GOVERNMENT OF MONGOLIA

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Investment Case for Air Pollution Reduction in

Mongolia

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Suggested citation. UNDP. Investment Case Study for Air Pollution Reduction in Mongolia. United Nations Development Programmeme; 2024. Licence: CC BY-NC-SA 3.0 IGO.

This document was produced with the financial assistance of the European Union. The views expressed herein can in no way be taken to reflect the official opinion of the European Union.

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Photo credit: Saruul Dolgorsuren

Acknowledgments

This report is a collaborative effort involving the Ministry of Health of Mongolia (MOH), Ministry of Economy and Development of Mongolia (MED), Ministry of Environment and Tourism of Mongolia (MET), the United Nations Development Programmeme (UNDP) and Triangulate Health Ltd.

The authors received support from the *Advancing Health and Environmental Sustainability through Action on Pollution* project, which was carried out with funding from the European Union.

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We want to express our gratitude to the National Center for Public Health (NCPH) and the National Agency of Meteorology and Environmental Monitoring (NAMEM) for providing data and valuable inputs to this report. Furthermore, we are grateful for Dr.Batzorig Bayartsogt, Dr. Unursaikhan Surenjav, Dr. Tsegmed Sambuu, Zoljargal Jargalsaikhan, Munkhbat Tsendeekhuu, Oyunjargal Lamjav, Enkhmaa Sarangerel and national stakeholders for their dedicated time to provide feedback and active participation in two stakeholder meetings – one held on January 2023 and one in May 2023.

The economic modelling was conducted by Triangulate Health Ltd. Additional input was provided by Brian Hutchinson, Research Public Health Analyst from RTI and Alper Cezmi Özdemir of Online United Nations Volunteers. Graphic design was by Zsuzsanna Schreck.

Abbreviations

AAP	ambient air pollution
ALRI	acute lower respiratory illness
BAR-HAP	benefits of action to reduce household air pollution
BC	black carbon
COI	cost-of-illness
COPD	chronic obstructive pulmonary disease
DALY	disability-adjusted life year
GDP	gross domestic product
HAP	household air pollution
IC	investment case
ICS	improved cookstove
IHD	ischemic heart disease
IER	integrated exposure response
LC	lung cancer
LMIC	low- and middle-income country
LPG	liquefied petroleum gas
NCD	non-communicable disease
OC	organic carbon
PM	particulate matter
$PM_{2.5}$	particulate matter with an aerodynamic diameter less than 2.5 micrometres
ROI	return on investment
SDGs	Sustainable Development Goals
UNDP	United Nations Development Programmeme
VSL	Value of statistical life
WHO	World Health Organization
YLD	years of health life lost due to disability
YLL	years of life lost

Contents

Burden

Ambient air pollution

In Mongolia, it is estimated that more than

2,800

people die each year due to ambient air pollution (AAP).

AAP causes

US$269 million

(MNT 905 billion) in economic losses each year, equivalent to 2.4% of Mongolia's GDP.

Household air pollution

In Mongolia, estimates suggest that around

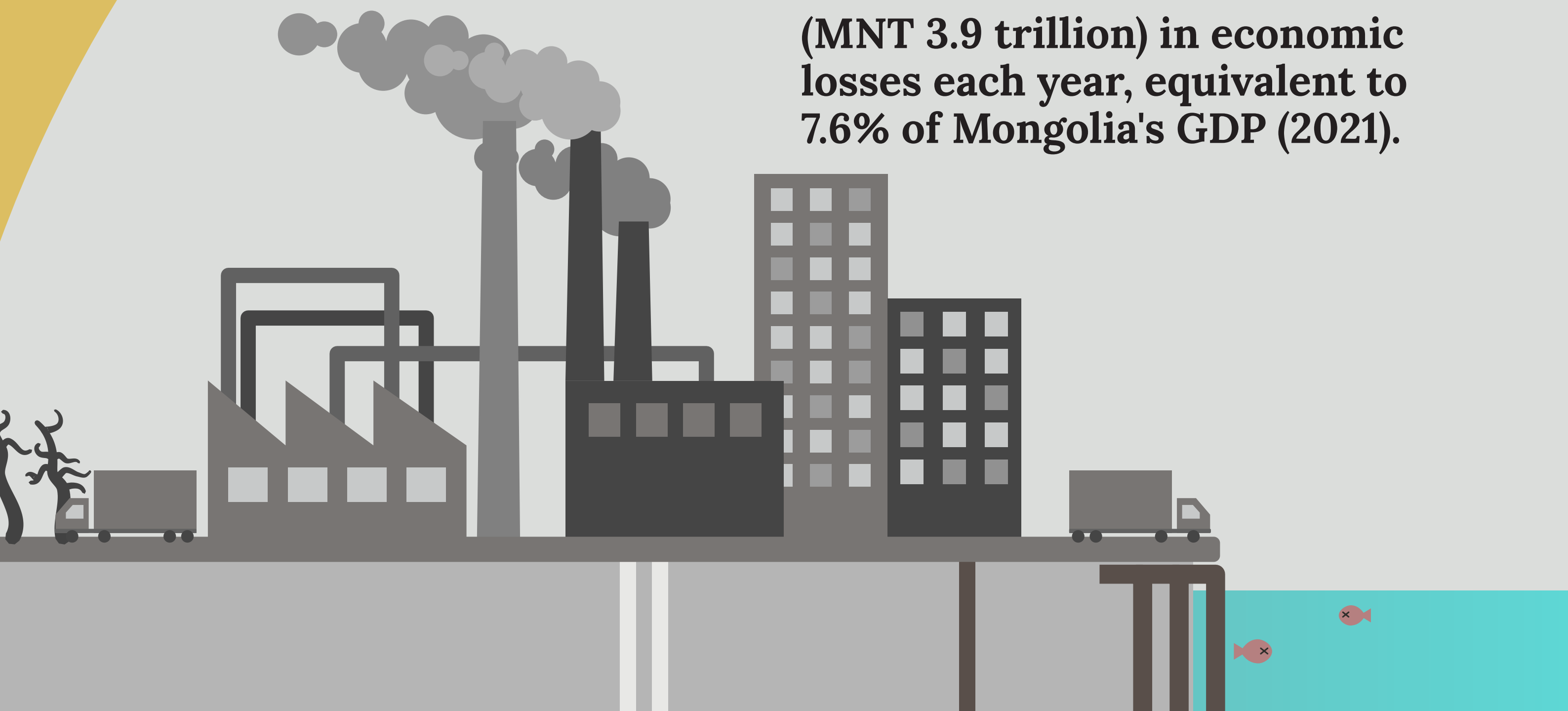
4,350

people die each year due to household air pollution (HAP).

HAP causes

US$1.2 billion

(MNT 3.9 trillion) in economic losses each year, equivalent to 7.6% of Mongolia's GDP (2021).



Why invest

Ambient air pollution

By 2055, investing now in proven interventions will avert

US$671 million

(MNT 2.3 trillion) in economic losses and save over

11,000 lives.

- Replace coal-based cookstoves with electric or gas
- Convert powerplants
- Reduce open fires
- Reduce road transport pollution

Household air pollution

Investing now in replacing coal-fueled stoves with a mixture of electric and gas stoves will avert

US$29 million

(MNT 97 billion) in economic losses over 31 years, generating an ROI of 4.8 to 1.

Note that due to limited data availability, only the cost of some AAP interventions could be determined.

Photo credit: Saruul Dolgorsuren

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. In addition, air pollution is associated with higher mortality rates, especially among the most vulnerable. Two major sources of air pollution: ambient air pollution (AAP), also referred to as outdoor air pollution, and household air pollution (HAP), also referred to as indoor air pollution, are of major concern in Mongolia.

This report includes findings from quantitative cost-of-illness analyses of the health, social and economic burden of AAP and HAP on the Mongolian population through ill-health, premature mortality, and reduced workplace productivity. The analysis includes the impact of air pollution on the six following diseases: acute lower respiratory infection, chronic obstructive pulmonary disease, ischemic heart disease, lung cancer, stroke and diabetes mellitus type 2.

The report further identifies relevant interventions to reduce air pollution in the Mongolian context and models the costs as well as health, environmental and economic benefits of these interventions.

Due to limited data availability, estimates of HAP burden and benefits are only provided for people living in urban areas of Mongolia (around 70 percent of the population). AAP estimates refer to the entire population.

Main findings of the investment case

Burden

Ambient air pollution

Ambient air pollution (AAP) in Mongolia causes more than 2,800 deaths and US$269 million (MNT 905 billion) in economic losses each year, representing 2.4% of GDP.

These economic losses are comprised of:

US$2.4 million (MNT 8.0 billion) in **healthcare expenditures,** with stroke and heart disease representing the biggest proportion.

US$4.8 million (MNT 16 billion) in **workplace productivity losses** from days absent from work and lower on-the-job productivity. This includes the time family members take off from work to care for children who become sick from exposure to outdoor air pollution.

US$262 million (MNT 881 billion) from **premature mortality** attributed to AAP representing the majority of the economic burden.

Household air pollution

Household air pollution (HAP) due to cookstove use causes around 4,350 deaths and US$1.2 billion (MNT 3.9 trillion) in economic losses each year, representing 7.6% of GDP.

Healthcare expenditures to treat illness associated with HAP equal totals **US$14 million (MNT 47 billion)** each year.

Environmental losses from carbon equivalent emissions reaches **US$107 million (MNT 360 billion)** each year.

Premature mortality due to HAP related illnesses results in **US$1.0 billion (MNT 3.5 trillion)** in economic losses each year.

Benefits

By acting now, the Government of Mongolia 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.

Ambient air pollution

Together these four AAP reduction interventions can avert US$671 million (MNT 2.3 trillion) by 2055 (or US$21 million and 396 lives per year).

Replacing the traditional coal-based cookstoves with electric or gas cookstoves can save more than **9,000 lives** and avert **US$487 million (MNT 1.6 trillion)** in costs (287 lives and US$15.2 million per year).

Equipping coal-fired powerplants with $PM_{2.5}$ filters or replacing them with new, cleaner power plants, can save more than **2,818 lives and avert US$149 million (MNT 502 million)** in costs (88 lives and US$4.7 million per year).

Reducing open fires can save **448 lives and avert US$24 million (MNT 81 billion)** in costs (14 lives and US$ 0.7 million per year).

Reducing road-transport pollution by increasing the fuel efficiency of vehicles can save **217 lives and avert US$12 million (MNT 40 billion)** in costs (7 lives and US$0.4 million per year).

Household air pollution

Selecting one of these three HAP-reduction interventions to replace coal based cookstoves can offer the following benefits:

Transitioning to electric cookstoves can save **656 lives and avert US$54 million (MNT 97 billion)** in costs over 31 years (21 lives and US$1.7 million per year), generating an ROI of 5.6 to 1.

Transitioning to liquefied petroleum gas (LPG) stoves can save **322 lives and avert US$26.5 million (MNT 89 billion)** over 31 years (10 lives and US$853 thousand each year), generating an ROI of 7.2 to 1.

An intervention currently under consideration by the Mongolian government to transition <10% of households from coal to either electric or LPG stoves could save **350 lives and avert US$29 million (MNT 97 billion)** over 31 years (11 lives and US$926,000 each year), generating an ROI of 4.8 to 1.

Recommendations

The results of this analysis and the following recommendations can be used by national stakeholders to strengthen the rationale for bold actions that can begin to transition Mongolia to cleaner and more efficient technologies:

1. Strengthen coordination on air pollution among key stakeholders.

This will require high-level political commitment and contribution to coordinating mechanism from different sectors, including the Ministries of Health, Finance, Environment and Tourism, Road and Transportation Development and others. Of note, Mongolia will develop a national multisectoral action plan on pollution and health in the framework of this project.

2. Incentivize shifts to alternative energy sources for households.

To reduce HAP and AAP, Mongolia should focus efforts to shifting to liquefied petroleum gas or electric-powered stoves in Ulaanbaatar as this generates the most favorable returns on investment (ROIs), saves the most lives, and produces the most economic societal and environmental benefits.

3. Invest in the AAP interventions modelled under the investment case.

Reduce AAP by replacing traditional coal based cookstoves with electric or gas, modernising traditional power plants to be more efficient and produce less pollutants, as well as reducing open fires and road-transport pollution.

4. Scale up monitoring of air pollution.

Increase national air pollution monitoring throughout the country and support ongoing research efforts to better understand the causes of HAP and AAP.

5. Raise awareness of the dangers of air pollution and the benefits of its reduction.

Launch campaigns that raise public awareness of ambient and household air pollution's health effects.

Photo credit: Saruul Dolgorsuren

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 incomes [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 [10], the WHO's Air Quality Guidelines recently reduced the recommended maximum exposure level from an annual average of 10 μg/m^3 to an annual average of 5 μg/m^3 to minimize AAP-attributable diseases [11,12]. 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 $PM_{2.5}$ μg/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 $PM_{2.5}$ μg/m^3, respectively) [13,14].

Household air pollution is caused by using solid fuels, such as wood and charcoal, for cooking and heating in homes. It is the world's leading environmental health risk, causing acute respiratory tract infections, chronic obstructive pulmonary disease (COPD), lung cancer, cardiovascular disease, cataracts, burns and poisonings, asthma, low birthweight and perinatal mortality [15]. HAP has also been cited as one of the major barriers to low- and middle-income countries (LMICs) achieving the Sustainable Development Goals (SDGs). HAP is also a major concern among women and young children who disproportionately spend more time in and around cooking areas [16,17]. As such, investment in clean energy infrastructure can support SDG 5 on gender equality and SDG 4 on quality education.

Both sources of air pollution, AAP and HAP, are of major concern in Mongolia. Indeed, $PM_{2.5}$ levels in urban areas far exceed WHO-recommended levels [18], and many Mongolian households rely on cookstoves fueled by coal [19]. Compared to more efficient technologies, these cookstoves contribute more to environmental harms (e.g., deforestation, pollutant emissions) and social inequities (e.g., imposing time burdens on women and children who are often responsible for household work) [20]. Exposure to pollution is a leading cause of morbidity and mortality. A recently published UNDP report '*Asia in Focus: Clean Air and the Business and Human Rights Agenda*,' highlighted the dramatic effects of air pollution in Asia, with Mongolia experiencing the highest air-pollution mortality rate among all countries examined, with 107 deaths per 100,000 habitants attributable to $PM_{2.5}$ emissions in 2019 [21].

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 Mongolia, India 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.

This investment case quantifies the health, economic, environmental, and social burden of AAP and HAP due to cookstove use in Mongolia. Specifically, this report presents the results of a cost-of-illness (COI) analysis and estimates the return on investment (ROI) of four interventions designed to reduce ambient and household air pollution. This investment case utilizes WHO's The Benefits of Action to Reduce Household Air Pollution (BAR-HAP) Tool to estimate the economic burden of HAP and calculate the economic returns associated with the transition to cleaner cooking energy sources. Additionally, the study utilizes a methodology developed by RTI International to evaluate AAP exposure levels, estimate morbidity and mortality attributable to AAP, calculate the economic burden imposed by AAP, examine sectoral contributions to AAP, and select and evaluate potential interventions.

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 Mongolia's commitment to achieving the SDGs as well as the objectives of the Paris Agreement and alleviating the burden of NCDs [22].

By investing in energy infrastructure, Mongolia can accelerate its development and generate substantial health, economic, social, and environmental benefits.

Photo credit: Saruul Dolgorsuren

2

Air pollution in Mongolia: status and context

2. Air pollution in Mongolia: status and context

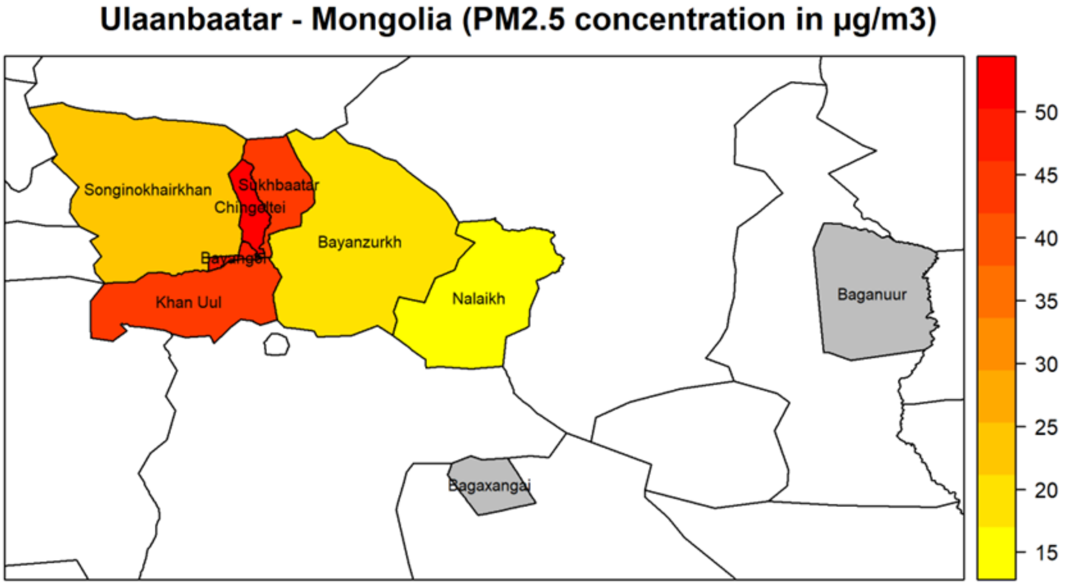
2.1 Air pollution in Mongolia

Ambient air pollution

Air pollution is a major challenge in Mongolia, and a substantial threat to the health of its population. Nearly half the population lives in Mongolia's capital, Ulaanbaatar. Ulaanbaatar is often ranked as one of the cities with the worst ambient air quality globally [23]. In 2019, the annual concentration of the key pollutant $PM_{2.5}$ was 60 μg/m^3 according to the WHO Air Quality Database [18]. This is twelve times the WHO air quality guideline level of 5 μg/m^3 for annual averages [24]. The concentration of other dangerous pollutants, including PM_{10} and NO_2, also exceed recommended guidelines.

Pollution is worst in the capital's central districts, with $PM_{2.5}$ levels in 2022 still exceeding 50 μg/m^3 in surrounding districts Bayangol, Chingeltei, Khan Uul and Sukhbaatar (**Figure 1**). While pollutant levels in Ulaanbaatar have decreased steadily since 2011, progress in improving air quality needs to be accelerated (**Figure 2**) [18]. Air quality in Ulaanbaatar is particularly poor in the winter. On the coldest days of the year, $PM_{2.5}$ concentrations can go up to 687 μg/m^3, equivalent to 27 times the limit deemed safe by WHO [25].

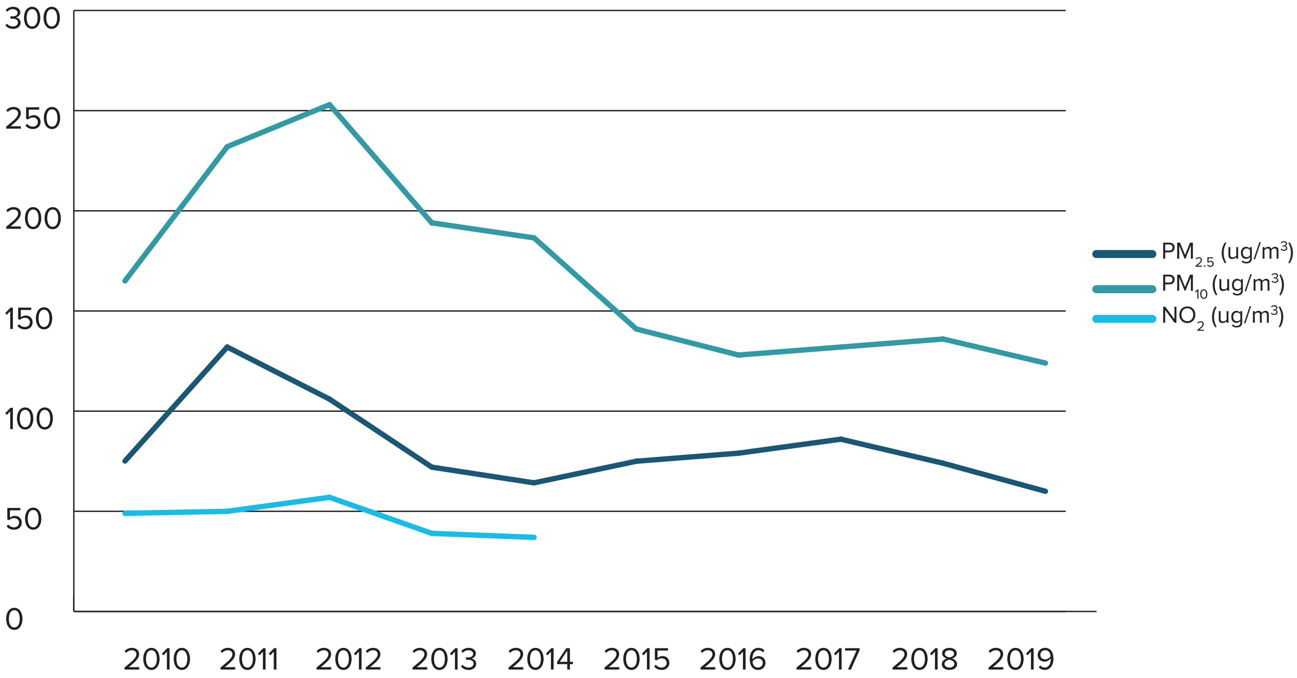
Figure 1. Concentration levels of $PM_{2.5}$ by districts in Ulaanbaatar, 2022. *No data was available on the grey marked districts. Source: The National Centre for Public Health in Mongolia.*



*With agricultural crop, straw/shrubs/grass and kerosene as other forms of fuel.

Figure 2. Trend of air pollution indicators in Ulaanbaatar, 2010-2019

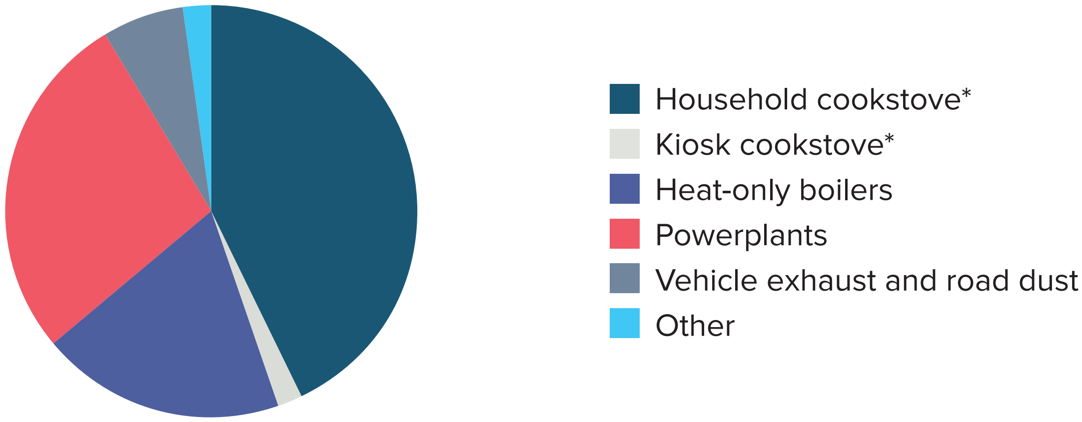
Source: WHO Air Quality Database, 2022



The largest contributor to fine particulate matter ($PM_{2.5}$) is coal and biomass combustion for heating in households. A study in 2010 found that half of the fine $PM_{2.5}$ emissions in Ulaanbaatar were derived from low-income ger households which often rely on coal as an energy source [23]. Gers are a Mongolian nomadic dwelling and form residential districts within the Ulaanbaatar region, in which 69 percent of the national population live [26]. On average it was estimated in 2011 that a ger household consumes five tons of coal and $3m^3$ of fuel wood per year [23]. More recent estimates from 2019 indicate that domestic raw coal burning can contribute up to 80 percent of the total $PM_{2.5}$ emissions in Ulaanbaatar [27].

Additional polluting factors include power plants, heat-only boilers, road dust and motor vehicles (**Figure 3**) [28]. The number of registered vehicles in Mongolia and Ulaanbaatar has been increasing steadily over past years, and the cars are mostly inefficient and highly polluting [29].

Figure 3. Contributors to PM 2.5 emissions by sector in Ulaanbaatar, Mongolia, 2010
Source [30]



*Includes coal and wood burning

Household air pollution

Indoor air quality in Mongolia is often poor, largely due to households using coal as the main source of fuel for cooking [31]. Of note, this household use of coal contributes both to indoor air pollution (HAP) and outdoor air pollution (AAP).

In 2021, 70 percent of the ger households in the ger district of Ulaanbaatar used coal stoves, while only 30 percent use improved stoves [19]. Around three-quarters (74 percent) of the households in ger districts also use additional electric stoves.

Due to the strong contribution to both HAP and AAP, in May 2019, the Government of Mongolia prohibited the distribution and use of raw coal in households and small businesses in Ulaanbaatar, instead introducing subsidized refined coal briquettes. A study assessing the impact of this initiative found that gers and houses using 'improved' fuel had a significantly lower pollution level (up to 86 ug/m^3) compared to households using traditional stoves and raw coal (up to 150 ug/m^3) [32]. However, even households with improved stoves still exceeded the WHO recommended air quality level of $PM_{2.5}$ greatly, highlighting that while the ban on raw coal was a step in the right direction, further action is required [32].

2.2 National legislation, strategy, and coordination

Relevant laws, including the Law on Air, the Law on Environmental Protection and the Law on Hygiene, establish legal frameworks to safeguard environmental quality and public health.[1] These laws empower governmental bodies to fund research, set norms for toxic substances, and suspend activities harmful to health and the environment. Specific regulations within

1 For a more detailed analysis of the legal landscape surrounding air pollution in Mongolia, please refer to "UNDP (2024): Legal Environment Assessment on Air Pollution and Noncommunicable Diseases, Mongolia."

these laws, such as those outlined in the Law on Air, prohibit activities contributing to air pollution and promote measures for its reduction.

In 1995, Mongolia passed the Law on Air, which aims to ensure the human right to live in a healthy and safe environment, maintain ecological balance, protect the atmospheric air in harmony with the current and future generations' interests and regulate relations pertaining to its sustainable use.

In 2017, Mongolia launched the national programme to reduce air and environmental pollution with the aim to reduce air pollutants by 80 percent, cut air and environmental pollution in half and only allow the use of raw coal in thermal power plants in Ulaanbaatar [33]. The programme includes a specific objective to improve air quality, under which there are 15 activities spanning four main categories: 1) strengthening air quality regulations, 2) research and response of impact of air pollution on human health, 3) prioritizing groups most vulnerable to air pollution and 4) strengthening public awareness of air pollution. This programme was designed to be implemented between 2017 and 2020, with annual reviews and evaluation conducted [34]. Unfortunately, many of the planned measures were not implemented due to insufficient funding [35].

Since 2019, the burning of domestic raw coal has been banned in Mongolia per Resolution No. 62 of 2018 [36]. Since the ban, coal-briquettes have been promoted as a replacement due to higher energy efficiency and reduced emissions of pollutants, among others. Assessing the impact of this policy in the Mongolian context, a 2022 study found that indoor carbon monoxide (CO) levels were lower in households using coal-briquettes compared to those using raw coal. However, CO levels still surpassed the WHO-recommended level of 4 mg/m^3 averaged over a 24-hour period [37]. A 2023 study also compared indoor air quality of gers in Ulaanbaatar following the coal ban. The study found that $PM_{2.5}$ concentration had decreased by 40 percent in ger housing using refined or improved fuels, but CO levels still exceeded recommended levels [32].

Air pollution is also identified as a key risk in Mongolia's *Vision 2050* [22]. Planned activities to tackle air pollution include raising awareness on air pollution sources and measures, reducing emissions from vehicles and intensifying redevelopment of ger areas. However, implementation of these measures has been challenging.

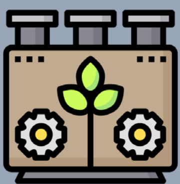
2.3 Implementation status of measures modeled under the investment case

Reduce household coal burning caused ambient air pollution by using gas and electric stoves for heating.

Domestic raw coal burning can contribute up to 80 percent of the total $PM_{2.5}$ emissions in Ulaanbaatar [38], with levels being the highest in the winter season [39]. Burning coal in the household to keep warm is common in Mongolia as half of the Ulaanbaatar population uses this method to heat gers [33]. In fact, ger households are the main source of air pollution and associated casualties in Ulaanbaatar as well as where the poorest and most vulnerable reside [40].

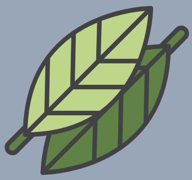
A traditional coal-powered cookstove used in a ger produces 300 mg of $PM_{2.5}$ per one megajoule (MJ) of heat produced, which is drastically higher than clean stove options which tend to produce levels of $PM_{2.5}$ from 1-10 mg per MJ of heat [40]. As such, in 2007 an agreement was signed between the United States of America's Millenium Challenge Cooperation and the Government of Mongolia which included the Energy and Environment Project. This project funded the energy efficient stove subsidy from 2008 to 2013. The results of this project found that while the energy efficient stoves required to be fueled less often, they also needed more coal per fueling and as a result there were no differences in overall fuel usage. However, the energy efficient stove households had $PM_{2.5}$ levels 65 percent lower and carbon monoxide levels 16 percent lower than traditional stove households [41].

As part of the national programme to reduce air and environmental pollution, one of the 15 measures dedicated to improving air quality specified identifying sources of HAP and the health risks [34]. However as of 2024 it is unclear how much of this measure has been implemented.



Powerplant conversion.

Behind household burning of coal, power plants are a leading contributor to $PM_{2.5}$ emissions. Estimates suggest around a quarter [28 percent] of $PM_{2.5}$ levels are attributable to power plants [23]. The three largest coal-powered power plants are the main source of district heating services, and use 3.6 million tons of coal each year to supply 80 percent of the energy needs in Ulaanbaatar [23]. Heat-only boilers are also used for a small number of buildings in Ulaanbaatar, often for industrial and commercial purposes. These also contribute to $PM_{2.5}$ emissions with estimates at around one-fifth of $PM_{2.5}$ levels [23].

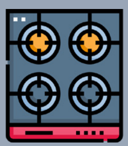


Reduce open fires.

Open fires are responsible for 8 percent of the burden of $PM_{2.5}$ in Mongolia. Part of this can be attributed to open air burning of waste materials in the agriculture and brick industry [42]. Assessing the cost, impact and scale of interventions to address this source of air pollution is complex. As a first step to gain insight into possible benefits of reducing open fires, this report estimates the economic and health benefits of a conservative reduction of open fires by 10 percent.

Using more fuel-efficient vehicles.

Latest WHO data indicates that there are 1.2 million vehicles registered in Mongolia [43], representing a 50 percent increase since 2016 [44]. This increase combined with limited highway and street capacity leads to heavy traffic and frequent traffic jams in Mongolia's capital [23]. Indeed, most of the vehicles in the country are located in Ulaanbaatar (61 percent) with nearly all (80 percent) not meeting emission standards and more than half being 11 years or older [45]. In addition to the vehicle exhaust, road dust, particularly from unpaved roads, contributes to air pollution [23]. Vehicle exhaust and road dust have reportedly been responsible for around 6 percent of $PM_{2.5}$ levels in Ulaanbaatar [23].



Reduce household air pollution by switching from coal to more efficient stoves.

Domestic burning of raw coal is the biggest source of ambient $PM_{2.5}$ emissions in Ulaanbaatar, contributing up to 80 percent of the emission burden [38]. Coal stoves are often used for heating and cooking, and coal remains the main source of fuel for cooking across Mongolian households [31]. This is particularly true for ger districts, where 70 percent of households used traditional coal stoves in 2021 [19]. These coal stoves also contribute to poor indoor air quality. In 2020, indoor particulate matter pollution was particularly high in gers and houses with traditional stoves (150 ug/m^3 and 128 ug/m^3, respectively) [32]. This is five- to six-times higher than the WHO recommended level of daily $PM_{2.5}$ exposure [1].

Table 1 summarises planned interventions to reduce air pollution which were based on a discussion with the Mongolian local team. The implementation status of these interventions in Ulaanbaatar are also described based on the most recent available evidence.

Table 1. Implementation status of interventions in Ulaanbaatar

Intervention	Status in Mongolia
Ambient air pollution	
Reduce household caused ambient air pollution by using gas and electric stoves for heating. 30 percent of Ulaanbaatar's households transition to gas and electric stoves over three years.	Burning coal in cookstoves is a common method used in Mongolia to heat households. Domestic coal burning is estimated to contribute as much as 80 percent of $PM_{2.5}$ emissions in Ulaanbaatar [38]. Previous efforts to switch to more energy efficient stoves did not reduce coal use but did decrease $PM_{2.5}$ levels [41].
Powerplant conversion. Over seven years, energy plants will be equipped with a $PM_{2.5}$ filter or replacing old plants with new and cleaner plants without loss of capital. Additionally, conversion could occur through the introduction of more sustainable energy such as solar or wind.	Power plants are a leading contributor to $PM_{2.5}$ emissions, responsible for around a quarter to $PM_{2.5}$ levels. The three largest coal-powered power plants use 3.6 million tons of coal each year [23].
Reduce open fires. Within one year and over the timeframe of the analysis (2024-2055), open fires will be reduced by 10 percent.	Open fires are responsible for eight percent of the burden due to $PM_{2.5}$ in Mongolia. The open air burning of waste materials in the agriculture and brick industry are partly responsible [42]. A possible intervention would entail the creation of awareness and increased control to prevent wildfires/ open fires, accidental or on purpose for agricultural reasons.
Using more fuel-efficient vehicles. Phasing out of old vehicles and/or replacing them with gas or more fuel-efficient vehicles over 31 years.	The number of vehicles in Mongolia has increased in recent years. Most vehicles are located in Ulaanbaatar and do not meet emission standards [45]. Vehicle exhaust and road dust is estimated to be responsible for <10 percent of $PM_{2.5}$ levels in Ulaanbaatar [23].
Household air pollution	
Over 15 years, one of the following three scenarios can be applied to Mongolia to replace coal stove use: 1. Coal to electric stove: replacing current coal stoves with electric stoves and a subsidy. 2. Coal to gas stove: replacing current coal stoves with stoves using liquified petroleum gas and a subsidy. 3. Coal to electric and gas stoves: replacing current coal stoves with electric stoves and stoves using liquified petroleum gas.	Coal is a common form of fuel used to heat stoves in Ulaanbaatar. Traditional coal-fired stoves lead to higher indoor pollution levels than improved stoves, and greatly exceed WHO indoor air quality guidelines in Mongolia [32].

2.4 Financing

Over the past decades, Mongolia has allocated significant but insufficient funds to tackling air pollution, with a reliance on support from external funding sources. Indeed, the 2020 report on air pollution spending by Mongolia's National Audit Office found that key ministries and implementing agencies do not allocate sufficient funds for the measures specified in Mongolia's National Programme for Reducing Air and Environmental Pollution [35]. Between 2008 and 2016, a total of MNT 550 billion (equivalent to US$227 million) was spent on air pollution reduction in Mongolia. This included US$106 million from external funds, US$50 million from donations, and US$79 million from the national budget (35). Between 2017 and 2020, US$161 million (MNT 456 billion) was allocated to reducing air pollution, of which US$101 million came from the national budget and the remaining US$60 million was derived from loans by the Asian Development Bank, the World Bank, the Government of China and other sources. In addition, from 2008 to 2016 the Government of Mongolia received around US$60 million in external assistance for air pollution reduction from various donors, including the Millennium Challenge Cooperation, the Governments of France and the United States of America, and the European Bank for Reconstruction and Development, amongst others [35].

In 2007, a US$285 million 5-year agreement from 2008 to 2013 was signed between the United States of America's Millenium Challenge Cooperation and the Government of Mongolia which included the US$47 million Energy and Environment Project. This project funded financial initiatives for energy-efficient and lower-emission alternatives in ger households as well as an upgrade of the electrical network and the development of the first commercial wind-powered electricity generation station in the country [46].

In December 2019, the Asian Development Bank approved a loan of US$160 to Mongolia for the Ulaanbaatar Air Quality Improvement Programme (Phase 2), supporting policy measures to supply clean heating through urban development solutions, increase air quality monitoring and supporting the National Committee for Air and Environmental Pollution Reduction [27].

Box 1. Gender and air pollution in Mongolia

Women face increased health risks from air pollution due to cultural norms and biological factors. Household responsibilities often place them in charge of cooking and heating with coal or biomass, exposing them to high levels of harmful particulate matter [47]. Women in Mongolia spend on average five hours each day on domestic and care responsibilities, increasing their exposure to household air pollution [48]. Moreover, long wait times seeking hospital treatment and caring for sick children negatively impacts caregivers' – primarily women's – productivity and earning potential [49]. Air pollution-attributable illness also increases pressure on the education and health sector in which the majority of employees are women (77 percent of Ulaanbaatar's education sector and 81 percent of the health and social welfare sector), likely leading to increased unpaid overtime [49].

Box 2. The impact of air pollution on child and maternal health in Mongolia

Air pollution poses a substantial 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 [50,51]. Pregnant women exposed to air pollution also face an increased risk of developing pregnancy-induced hypertensive disorders, postpartum depression, pregnancy loss, miscarriage and stillbirth [52]. In Mongolia, where pollution levels are significantly higher in winter months, women who become pregnant between November and January are more likely to have premature births in May and August, and fetal death is around 3.5 times more common during winter than summer [53].

Mongolia has demonstrated commitment to addressing this issue. One notable initiative is the Impact of Air Pollution on Maternal and Child Health Project (2018-2023), which was run as a collaboration between the Government of Mongolia, UNICEF and the Swiss Agency for Development and Cooperation. This project included research, policy dialogues and initiatives to improve air quality, such as the installation of small, low-cost air quality sensors across the country and a pilot initiative to improve community-based maternal and child healthcare [53].

Addressing the gendered impacts of air pollution in Mongolia requires a multifaceted approach. Promoting cleaner fuels and increasing women's access to healthcare and education are all crucial steps.

2.5 Challenges in addressing air pollution

Achieving lasting progress on air pollution requires sustained focus and collaboration across all levels of government. While Mongolia has implemented a variety of policies and programmes in recent years, including improved stoves and energy efficiency initiatives, significant challenges remain. The National Committee for Air and Environmental Pollution Reduction (NCEPR), previously responsible for overseeing policy implementation, has seen its structure and function change, resulting in reduced activity under the recent Government. However, consistent political commitment is essential to ensure these efforts have a lasting impact and translate into meaningful improvements in air quality.

A major hurdle is the continued reliance on coal for heating, particularly in Ulaanbaatar's ger districts, where 60 percent of the capital's population live [54]. The Government's 2019 ban on domestic raw coal use in six districts of Ulaanbaatar showed initial promise, halving the maximum $PM_{2.5}$ and PM_{10} concentrations and substantially reducing the number of days with extreme pollution in Ulaanbaatar [55]. However, challenges arose, including insufficient planning for stove compatibility, inadequate information dissemination and increased cases of carbon monoxide poisoning, highlighting the importance of comprehensive measures and updated standards to address air pollution and public health concerns effectively. Moreover, while more households are using improved stoves, HAP still exceeds WHO recommended levels even if improved stoves are used [32]. This highlights the need for finding alternative heating solutions and incentivising switching to electric or gas stoves.

Air pollution is exacerbated by urban migration. Ulaanbaatar is growing rapidly, nearly tripling in size from 1998 to 2018 [56]. The transport system has not caught up with this growth, with road infrastructure not fit for the number of vehicles, leading to congestion and further pollution. This led to Ulaanbaatar introducing an even-odd car ban in January and February 2024, where vehicles are only allowed on roads on alternating days based on their license plate number [57].

Another challenge is the lack of robust enforcement mechanisms. While emission standards exist, there are limited measures to penalize those who exceed them. This weak enforcement allows polluters to continue operating unchecked, jeopardizing public health and the environment.

Photo credit: Saruul Dolgorsuren

3

Methodology

3. Methodology

3.1 Institutional and context analysis

An institutional and context analysis (ICA) was conducted as part of the investment case. The ICA included a review of publicly available documents on air pollution and NCDs, peer-reviewed articles, reports, policy documents, interviews with relevant stakeholders (including from the National Committee of Pollution Reduction), in addition to the Legal Environment Assessment conducted by UNDP in collaboration with the MOH of Mongolia.

3.2 Economic modelling

A cost-of-illness quantitative analysis was conducted to assess the economic, health and social burden of air pollution. In addition, the health and economic benefits of investing in air pollution control interventions were assessed. Ambient air pollution (AAP) and household air pollution (HAP) were assessed separately based on the available resources and tools. More detail on the methodology is provided in the **Annex**.

The AAP analysis estimates costs at a national level, with a more detailed breakdown of costs provided for the Ulaanbaatar region. Bagakhangai and Baganuur districts of Ulaanbaatar were omitted from the analysis due to low data availability. In annex **Table A2**, the disease burden from which the AAP costs are calculated are presented at national and Ulaanbaatar district level.

The HAP analysis focusses on the urban population of Mongolia only, of which Ulaanbaatar accounts for around 70 percent. People living in rural communities are excluded. The HAP analysis therefore covers a total population of 2.37 million (urban population) out of Mongolia's entire 3.39 million inhabitants. The timeframes of the return on investment analysis for AAP are 2024–2030, 2024–2035, and 2024–2055. For HAP, a 31-year time horizon was used from 2024–2055.

The economic modelling was performed in US$. To convert to MNT, the official conversion rate from 1 June 2024 was used, where US$1 equals MNT 3369.68 [58].

Ambient air pollution

Assessing the health and economic burden of ambient air pollution (AAP)

We assessed the following aspects in the analysis:
1) **Exposure concentration level.** Level of exposure to air pollution was assessed by using $PM_{2.5}$ exposure concentration data provided by the air pollution monitoring network. This study used a model assessing six diseases which were chosen based on their prevalence and linkages with air pollution, including:

i. acute lower respiratory infection (ALRI)
ii. chronic obstructive pulmonary disease (COPD)
iii. ischemic heart disease (IHD)
iv. lung cancer
v. stroke
vi. diabetes mellitus type 2 (only available for AAP)

2) **Disease burden.** Burden of the six diseases attributed to elevated levels of $PM_{2.5}$, measured in annual deaths and incidence of new cases.

3) **Economic burden.** The economic burden of AAP was assessed by calculating the sum of the healthcare expenditures, workplace productivity losses and premature mortality. Workplace 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). Additionally, the analysis accounted for caretaker (i.e. caring for children) absenteeism and additional productivity losses from the added burden of family members caring for sick children.

4) **Economic benefits** for four interventions were estimated, including avoided healthcare costs to treat AAP-related illnesses, as well as avoided productivity losses from premature mortality, absenteeism, presenteeism and caretaking of ill family members.

- **Intervention A.** Household reduction by the introduction of gas and electric cooking stove and heating
- **Intervention B.** Powerplant conversion
- **Intervention C.** Open fire reduction
- **Intervention D.** Reduction of road transport pollution

Due to the complexity of the interventions, only Intervention A includes a cost analysis.

5) **Costing and return on investment (ROI) analysis.** Due to the complexity of the interventions, only Intervention A includes a cost and ROI analysis. The economic benefits of Intervention A were divided by implementation costs in order to determine the ROI. The resulting value (ROI) represents the return for every dollar invested.

Household air pollution

To estimate the health and economic burden attributed to HAP, the WHO Benefits of Action to Reduce Household Air Pollution (BAR-HAP Tool) was used [14,15]. The BAR-HAP Tool is a planning tool to assess the costs and benefits of different interventions that aim to reduce cooking-related household air pollution,

1) **Disease burden due to HAP-related morbidity** (incidence and prevalence) and mortality due to five diseases:

i. acute lower respiratory infection (ALRI)
ii. chronic obstructive pulmonary disease (COPD)
iii. ischemic heart disease (IHD)
iv. lung cancer
v. stroke

2) **Economic burden** including the health, social and environmental losses in addition to premature mortality. Social losses include time expenditures to collect firewood for fuel and time loss due to cooking on inefficient cookstoves. Environmental losses include forest loss from demand for cookstove fuel and carbon emissions from cookstove use [59].

3) **Benefits of interventions.** Three household energy transition interventions to transition from coal cookstoves were selected (**Table 2**). Note the model uses charcoal briquettes as a proxy for coal. The health benefits, economic benefits and costs of these interventions were estimated using the BAR-HAP Tool. As these interventions represent different options they are mutually exclusive and there are no combined benefits.

Table 2. Overview of HAP interventions

Intervention	Definition
A: Coal to electric stove	Replacing current traditional coal stoves with electric stoves with an uptake of 30% and a subsidy.
B: Coal to gas	Replacing current traditional coal stoves with stoves using liquefied petroleum gas (LPG) with an uptake of 30% and a subsidy.
C: Mixed model	Replacing current traditional coal stoves (ICS natural draft) with electric and LPG stoves. The model assumes an uptake of 5.9% of electric and 2.2% for gas stoves. This was based on a planned mixed transition currently under consideration by the Mongolian government, which aims to transition 40,000 households away from coal (25,000 to electric and 15,000 to gas).

4) Costing and ROI analysis.
The economic benefits of the intervention were divided by the cost in order to determine the ROI. The resulting value (ROI) represents the return for every dollar invested.

4

Results

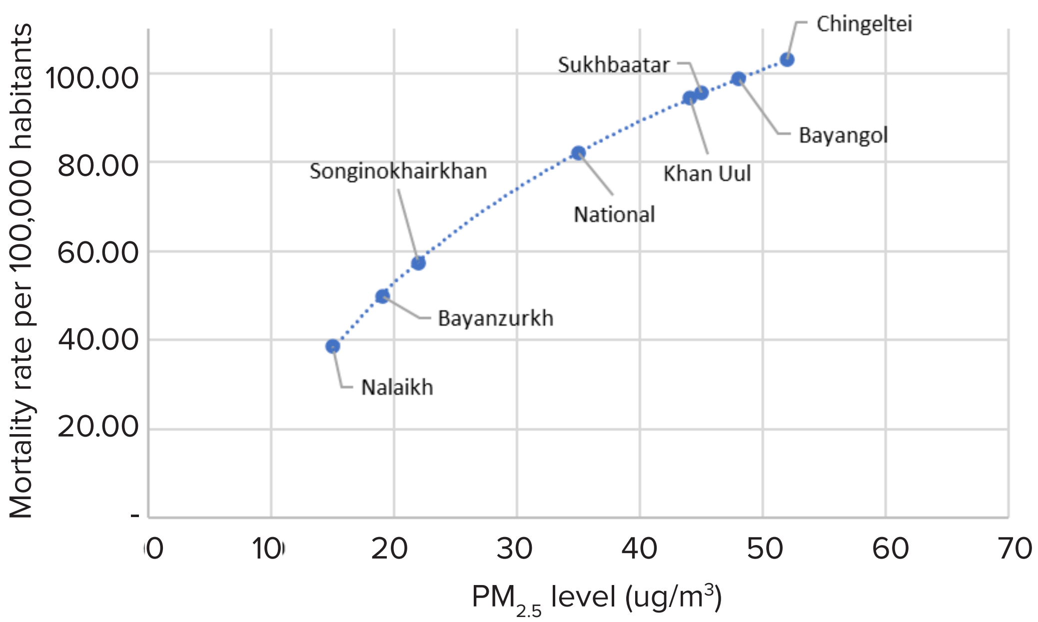
4. Results

4.1 Ambient air pollution analysis

Disease burden assessment

The high levels of air pollution drastically affect population health in Mongolia. We estimate that 2,839 deaths in 2024 can be attributed to $PM_{2.5}$ air pollution alone across the country. Across districts of Ulaanbaatar, the overall mortality rate is highly correlated with the pollution levels in each district, highlighting the need to improve air quality (**Figure 4**).

Figure 4. Annual $PM_{2.5}$-associated mortality rate per 100,000 habitants, by Ulaanbaatar districts and at the national level, 2024



Economic burden assessment

The total estimated economic burden in 2024 of ambient air pollution in Mongolia is US$269 million (MNT 905 billion) (**Table 3**). These costs can be broken down into direct healthcare costs, workplace productivity losses from absenteeism and presenteeism as well as productivity losses due to premature mortality. The AAP economic burden in Mongolia is mainly driven by losses due to premature mortality in people suffering from stroke and IHD (**Table 3** and **Figure 5**), while direct healthcare costs only make up 0.9 percent of the economic burden of AAP.

Figure 5. Distribution of economic burden attributed to AAP, 2024

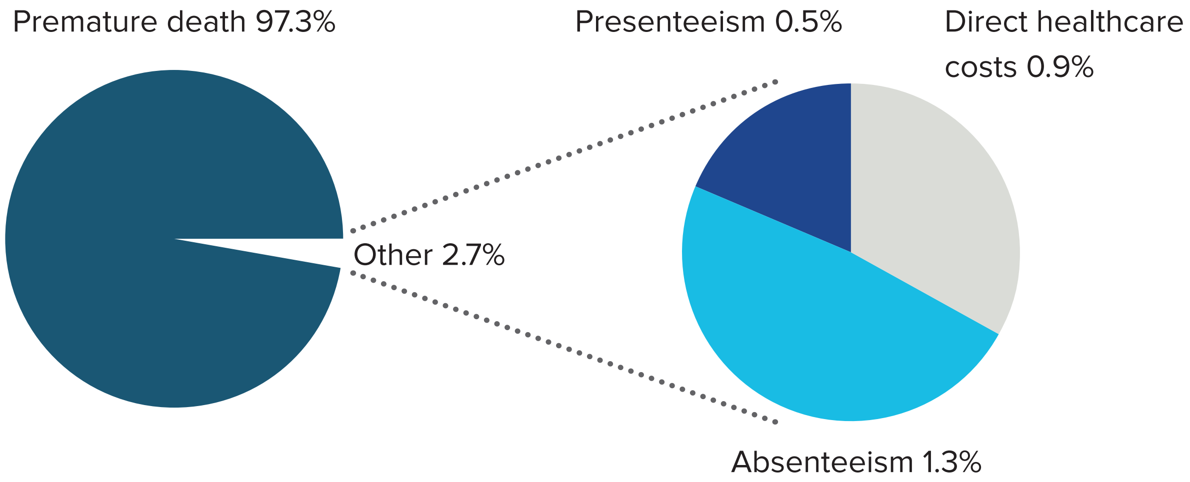


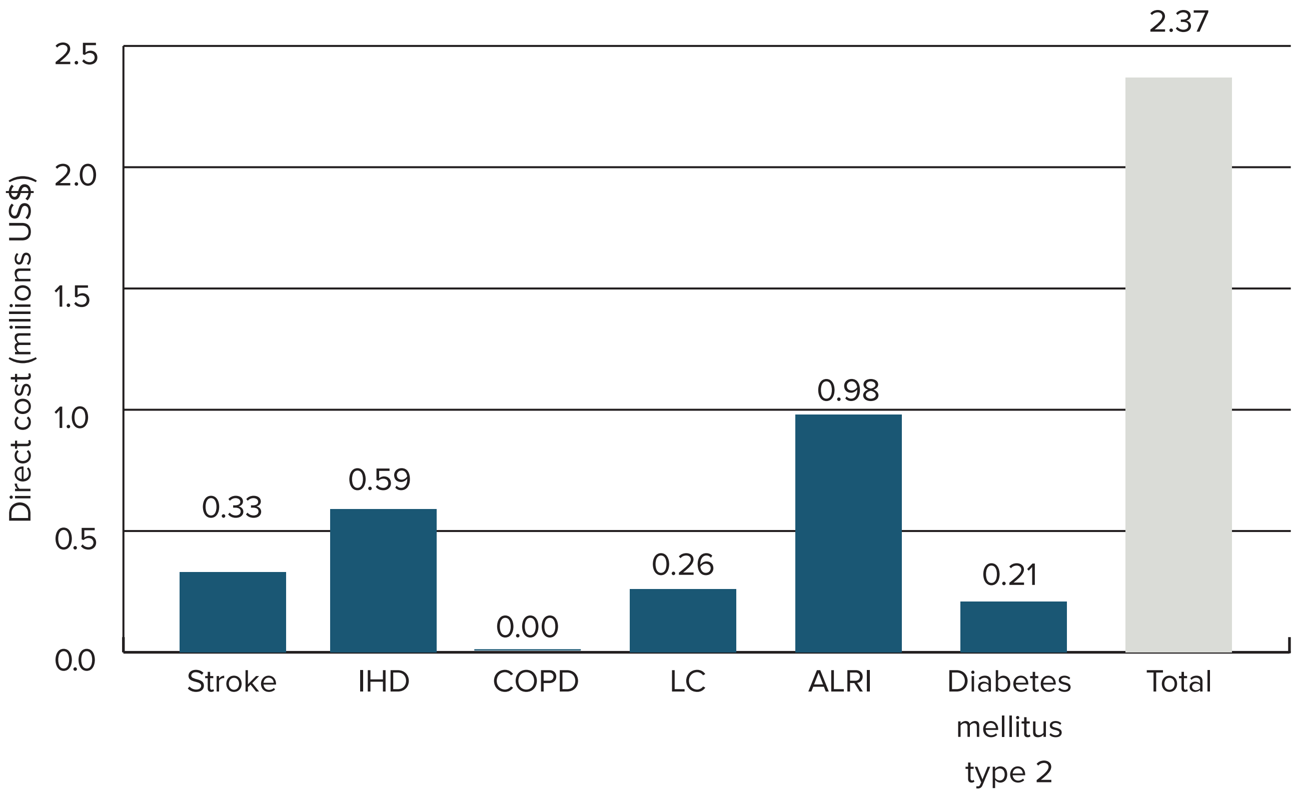
Table 3. Total national economic burden attributable to AAP, by disease, in 2024 (in US$ millions)

Burden	Costs by disease 2024 (millions US$)						
	Stroke	IHD	COPD	LC	ALRI	Diabetes mellitus type 2	Total
Indirect costs							
Absenteeism	0.87	2.25	0.03	0.04	0.21	0.07	3.46
Presenteeism	0.36	0.64	0.21	0.04	0.09	0.02	1.35
Premature death	119.24	102.99	4.77	13.16	18.75	2.61	261.51
Total indirect costs	120.46	105.87	5.01	13.23	19.05	2.70	266.32
	45%	40%	2%	5%	7%	1%	100%
Direct healthcare costs	0.33	0.59	0.00	0.26	0.98	0.21	2.37
	14%	25%	0%	11%	41%	9%	100%
Total economic burden	**120.79**	**106.46**	**5.01**	**13.49**	**20.03**	**2.91**	**268.70**

Healthcare expenditures

Total annual healthcare expenditures related to AAP were estimated at US$2.37 million (MNT 8.0 billion) (**Figure 6** and **Table 3**). Acute lower respiratory infections (ALRI), ischemic heart disease (IHD) and stroke represent 91 percent of the total direct costs.

Figure 6. Healthcare expenditures attributed to AAP, 2024



Workplace productivity losses

Workplace productivity losses include losses due to absenteeism and presenteeism. IHD and stroke represent the highest proportion of productivity losses (**Figure 7**).

Figure 7. Workplace productivity losses from absenteeism and presenteeism, attributable to AAP, 2024 (millions US$)

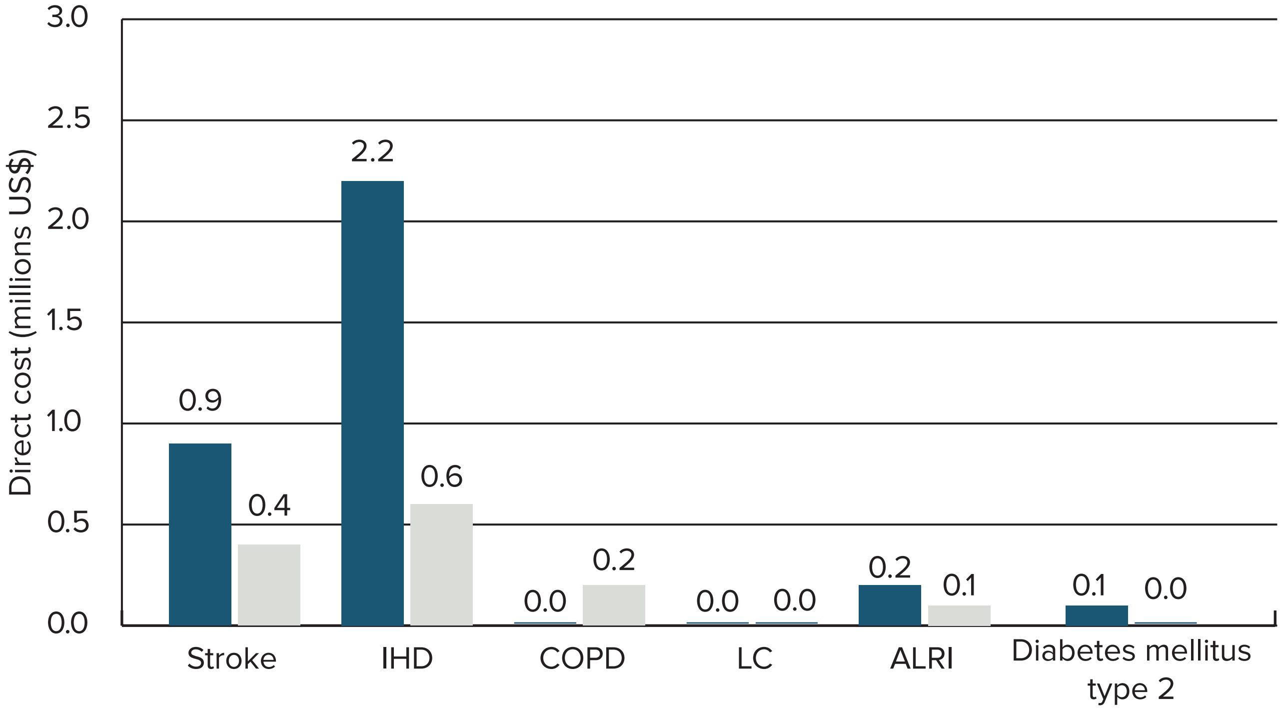
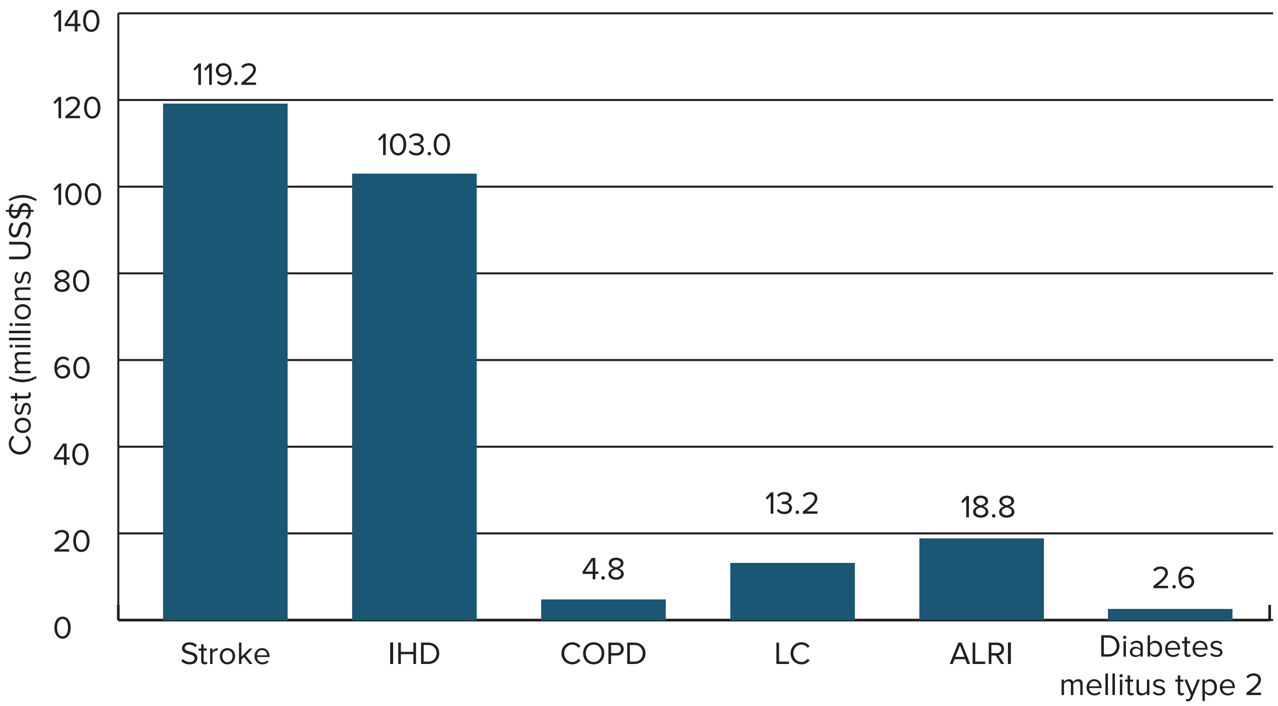


Figure 8. Productivity losses due to premature death, attributable to AAP, 2024



Costs and benefits of interventions

The focus for the four interventions was the city of Ulaanbaatar as there was direct $PM_{2.5}$ data for it districts required to estimate the health and economic effects. Only the cost for Intervention A, the conversion of traditional coal stoves to electric and gas stoves, was able to be estimated. This was due to the complexity and the lack of data and insights required to estimate the exact costs of the other interventions. Transitioning 127,279 households between 2024 and 2055 is estimated to cost US$367,723 (MNT 1.2 billion) (**Table 4**).

Table 4. Costs of Intervention A, replacing old coal stoves with new electric and gas cookstoves in Ulaanbaatar for a 30 percent uptake (in US$ thousands)

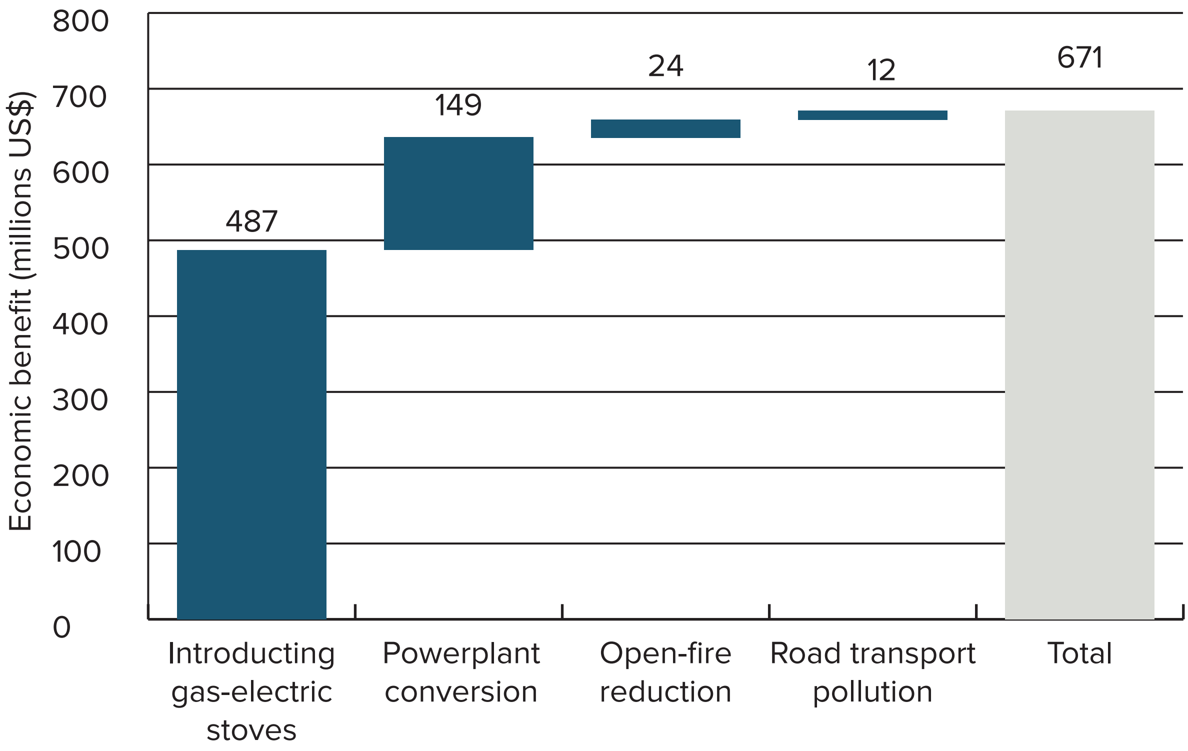
Cost	2024	2025	2026	2027	2028	2029	2030	Total		
								2024 - 2030	2024 - 2035	2024 - 2055
Capital cost	1,576	1,690	1,812	1,943	2,083	-	-			
Reccurent cost	3,111	3,336	3,577	3,835	4,113	4,410	4,729			
Total	**4,686**	**5,025**	**5,389**	**5,778**	**6,196**	**4,410**	**4,729**	**36,213**	**65,508**	**367,723**

The estimated health and economic benefits of the four AAP interventions are shown in **Table 5 and Figure 9**, respectively. Replacing coal-fuelled stoves with gas/electric stoves reaps the highest economic benefits (US$487 million or MNT 1.6 billion), followed by the conversion of powerplants (US$149 million or MNT 502 million). These two interventions also result in the biggest reduction in disease incidence and premature mortality. In total, all four interventions are estimated to avoid over 12,600 deaths and 126,000 disease cases.

Table 5. Estimated health benefits of the four interventions, 2024-2055

Intervention	Reduced incidence	Reduced premature death
Introducting gas-electric stoves (30% uptake)	91,746	9,195
Powerplant conversion (50% coverage)	28,121	2,818
Open fire reduction (10% reduction)	4,468	448
Road transport pollution (50% reduction)	2,169	217
Total	**126,504**	**12,678**

Figure 9. Estimated economic benefits of the four interventions, 2024-2055 (in US$ millions)



Return on investment

The ROI could only be determined for the intervention of replacing traditional cooking stoves with gas and electric stoves (Intervention A), given that only the costs for this intervention could be estimated. Replacing traditional cooking stoves with gas or electric stoves has an ROI of 2.4 when calculated both in the short-term (2024-2030) and the longer-term (2024-2055).

The economic benefit is estimated at US$487 million (MNT 1.6 trillion) and estimated costs are US$201 million (MNT 677 billion) (**Table 6**). For the other interventions only the benefits were estimated, which could be a guiding number of the maximum cost of a possible intervention.

Table 6. ROI for intervention (costs and benefits in US$ millions)

	2024–2030			2024–2035			2024–2055		
Intervention	Total discounted costs	Total economic benefits	ROI	Total discounted costs	Total economic benefits	ROI	Total discounted costs	Total economic benefits	ROI
A. Introducting gas-electric stoves (30% uptake)	32	76	2.4	54	167	2.1	201	487	2.4
B. Powerplant conversion (50% coverage)		-			33			149	
C. Open fire reduction (10% reduction)		5			9			24	
D. Road transport pollution (50% reduction)		1			3			12	
Total benefits		**82**			**213**			**671**	

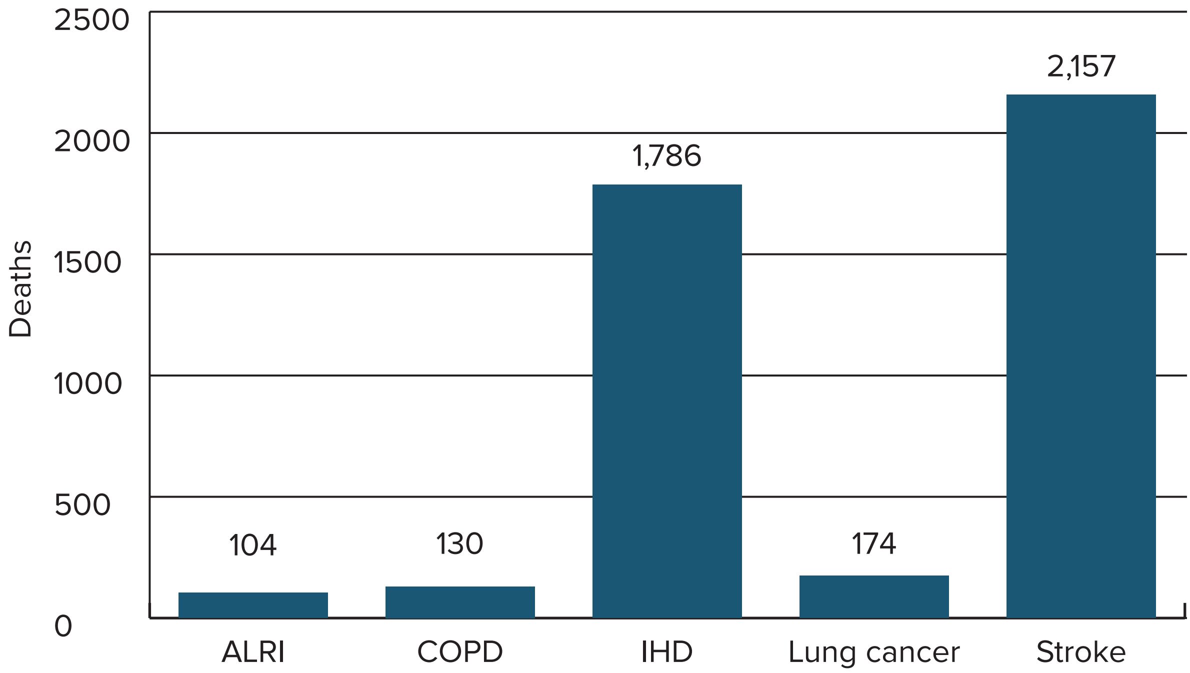
Note: For Interventions B,C and D, no intervention cost could be estimated. Therefore the total benefits is illustrative for the maximum cost the intervention may cost in order to have a ROI >1.

4.2 Household air pollution analysis

Disease burden assessment

In 2022, total deaths due to HAP in Mongolia reached an estimated 4,350 across all five diseases combined, with stroke and IHD causing the most deaths (**Figure 10**). This number includes deaths due to HAP and deaths caused by HAP-driven AAP. The latter is due to the assumption that HAP can contribute to AAP, thus being indirectly responsible for a proportion of AAP-attributable deaths.

Figure 10. Estimated deaths due to HAP in Mongolia in 2022



Economic burden assessment

The total annual economic burden attributable to HAP is US$1.2 billion (MNT 3.9 trillion), accounting for 7.6 percent of 2021 GDP. Premature mortality contributed the most to the burden, followed by social losses, healthcare expenditures and environmental losses (**Figure 11** and **Table 7**).

Figure 11. Total economic burden attributed to HAP in Mongolia, 2022

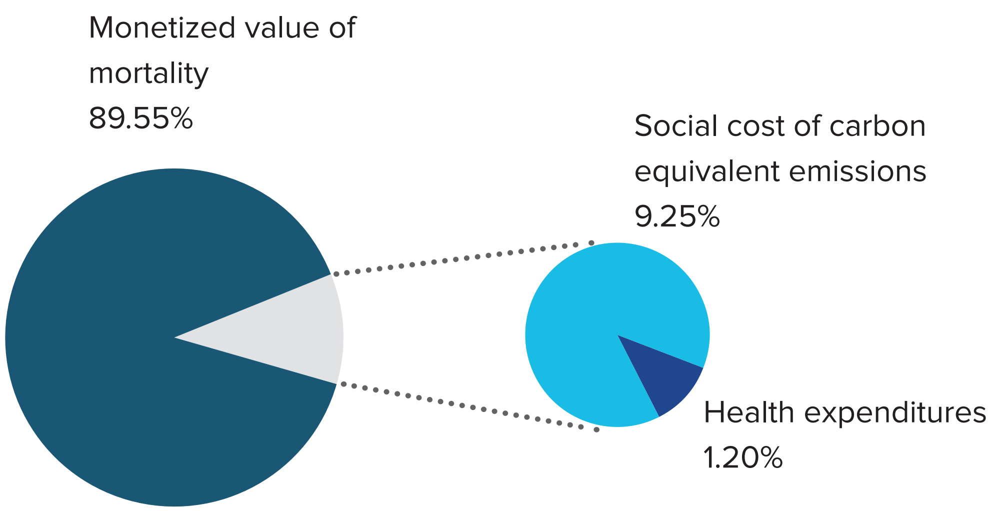


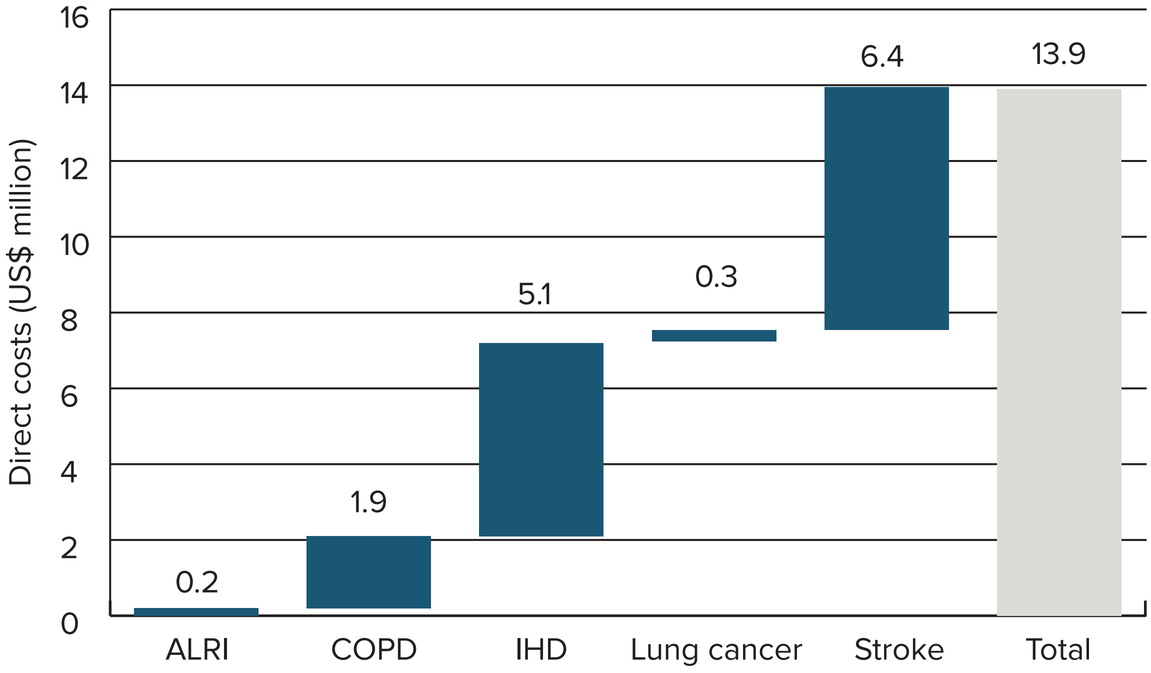
Table 7. Total economic burden attributable to HAP in Mongolia, by disease, 2022 (in US$ millions)

Burden	Costs by disease 2022 (millions US$)						
	ALRI	COPD	IHD	Lung Cancer	Stroke	Total	Per GDP
Indirect costs							
Premature mortality	8.9	289.1	129.0	1.5	605.8	1,034.2	6.8%
Carbon equivalent emissions	8.7	6.0	35.0	3.5	53.6	106.8	0.7%
Total indirect costs	**17.7**	**295.1**	**164.0**	**5.0**	**659.3**	**1,141.0**	**7.5%**
	2%	26%	14%	0%	58%	100%	
Direct healthcare costs	**0.2**	**1.9**	**5.1**	**0.3**	**6.4**	**13.9**	**0.1%**
	2%	14%	37%	2%	46%	100%	
Total economic burden	**17.9**	**297.0**	**169.1**	**5.3**	**665.7**	**1,154.9**	**7.6%**

Healthcare expenditures

Healthcare expenditures attributable to HAP include spending on medication, treatments and hospitalization, among others. **Figure 12** shows the healthcare expenditures for the five diseases. Heart disease and stroke have the highest expenditures, together accounting for 83 percent of HAP-attributable healthcare expenditures.

Figure 12. Healthcare costs attributable to HAP in Mongolia, 2022 (in US$ millions)



Health and economic benefits assessment

The HAP interventions modeled included:

A. shifting from traditional coal to electric stoves,
B. shifting from traditional coal to liquefied petroleum gas (LPG) or
C. a mixed model shifting traditional coal to both electric and gas stoves.

As these interventions provide different options on shifting to more efficient stoves, only one of the three interventions can be implemented at one time.

Annual costs of intervention

For each year in the 31-year period, Intervention A is estimated to cost the government around US$309,052 (MNT 1.0 trillion), Intervention B US$118,224 (MNT 398 billion) and Intervention C US$193,526 (MNT 652 billion). Table A2 in the Annex provides more detail on the annual costs of the three interventions.

Health benefits

Over the 31-year period, Intervention A is estimated to avoid 656 deaths, Intervention B 322 deaths and Intervention C 350 deaths. Table A3 in the Annex provides more detail.

Economic benefits

The economic benefits of the three interventions are divided into 1) avoided healthcare costs from treating HAP-attributable diseases, 2) time savings from not needing to collect fuel, and 3) and in the value of reducing two different sets of pollutants — a basic set including only

Kyoto protocol pollutants, and an extended set that also includes carbon monoxide, organic carbon, and black carbon (**Table 8**). Climate-forcing pollutants are only reduced for scenario B. This is because the transition to electricity still requires coal-fueled power plants, which are responsible for more pollutants.

Table 8. Annual economic benefits of the three interventions (in US$)

Economic benefit	Intervention benefits (US$)		
	A Traditional to electric	B Traditional to LPG	C Mixed transition
Value disease reductions	1,738,549	853,330	926,791
Time savings	253,783	125,941	135,689
Environmental Reduction in climate-forcing pollutants	-1,277,960	257,156	-423,147

Note: A. 30% traditional stove to electric stoves, B. 30% of traditional stoves ICS to LPG stoves, C. Mixed transtion 8.1% traditional stoves to 2.2% LPG and 5.9% electric

Return on investment

All three HAP intervention scenarios have a positive ROI (**Table 9**). The planned mixed transition to both electric and gas stoves (intervention C) has an ROI of 4.8. The ROI for the two interventions considering only one type of transition is slightly higher, at 5.6 to 1 for converting to electric stoves (Intervention A), and 7.2 to 1 for converting to LPG stoves (Intervention B). This is likely due to the higher coverage modelled in interventions A and B, whereas Intervention C coverage assumptions are based on an already planned policy intervention in the country.

Table 9. ROI of the three interventions (in US$)

Economic benefit	Intervention benefits (US$)		
	A Traditional to electric	B Traditional to LPG	C Mixed transition
Discounted costs	309,052	118,224	193,526
Discounted benefits	1,738,549	853,330	926,791
ROI	5.6	7.2	4.8

Note: A. 30% traditional stove to electric stoves, B. 30% of traditional stoves ICS to LPG stoves, C. Mixed transtion 8.1% traditional stoves to 2.2% LPG and 5.9% electric. Costs only included government costs, and the benefits only include the value of disease reductions

5

Conclusion

5. Conclusion

Our findings indicate that both ambient and household pollution pose a significant health, economic, social and environmental burden on the people of Mongolia. More than 2,800 lives and around US$369 million (MNT 905 billion) are lost each year from AAP. HAP causes its own burden, leading to an estimated 4,350 deaths and US$1.2 billion (MNT 3.9 trillion) in economic losses each year.

Coal-fired cookstoves are by far the leading cause of air pollution in the nation's capital Ulaanbaatar. Considering that more than half of the population resides in Ulaanbaatar, by acting now to assist households living in the capital city transition towards cleaner cookstoves, the Government of Mongolia can significantly reduce the national burden from air pollution.
Further, the investment case findings demonstrate that implementing interventions to reduce air pollution would reduce costs and save lives. To reduce AAP, replacing traditional cookstoves with electric or gas cookstoves, converting powerplants to be more efficient and less polluting, reducing open fires and road-transport pollution in Ulaanbaatar can avert US$671 million (MNT 2.3 trillion) in economic costs by 2055.

To reduce HAP, replacing current traditional coal stoves with liquefied petroleum gas stoves in Ulaanbaatar can save 10 lives and avert US$853 thousand (MNT 2.9 billion) each year generating an ROI of 7.2 to 1 31 years.

6

Discussion

6. Discussion

The widespread national economic and health burden of ambient air pollution (AAP) illustrates the need to invest in ambient air quality control efforts. AAP abatement measures will require a cross-sectoral effort to identify, implement, and enforce the best air quality control policies aligned with Ulaanbaatar's priorities. Considering the limited public awareness of the AAP's health impact, developing local ground monitoring systems will offer communities and stakeholders the tools to combat AAP's environmental and health burden. Implementing residential abatement measures can curb Mongolia's largest source of human-made AAP. At the same time, meeting climate change commitments will reduce the impact of natural sources of AAP. Investing in air quality control initiatives will enable Mongolia to reduce its health and economic losses in the short-term while paving the way for long-term sustainable growth.

In addition to AAP, household air pollution (HAP) due to cookstove use causes around 4,350 annual deaths as well as US$1.15 billion (MNT 3.9 trillion) in health-related economic, social and environmental losses in Ulaanbaatar each year. These estimates provide a clear case that households in Ulaanbaatar need to transition to more efficient cooking methods. The Government of Mongolia is already addressing this. Indeed, based on information received from the Ministry of Environment and Tourism of Mongolia, a resolution is currently under review to transition 15,000 households from coal usage to gas. In addition, 25,000 households in the ger district would receive access to 4kwt electric grid capacity extension for cooking and heating. This report estimates the costs and ROI for this planned mixed transition from coal to both gas and electric (HAP Intervention C). We estimate this planned transition would cost the government US$194,000 (MNT 652 million) annually. Note this estimate includes cost of stove subsidies as well as administration and programme costs, and around 65 percent of the total costs will be for stove subsidies. This planned transition could save 350 lives and avert US$28.7 million (MNT 97 billion) over 31 years, generating an ROI of 4.8 to 1.

A key challenge with this transition is that most ger households in Ulaanbaatar are not connected to a resilient electricity grid. Different strategies to overcome this in the medium-term (for example through mini-grid or off-grid solutions) as well as long-term (for example through decentralization and increasing the number of substations) have been discussed elsewhere [60].

Another point for consideration is that household energy transitions have implications on electricity production as well as imports. Indeed, increasing electricity consumption to reduce air pollution requires investments in the capacity of electricity transport, i.e. enhancing and strengthening the power grid and investing in the transition from polluting towards more sustainable electricity production. This can be achieved by, for example, installing $PM_{2.5}$ filters in coal-fueled power plants, or transitioning to gas-powered plants as well as wind, solar or nuclear energy. Points for discussion are which subsidies are foreseen by the government to incentivize a behavior change by the population without affecting the economy. By investing in energy infrastructure in a collaborative manner, Mongolia can accelerate its development and generate substantial health, economic, social and environmental benefits. This benefit may be greater for women and children who bear the most harms caused by HAP due to cookstove use.

Our economic burden findings are lower than recently published data by Egerstrom et al. [61] who quantified the number of avoidable annual deaths and associated economic benefits from meeting the WHO air quality guidelines in Mongolia [24]. This is likely because Egerstrom et al. takes a wider disease scope and use a higher Value of a Statistical Life (VSL), resulting in a higher mortality rate per 100,000 persons.

This study has key limitations. This analysis was unable to investigate the implementation of all four of the AAP-reductions interventions in Ulaanbaatar and nationally. This is largely due to data limitations. In addition, this study used different models with varying methods for AAP and HAP, which apart from the effects on morbidity and mortality could also result in deviations in the included costs. Furthermore, the BAR-HAP Tool is limited in the sense that it does not include indoor air pollution through heating, which could lead to an underestimate of the overall air pollution burden. Both tools use VSL to calculate the cost of a premature death. This approach could lead to an overestimate of the cost of avoided premature deaths and lead to higher ROIs. A more refined way of calculating the cost of a death, by age and context should be considered. In other words, the value of a premature death is often seen as age dependent as are comorbidities. Lastly, the BAR-HAP Tool does not include productivity loss due to absenteeism and presenteeism caused by disease morbidity. Including these would increase the economic burden of HAP and have a positive effect on the ROIs. Further details on limitations are provided in the **Annex**.

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7

Recommendations

7. Recommendations

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

1. Strengthen coordination among key stakeholders.

As the causes and effects of air pollution are far-reaching, improving air quality requires political commitment across different sectors. Therefore, a high-level mechanism should be in place to coordinate the many past and ongoing efforts of fighting air pollution in the country and ensure continuity and sustainability of interventions and policies across governments. This could involve reinstating the National Committee for Air and Environmental Pollution Reduction, and encouraging participation by key ministries including Ministries of Health, Economy, Energy, Environment, Construction, Road and Transport, amongst others. Encouraging participation and strengthening collaboration with national gender machineries and gender focused CSOs is also vital to address air pollution and advance gender equality in health outcomes in the country.

Additional mechanisms should be in place to improve engagement among the national, regional and local levels. Government officials can collaborate with NGOs and community organizations as needed to support community buy-in and support for transitioning from traditional cookstoves to electric stoves among other air pollution reduction measures.

Of note, Mongolia has already committed to enhancing national coordination structures to better respond to the health impacts of pollution. Indeed, in the framework of this project, the country has committed to developing a national multisectoral action plan on pollution and health.

2. Incentivize shifts to alternative energy sources for households.

The vast majority of ambient air pollution in Mongolia is caused by coal used for heating and cooking in households. Importantly, this doesn't just contribute to AAP, but burning coal also leads to poor indoor air quality, making it a major contributor to the HAP-related health and economic burden. To improve both AAP and HAP, Mongolia should focus efforts to shifting to liquefied petroleum gas or electric-powered stoves in Ulaanbaatar as this generates the most favorable ROIs, saves the most lives and produces the most economic societal and environmental benefits. To this end, the country should build on previous efforts to provide more efficient stoves and heating systems across the country [62,63].

Importantly, the Government of Mongolia should ensure that such energy transitions do not negatively affect the economy. Indeed, Mongolia should recognise the potential economic impact of transitioning away from traditional fuels. Energy providers should collaborate with the government to develop a plan for subsidies and financing mechanisms. This will incentivize the population to adopt cleaner technologies without causing economic hardship. Moreover, this should be accompanied by public awareness campaigns to communicate the health, environmental and economic benefits of switching to alternative food and heating sources (see also recommendation 5).

To further enhance uptake, Mongolia should provide technical support and training for the installation, use and maintenance of electric stoves. This can be achieved through community workshops or collaboration with local technicians and electricians.

3. Invest in the AAP interventions modelled under the investment case.

Reduce AAP by replacing traditional coal based cookstoves with electric or gas (see above), modernising traditional coal power plants to more efficient energy sources, reducing open fires and reducing road-transport pollution. While not all the above interventions could be costed due to a lack of data, each intervention provides key health, environmental and economic benefits and helps address air pollution in a multisectoral way.

Recently, Mongolia has made efforts to combat congestion in Ulaanbaatar through an even-odd car ban, which only allows vehicles to be used on alternate days based on license plate numbers. The transportation package in the investment case suggests and models the phasing out of old vehicles and upgrading to more fuel-efficient cars. Shifting to higher fuel efficiency could be implemented by imposing a minimum efficiency threshold for manufacturers while fining non-compliance, or by introducing subsidies for fuel-efficient vehicles alongside taxation of less fuel-efficient cars. Mongolia could look to other countries and regions that have recently made progress on policies tackling fuel emissions of cars and vans. 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 [64].

4. Scale up monitoring of air pollution.

While data on air pollution and related indicators is available for Mongolia’s capital, this is not the case for other cities and more rural areas in the country. Mongolia should increase and expand national air pollution monitoring efforts and support ongoing research efforts to better understand the causes of ambient and household air pollution throughout the country. This could also involve developing local air quality monitoring systems or include public reporting, thus empowering communities to hold stakeholders accountable for progress.

Mongolia should also consider increasing its use of gender-disaggregated data across population statistics, particularly in Ger areas [49]. Reliable gender-disaggregated data is essential for gender-sensitive planning, monitoring and implementation of air pollution management.

5. Raise awareness of the dangers of air pollution and the benefits of its reduction.

Create public awareness campaigns to educate citizens about the health risks of household and ambient air pollution. Campaigns should also cover the key causes of air pollution in the country and associated health risks as well as ways to reduce pollution. This includes highlighting the benefits of the priority intervention for Mongolia, which is to replace coal use in households with alternative fuel sources.

It is often most effective to communicate through a variety of media outlets, including TV, public transport and social media. This multimedia approach has for example been used by a recent Occupational Safety and Health campaign put together by key stakeholders across government and civil society, including the Ministry of Labor and Social Protection, the Occupational Safety and Health Center of Mongolia, the Confederation of Mongolian Trade Unions, and the Mongolian Employers' Federation [65].

Finally, as mentioned in the methodology section, our estimates for the health and economic burden of AAP were derived from epidemiological data and pollution exposure levels from 2019. These estimates were then adjusted for population changes for every year from 2019 to 2050. For a matter of clarity and readability, we chose to present the results from 2024, although 2019 remains our baseline year. This clarification is essential to understand that our model did not capture changes in the main parameters between 2019 and 2024.

Annex

Annex

A.1 Extended methodology

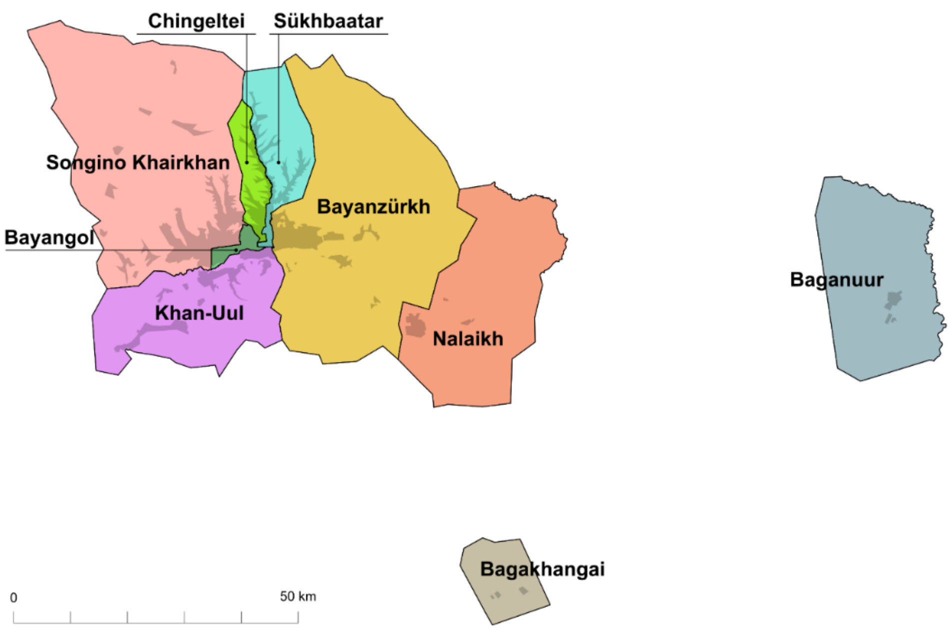
Estimating the economic burden

To understand the health and economic impact of air pollution in Mongolia, two approaches were undertaken including the assessment of ambient air pollution (AAP) as well as the assessment of household air pollution (HAP). This study used a model assessing six diseases which were chosen based on their prevalence, including:

1) acute lower respiratory infection (ALRI),
2) chronic obstructive pulmonary disease (COPD),
3) ischemic heart disease (IHD),
4) lung cancer, and
5) stroke
6) diabetes mellitus type 2 (only available for AAP as the BAR-HAP Tool did not allow to include an extra disease).

Due to limited data availability, the geographic scope of both analyses focuses on the Ulaanbaatar districts (see **Figure A1**). Districts Bagakhangai and Baganuur were omitted from the study due to low data availability. In the Annex we include additional data that presents estimates at a national level. The timeframe of the data analysis is 2019 to 2025 or in some cases projections to 2050. The longer time horizon aims to estimate the long-term impact that public environmental health interventions have.

Figure A1: Map of the districts in Ulaanbaatar



Ambient air pollution

The first part of this report describes results of the AAP model. To do this an Integrated Exposure Response (IER) model in R and an Excel model (developed by RTI International) was used to calculate the attributable burden caused by AAP. The analysis includes four aspects:

1) Exposure concentration level

To assess the level of exposure to AAP this study uses $PM_{2.5}$ exposure concentration data provided by the Mongolian national air pollution monitoring network with more than 42 monitoring ground stations, of which, 18 are located in the capital Ulaanbaatar.

2) Disease burden

To calculate the excess disease burden due to elevated levels of AAP, the difference in the number of deaths and cases between Mongolia's current pollution levels and the number of deaths and cases of disease that would occur if a healthier pollution standard were achieved were estimated.

For this report, it was agreed to use the WHO's recommended maximum annual exposure of 5 $\mu g/m^3$ [12,66]. We use age-specific exposure-response functions that estimate the risk of someone developing or dying from one of the six diseases of interest (ALRI, COPD, IHD, lung cancer, stroke or diabetes) based on the concentration of $PM_{2.5}$ they are exposed to [67].

The analysis then calculates annual deaths and new cases of the six diseases attributable to Mongolia's 2024 AAP from the following variables:

a) average $PM_{2.5}$ exposure concentration in 2024;

b) the number of people exposed to that $PM_{2.5}$ concentration;

c) the age distribution; and

d) the baseline disease incidence and deaths from the six diseases [67].

We used Mongolia's 2022 age distribution (68) to estimate the number of people at risk for each specific AAP-attributable disease. Methods for defining the detailed health risks due to long-term exposure to $PM_{2.5}$ have been described elsewhere [67,69]. To estimate the impact of safer AAP levels on disease burden in 2024, we followed the abovementioned process and used the target $PM_{2.5}$ concentration level of 5$\mu g/m^3$.

3) Economic burden

To calculate the cost-of-illness associated with AAP, we calculate the sum of the healthcare expenditures, productivity losses and premature mortality:

a) healthcare expenditures for treating AAP-attributable diseases,

b) economic value of premature mortality due to AAP-attributable diseases,

c) productivity losses from AAP-attributable disease incidence, which 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). Additionally, given that children under the age of 15 often require adult family members to care for them, the analysis accounted for the caretaker absenteeism for cases of AAP-attributable ALRI in children (i.e., days of work someone misses) [69]. As women in Mongolia typically act as the primary informal caretaker for sick family members, this value represents the additional productivity losses that Mongolia experiences because of the added burden that Mongolian women face when caring for children sick with AAP-attributable ALRI.

4) Economic benefits for four interventions

Based on the main causes of AAP in Mongolia, we developed four transition interventions that can reduce ambient air pollution $PM_{2.5}$. These are: introduction of gas or electric stoves, powerplant conversion, open fire reduction and the reduction of road transport pollution.

Intervention A. household reduction by gas and electric cooking stove and heating

For this intervention, we set the following assumptions:

- The $PM_{2.5}$ contamination level was set at 60 percent, a level indicated by the World Bank [19]. The general residential coal combustion contribution effect on $PM_{2.5}$ concentration is estimated at 8.9 percent for Ulaanbaatar. If we include also residential coal combustion, it will reach 12 percent. However, for our intervention we will use higher values as contamination occurs close to people's homes.
- A timeframe of five years.
- Focus on Ulaanbaatar, with an included population of about 1.45 million
- An uptake of 30 percent of the population transitions, which represents 117,730 households taking an average household size of 3.7 people.
- The average cost for a gas or electric stove per included household is set at US$62.00.
- The excess electricity required for this is assumed to be produced without any impact on the $PM_{2.5}$ concentration. Mongolia can achieve this by using sustainable energy like solar or wind energy, or by introducing filters on coal-powered electricity plants.

Intervention B. powerplant conversion

For this intervention, we set the following assumptions:

- The estimated reduction of primary as well as secondary $PM_{2.5}$ is conservatively estimated at 50 percent. This estimate is loosely based on production data from the Netherlands that currently produces approximately 40% of CO_2 neutral (excluding Nuclear) [70].
- The costs of electricity are assumed to stay the same considering current developments in electricity production [71].
- The timeframe is 15 years (a lag period of 7 years is included before any effects become noticeable).

Intervention C. Open fire reduction

For this intervention we set the following assumptions:

- Although details are missing on the exact origin of the fires and required costs for prevention, we will run three hypothetical interventions where open fires will be reduced by 10 percent. The main reason is that it is difficult to estimate.
- The averted economic burden could be reinvested into interventions which help reduce the health burden if a positive ROI is achieved.

Intervention D. Road transportation

For this intervention, we set the following assumptions:

- Phasing out of old vehicles and/or replacing them with gas or more efficient ones.
- Timeframe of 5 years.
- Reduction of 50 percent reduction of primary $PM_{2.5}$ concentration caused by road transportation through upgrading the vehicle stock to new more fuel- efficient cars in combination with other interventions [22].
- The estimated equivalent percentage of sector specific $PM_{2.5}$ was set at 26.1 percent, as to hold a conservative measure since gas as well as electric cars do cause other types of pollution.
- Like in the previous interventions we did not include any intervention cost but show the avertable health and economic. This can be an indicator of the maximum intervention cost if a positive ROI is desired.
- The introduction of electric vehicles is not seen as a viable option as $PM_{2.5}$ emissions don't differ between the combustion engine vehicle and electric vehicle [23].

The transition interventions were analysed by adjusting existing models provided by RTI. For the interventions with insufficient information on the cost of intervention we calculated the likely reduction of the economic and health burden. The cost-savings could then be interpreted as the maximum cost of intervention if a ROI > 0% would be required to have a return beyond the investment.

5) Cost analysis

Only for intervention 'A' the conversion of coal stoves to electric stoves we estimated the cost of the intervention. The costs consist of two parts capital costs and recurring costs. The capital costs consist of the actual conversion of the old into the new electric and gas cookstoves, and the recurring costs consist of extra costs related to the change in fuel usage. The capital costs are occurring in the first five years, when the actual conversion takes place. The recurring costs are yearly and will proceed during the whole period.

It was not possible to estimate the costs of the other interventions due to their complexity. The road transport intervention in particular includes broad range tactics focus points such as fuels, phasing out older cars, traffic limitations, speed limits, making it considerably difficult to estimate a cost.

6) Return on investment (ROI) analysis

The economic benefits of the intervention was divided by the cost to implement the intervention in order to determine the ROI. As only the cost for intervention A was able to be calculated, only this intervention has an estimated ROI.

Household air pollution

To estimate the disease burden and the economic burden attributed to HAP, the WHO Benefits of Action to Reduce Household Air Pollution (BAR-HAP Tool), a planning tool to assess the costs and benefits of different interventions that aim to reduce cooking-related household air pollution, was used. The tool's structure and methods have been described in the BAR-HAP Tool user guide [14,15].

The BAR-HAP Tool quantifies the extent to which HAP due to cookstove use in Mongolia contributes to disease and economic burden.

1) Disease burden: Morbidity (incidence, prevalence) and mortality due to four diseases: a) acute lower respiratory infections in children under five; b) cardiovascular disease (i.e. stroke, ischemic heart disease), c) chronic obstructive pulmonary disease, and, d) lung cancer.

2) Economic burden [59]: including the health, social and environmental losses in addition to premature mortality.

a) Healthcare expenditures: Expenditures to treat HAP-attributable diseases estimated by using incidence rates, excess incidence by cooking method, fatality rates, including costs of hospitalization, treatments, medication, laboratory and diagnostic tests amongst others.

b) Social losses: time expenditures to collect firewood for fuel and time loss due to cooking on inefficient cookstoves. These are estimate with an opportunity hourly rate multiplied by the saved timed.

c) Environmental losses: kilograms of wood biomass loss from forests because of demand for cookstove fuel and tons of carbon equivalent emissions from cookstove use. This is estimated by also including the different fuel needs and emissions of each cookstove type. The change of equivalent carbon emissions is multiplied by a cost per ton, which comes from literature.

d) Premature mortality: associated with HAP-attributable disease mortality using the value of a statistical life for the estimate.

3) Interventions analyzed

Together with the UNDP Mongolia team and feedback from a stakeholder meeting in May 2023, we developed three household energy transition interventions from existing baseline levels of cookstove use. We used a 15-year programme duration. The three interventions are: A. shifting from coal to electric stoves, B. shifting from coal to gas or C. a mixed model shifting coal to both electric and gas stoves.

Table A1. Overview of HAP interventions

Intervention	Definition
A. Coal to electric stove	Replacing current coal stoves (Improved cookstove, (ICS) natural draft) by electric stoves with an uptake of 30% and a subsidy
B. Coal to gas	Replacing current coal stoves (ICS natural draft) by stoves using liquefied petroleum gas (LPG) with an uptake of 30% and a subsidy.
C. Mixed model	Replacing current coal stoves (ICS natural draft) with electric and LPG stoves. An uptake of 5.9% of electric and 2.2% for gas stoves was used. These levels were estimate based on the given number of 40,000 households transitioning to LPG and electric cookstoves.

The health benefits, economic benefits and costs of these interventions were estimated by using the BAR-HAP Tool.

4) ROI analysis

The economic benefits of the intervention was divided by the cost to implement the intervention in order to determine the ROI.

Limitations

High quality data are critical for analyses using quantitative models, including the BAR-HAP and AAP model. For this investment case, suitable data were available, and few assumptions were made. The strength of this analysis is the use of national data sources were possible. Data sources included: the Metropolitan Statistical Office, Mongolian National Statistical Organisation, World Bank and Institute for Health Metrics and Evaluation (IHME) Global Burden of Disease, 2019. The majority of data were provided by national experts and in case international data was taken confirmation by national experts were received. In this section we describe the data limitations.

The HAP interventions focus on cooking methods. Heating methods were not included as the BAR-HAP Tool does not provide this. The exact impact of this omission is not clear, but it is likely that numbers of pollutants could be even more reduced if heating alternatives are included.

To estimate the health burden of AAP, $PM_{2.5}$ data was obtained for the Ulaanbaatar districts and provided to the Mongolian team by National Centre for Public Health in Mongolia. However, due to limited data availability, not all districts were included, and a limited timeframe was chosen. The impact of the missing data from some districts on the accuracy of the model is expected to be small as they are more remote settings with relatively small populations. Baganuur has a population of 3,024; and Bagakhangai 3,864. The limited period could have affected the accuracy of the burden estimate as the used average and trend could under or overestimate the results. Additionally, as the $PM_{2.5}$ data included extremely high outliers, we removed those using the Interquartile Range (IQR) 1.5 rule. In short, this common method removes any value that is 1.5 x IQR greater than the third quartile is designated as an outlier and any value that is 1.5 x IQR less than the first quartile is also designated as an outlier.

Due to limited future migration data estimates, we were unable to include migration forecasts between districts in our analysis. If migration between districts is common, this could impact our results. Lastly, the AAP model included wind-blown dust as a crucial factor for AAP, causing a big economic burden. For the analysis in the AAP model the burden caused by wind-blown dust was set at 15%. There are a number of uncertainties surrounding wind-blown dust. One of them is that the composition of this dust might vary from other sectors such as households and traffic. This equitoxicity might cause over or underestimates. Additionally, wind-blown dust could be cross-border dust and thus not be impacted by national interventions (72). However, further research is required on the cause of the wind-blown dust and interventions. Finally, the RTI model for the AAP calculations used a value of a statistical life (VSL) approach which attaches a value to a person's life. This approach may lead to overestimations of the economic burden. We used a conservative value of US$210,000 based. This was taken from an article that specifically calculated the VSL for Mongolia and we adjusted it for inflation and exchange rate [73].

A.2 Additional results

Disease burden

Ambient air pollution disease burden

Table A2. Mongolia's annual average AAP, population count and disease burden (mortality) national and for Ulaanbaatar in 2024

Region	$PM_{2.5}$	Pop	Stroke	IHD	COPD	LC	ALRI	Diabetes mellitus type 2	Total deaths	Share of national deaths	Mortality rate (per 100,000 habitants
National	35	3,454,012	1,244	1,241	78	169	81	26	2,839		82.21
			44%	44%	3%	6%	3%	1%	100%		
Ulaanbaatar regions											
Bayangol	48	246,500	108	105	7	14	8	2	244	8.6%	98.99
Bayanzurkh	19	400,319	86	90	5	12	5	2	200	7.0%	49.85
Khan Uul	44	218,490	91	89	6	12	6	2	206	7.3%	94.45
Songinokhairkhan	22	356,155	88	91	5	12	5	2	204	7.2%	57.33
Chingeltei	52	156,990	72	69	5	10	5	1	162	5.7%	103.06
Sukhbaatar	45	150,727	64	62	4	9	4	1	144	5.1%	95.63
Nalaikh	15	40,595	7	7	0	1	0	0	16	0.5%	38.46
Ulaanbaatar			**516**	**513**	**32**	**70**	**34**	**11**	**1,176**	**41.4%**	

Intervention cost analysis

Annual costs of HAP interventions

Intervention 'C' has the lowest total cost as it also a lower coverage than the other two. A notable difference is the fuel cost between electric and LPG. This is caused to a great extent by the differences in price, but above all the cooking efficiency of electric versus gas stoves.

Table A3. Average cost of intervention per year (in US$)

Cost type	Intervention costs (per year)		
	A Traditional to electric	B Traditional to LPG	C Mixed transition
Administration	34,138	34,138	34,138
Stove subsidy	210,421	57,317	126,434
Programmeme	64,492	26,769	32,954
Total government cost	309,052	118,224	193,526
Stove cost after subsidy	26,910	13,353	-7,754
Fuel cost after subsidy	-1,488,992	-418,072	-702,476
Maintenance	60,271	29,910	32,225
Average learning cost	8,258	3,428	4,219
Total private cost	**-1,393,553**	**-371,381**	**-673,786**
Total government and private cost	**-1,084,501**	**-253,158**	**-480,260**

Note: A. 30% traditional stove to electric stoves, B. 30% of traditional stoves ICS to LPG stoves, C. Mixed transtion 8.1% traditional stoves to 2.2% LPG and 5.9% electric

Health benefits

Health benefits from HAP interventions

The health benefits of the three interventions are shown in **Table A4**. It shows the reduced premature deaths and the reduced morbidity (incidences). Additionally, it distinguishes between direct and indirect health benefits. Direct benefits are directly related to HAP and indirect benefits are due to spillover of HAP to AAP. Furthermore, it shows the avoided DALYs (Disability Adjusted Life Years) of the 15-year programme duration.

Table A4. Health benefits of the three interventions (# persons)

Cost type	Intervention costs (per year) A Traditional to electric	B Traditional to LPG	C Mixed transition
Premature deaths reducton (yearly)			
Direct	13.3	6.6	7.1
Indirect	7.8	3.8	4.2
Total premature death reduction	21.2	10.4	11.3
Reduced morbidity (yearly)			
Direct	423.7	208.3	226.0
Indirect	248.6	122.2	132.6
Total morbidity reduction	**672.3**	**330.6**	**358.6**
DALYs avoided during 31-year programmeme duration	**5,807.8**	**2,852.0**	**3,096.4**

Note: A. 30% traditional stove to electric stoves, B. 30% of traditional stoves ICS to LPG stoves, C. Mixed transtion 8.1% traditional stoves to 2.2% LPG and 5.9% electric

Photo credit: Saruul Dolgorsuren

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