was computed as a sum of the fixed and variable costs present. The fixed capital costs were amortized for the duration of the intervention. Amortization involves spreading the cost of an asset or expense over its useful life through regular, incremental payments or adjustments. The operations and maintenance costs were computed based on operating cost overheads and other energy requirements. Government subsidies for increasing take-up/promotional activities were accounted for. However, taxes were excluded from the analysis. Benefits obtained such as scrap value of vehicles were deducted from the total costs wherever applicable to arrive at the net cost of the intervention.

Collected data underwent verification by cross-referencing it with information available from online dashboards whenever possible. The remaining data relies entirely on stakeholder input and may be susceptible to bias, inaccurate recall or exaggerations.

Intervention 1: Use of agricultural residues in industries and power plants

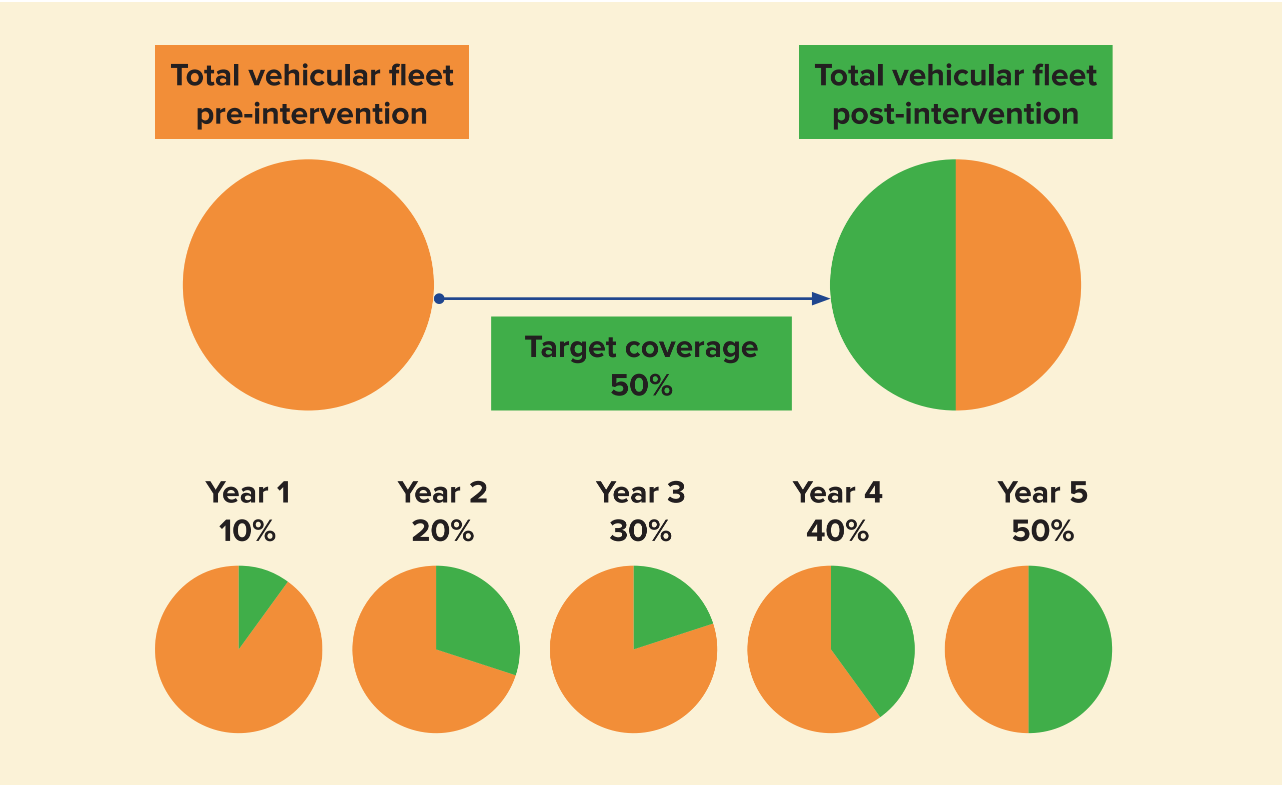
Based on suggestions from Punjab and Haryana State Pollution Control Boards, it was identified that one machine needs to be assigned to each village to collect and transport the residue from fields to industries and powerplants. After obtaining the total number of villages in each region, the total number of machines required to collect and transport residue was estimated. Since most of the villages involved in cultivation lie at the outskirts of the city, all villages within a 5km radius outside city limits were also considered. For in-situ management of agriculture residues, the number of machines (e.g., happy/super seeders) required on a sharing basis per village was determined. It was assumed that these would be procured by farmers' collectives/groups in each village and can be rented out by individual farmers as per their requirement. A government subsidy of 80 percent per farmer group purchase was applied.

Intervention 2: Buses on electricity

To arrive at the cost of electrification, the current composition of vehicles was considered. Based on target coverage to be achieved, the number of e-buses to be procured and their costs were estimated. The existing share of vehicle stock is fully diesel driven in Amritsar and compressed natural gas (CNG) based in Gurugram. For computation purposes, the excess expenditure beyond existing funds allocated by the government/ individual was only accounted for if the revised expenditure was lesser than the initial outlay, then this was considered as a cost cut or benefit to the stakeholder and represented as a negative expense (saving).

The analysis assumes one-fifth of the buses would be converted annually across the implementation period (**Figure A12**). A static fleet count was assumed for the intervention. The net cost of the intervention was computed after subtracting the scrap benefits from total expenditure.

Figure A12: Conversion to e-buses — pre- and post-intervention



Intervention 3: Two- and three-wheelers on electricity

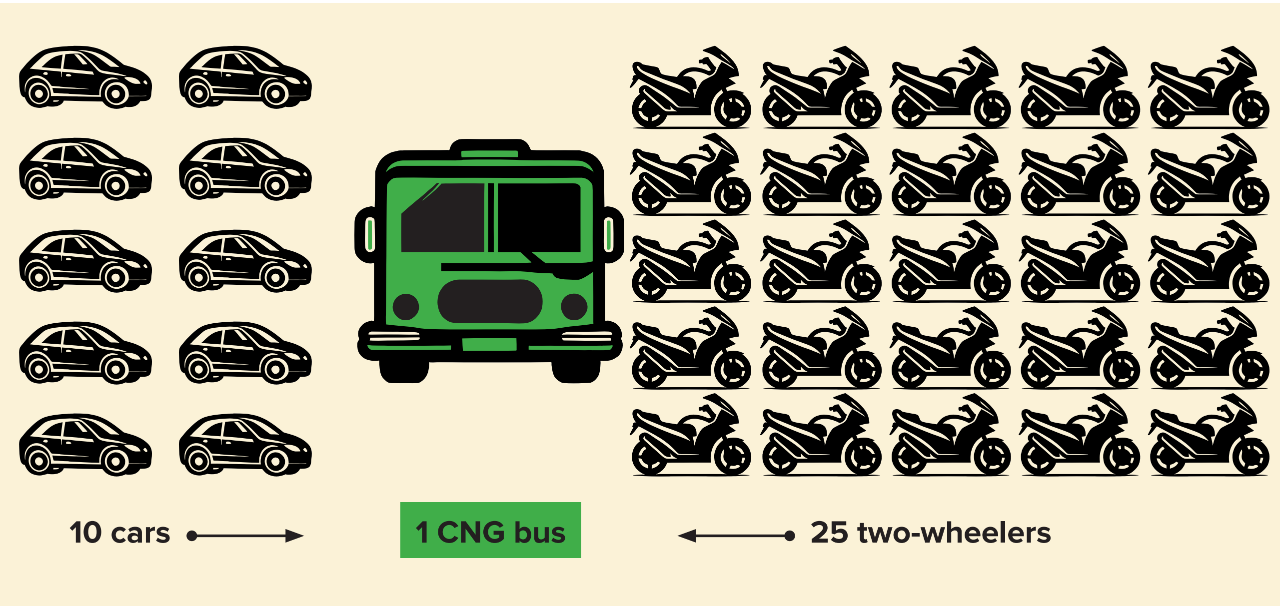
To arrive at the cost of electrification, the current composition of vehicle stock by fuel category was considered. Currently 97 percent of the two-wheelers on road in both the target cities are petrol driven, and the remaining are electric. Amidst three-wheelers there is a mix of CNG, diesel, electric and PNG fuelled vehicles. We assumed that the three-plug charger cost is in-built in the two- and three-wheeler costs and therefore separate infrastructure cost was not included. The increased fuel consumption costs were included in the operational costs computed.

The implementation of the intervention involves efforts from both Government and private individuals. As two- and three-wheelers are owned by private individuals, a considerable component of the expenditure will be out of pocket. From the government side, subsidies offered to increase uptake were included. The subsidies amount to almost 10 percent of the vehicle purchase cost.

Intervention 4: Modal shift of private vehicles to buses

This intervention requires behavioural changes and depends on individual's personal preferences, hence an uptake rate of 15 percent was considered. The modal shift will result in a net reduction in fuel consumption due to lesser vehicular kilometres travelled and reduction in concentration of pollutants released by combustion of petrol/diesel. There will be lower infrastructure costs due to fewer vehicles on the road and hence also result in lesser traffic related deaths and injuries. The existing number of private cars and 2 wheelers was considered, and their average occupancy was utilized to determine the number of CNG buses required over and above the existing fleet **(Figure A14**).

Figure A14: Modal shift of cars and 2 wheelers to CNG Buses



The scrap value of private vehicles was not considered for this estimation as the take-up depends solely on the private individual's willingness to alter their transportation preferences.

Intervention 5: Shift of industries to cleaner fuel

This intervention aims to convert industries currently running on solid and liquid fuels to gaseous ones. Usage of natural gas offers a potentially less-polluting alternative to the industrial sector. The total number of industries as well as those relying on solid/liquid fuel was obtained. The cost for new gas fired equipment was accounted for. Industries currently running on solid fuel need to procure new gas pipelines while those on liquid fuel can retrofit their equipment resulting in lesser capital expenditure. The cost of connection until doorstep was considered. Doorstep downstream depends on the length of pipe required as per industry needs. The safety and automation cost were also considered for computation.

Intervention 6: Enforcement of APCD and stricter control of emissions

Continuous emission monitoring systems (CEMS) help determine the emission rate of particulate matter. The installation of CEMS has an impact on the industrial site's polluting nature as the presence of a monitoring system and anticipation that the regulator might levy penalties based on the data can influence the behaviour of the industry. Currently all industries within Amritsar and Gurugram have Air Pollution Control Devices[4] installed. The need now is to have stricter enforcement of CEMS and a stringent sanctions mechanism. The financial implication of installing these emission monitoring systems was considered. The total number of industries within city limits was obtained along with the number of those who already have CEMS installed. To ensure stricter enforcement, the need to recruit additional personnel was identified. Allocation by the government for their compensation as well as site visits and other promotional expenses was considered.

Intervention 7: Mechanized cleaning of roads

The mechanical cleaning of roads is done in two shifts per day in both arterial as well as sub-arterial roads. The frequency of cleaning was taken as twice a week. For this intervention, arterial and sub-arterial roads in a 5km radius around the cities were also considered as resuspended particulate matter at the periphery also brings down the quality of air in the city. The net cost of the intervention was computed considering the total number of trucks needed, their operations and maintenance costs, total road length to be vacuumed, frequency of cleaning per week and the time frame of the intervention. The scrap benefits obtained by disposing of the machines that need replacement were subtracted from the total costs. The cost of procurement of the new machines were annualized for the implementation period.

Intervention 8: Pavement of arterial roads

The cost of wall-to-wall paving was estimated based on the total construction cost of the pavement and its annual repair cost. The width of road to be paved was considered as 2.5 meters and we assumed that 80 percent of the road length will be covered, adjusting for the intersections and corners. According to data obtained, 32 tiles can be accommodated in 1 square meter and the construction rate per square meter is Rs.20. The net cost of the intervention was estimated including capital and repair and maintenance costs.

Intervention 9: Road greenbelt development

The total green belt area to be covered was assumed to be 40 percent of the existing arterial road length. Initial land preparation costs per acre was computed based on data gathered from implementing authorities. Labour (landscaping) and maintenance costs were considered while computing the net intervention costs.

4 Air pollution control devices (APCD) are of devices installed in the smokestack of industries to prevent particulate and gaseous pollutants from entering the atmosphere. The Pollution Control Board plays a crucial role in monitoring, regulating, and controlling environmental pollution in India through various mandates, including monitoring and audits, to ensure compliance with emission standards.

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