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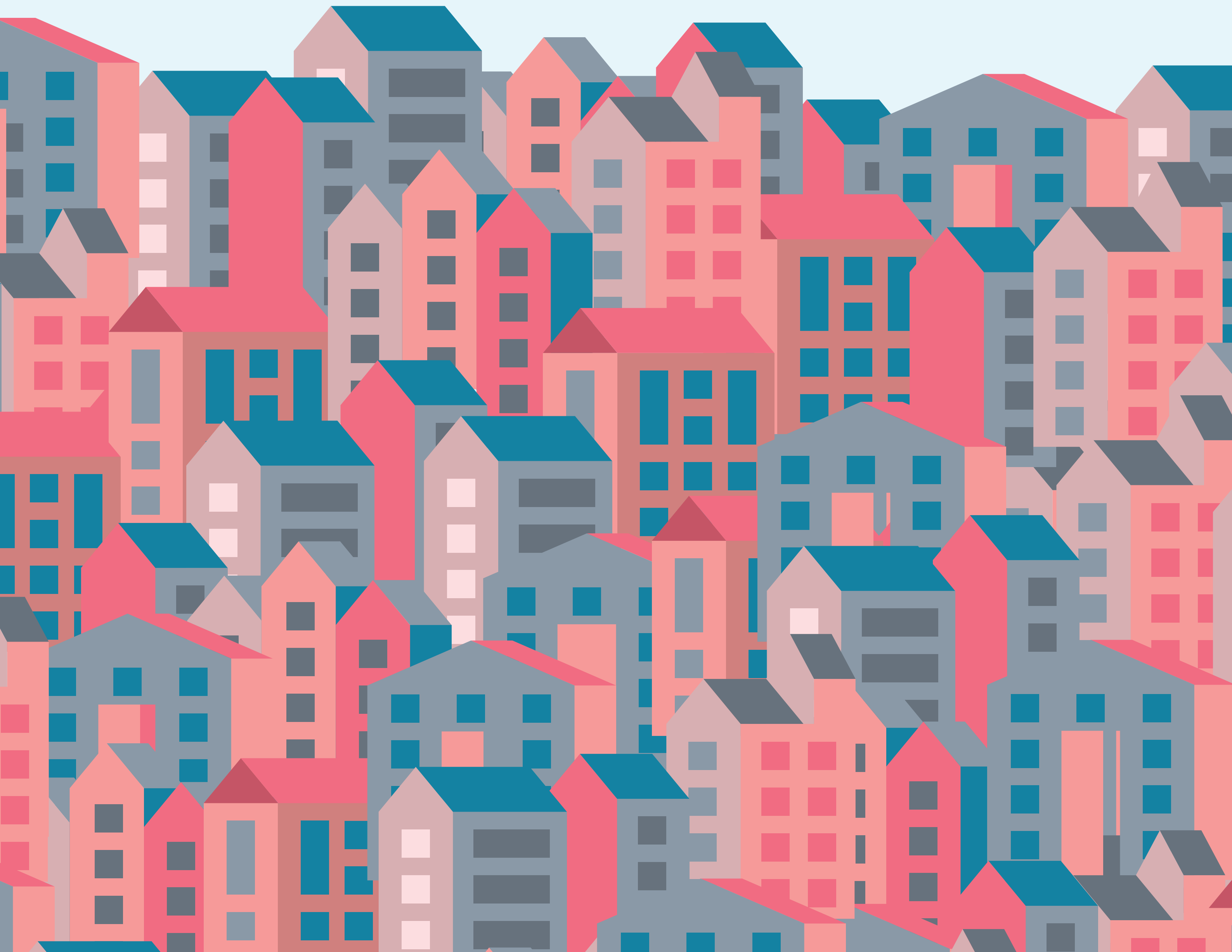
Methodology for Developing Household and Ambient Air Pollution Investment Cases



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This document was written by Christina L. Meyer, Gavin Allman, Dr. Michael Nnachebe Onah, Lily Morrel, Brian Hutchinson, Dr. Rachel Nugent of Research Triangle (RTI) International; Daisy Lanvers, Daniel Grafton, Rachael Stanton of UNDP and Sebastien Poix from the University of Limerick. Additional expertise and input were provided by Suvi Huikuri, Chibulu Luo and Odd Hanssen from UNDP and Enrique Flores and Wing Yin Cheng from United National Volunteers. Economists who led the investment case work in the three pilot countries – Professor Khalifa Elmusharaf in Ethiopia; Arnold Hagens in Mongolia; and Dr. Poornima Prabhakaran and Dr. Shankar Prinja in India – also contributed to the methods by providing feedback through the pilot experiences.

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Foreword

Investment cases in health estimate the economic burden of a disease or risk factor and measure the costs and benefits of scaling-up interventions to reduce this burden. Alongside their economic component, investment cases provide an assessment of the policy landscape on health in a country, including identifying policy gaps, financing opportunities, policy windows and key priority actions. With this assessment and the flexibility to project multiple intervention scenarios, investment cases are vital tools for strategizing approaches to health and health-affecting policies.

The United Nations Development Programme (UNDP), alongside the World Health Organization (WHO) and the UN Inter-Agency Task Force on the Prevention and Control of Non-communicable Diseases (UNIATF) and other key partners, has developed 75 investment cases on health, ranging from topics such as tobacco control, non-communicable diseases (NCDs), primary health care, road safety, mental health, nutrition, to recently including access to treatment, HIV and TB, and air pollution.

This Methods Note serves as a comprehensive guide for economists on how to conduct the economic modelling components of a national investment case on household and/or ambient air pollution.[1] This report describes both the data and the tools that can be used to develop such an investment case. Two distinct tools are used, each for a specific type of investment case. For household air pollution investment cases, an enhanced version of WHO's Benefits of Action to Reduce Household Air Pollution (BAR-HAP) Tool is used. For ambient air pollution investment cases, the Ambient Air Pollution Tool (AAP Tool), developed by Research Triangle Institute (RTI) International, is employed. UNDP has used both these tools to develop air pollution investment cases in Ethiopia, Mongolia, and India.

The primary audience for this Methods Note comprises individuals involved in, or supporting, the development of an investment case on ambient and/or household air pollution. It may also interest policymakers who wish to gain a deeper understanding of the tools and approaches used in developing an air pollution investment case.

Section 1 of this document overviews the process of completing a robust investment case, including assembling an investment case team and necessary steps. **Section 2** provides guidance on how to carry out a household air pollution investment case using WHO's BAR-HAP Tool. **Section 3** offers a comprehensive overview of the assumptions and steps involved in the development of the AAP Tool, along with guidance on its application. **Section 4** outlines how economists may combine the results from both types of investment cases. A separate appendix is available upon request, offering additional details on data inputs, sources, and in-depth guidance on the tools used to develop both ambient and household air pollution investment cases. **To request this appendix, please contact Suvi Huikuri at suvi.huikuri@undp.org.**

1 Similar guidance notes developed by UNDP are available online for developing mental health investment cases and NCD investment cases.

1

Investment case process

1. Investment Case process

This section outlines the steps to follow, including key considerations for assembling a team to guide the investment case process and preliminary activities, such as data collection, for teams to establish a foundation for the investment case. The recommended activities provide a flexible framework, allowing investment case teams to incorporate additional activities as needed.

Assembling the investment case team

A typical investment case team is composed of government representatives, multinational stakeholders, and civil society. **Table 1** outlines a possible structure of an investment case team. Each investment case should identify at least:

A policy specialist	Tasked with overall implementation and coordinating the various activities required (e.g. drafting of reports, conducting interviews).
A lead economist	Responsible for leading and coordinating all aspects of the economic modelling.
A gov't representative from the ministry owning the investment case	Liaises with other government sectors and facilitates country-level communications around key activities such as data collection, investment case launch and handover events.

A diverse team can more effectively access data and provide insights on the current state of air pollution in a country while also identifying pathways to mitigate this issue. Each investment case may benefit from additional representation by relevant stakeholders, depending on specific national contexts.

Table 1. Recommended composition of an investment case team

Government	Multinational	Civil society	Other
Ministry of Health	WHO	Environmental Groups	Economist
Ministry of Energy or Environment	UNDP	NCD Alliances	Policy specialist
Bureau of Statistics or other LSMS[1] producers	UNEP		Academic researchers
Ministry of Finance and/or Ministry of Economy and Planning			Private sector

1 The World Bank's Living Standards Measurement Survey

Data collection

The economist undertakes a review of shared background documents and publicly available online information relevant to air pollution in the country. The economist should review published and gray academic literature, relevant reports of survey findings (e.g. from Demographic and Health Surveys, or LSMS), online databases, emissions reports, and other sources to identify the analytical parameters detailed in the data request form relevant to each air pollution tool. Economists may find academic literature that reports findings from ambient air pollution (AAP) and household air pollution (HAP) interventions, their effects on reducing particulate matter 2.5 ($PM_{2.5}$) levels, as well as implementation costs (e.g. cookstove programme evaluations). Ethnographic research can provide useful background information for the context section of the investment case report. If identified, experts (e.g. civil society representatives, regulators, industry professionals, academics, government leads) can be interviewed for additional background information, to help identify the cost of programmes or policies, and to find additional resources. Gathered data should be used to populate the Data Collection workbook of each tool.

Institutional and context analysis (ICA)

The investment case team also conducts an institutional and context analysis (ICA) of the country context for the investment case. This ICA informs the report, providing an overview of the air pollution situation, government arrangements, and existing strategies and legislation related to air pollution. The ICA begins with a desk review, which is then complemented by a series of interviews with key stakeholders, including government representatives, civil society, non-governmental organizations (NGOs), and academia. These interviews help identify barriers and opportunities for air pollution control measures, further informing the investment case report and its recommendations. An example of areas to be explored during the ICA include:

1. What are the needs, opportunities, and challenges for air pollution-related interventions generally?
2. Who are the relevant actors, how do they operate, and are they effective and efficient?
3. What current and potential mechanisms, strategies and opportunities exist for financing air pollution responses?
4. What are the political, economic and other priorities and incentives of relevant actors? How do these relate broadly to air pollution-related interventions?
5. Which cost-effective measures to abate air pollution are most feasible given the political and economic context? How are relevant actors likely to perceive them?
6. How likely are the priority measures to be implemented and what factors or strategies can expand the political space for adoption, implementation and enforcement?

Economic modelling

Once the investment case team is assembled, the economist can start the economic modelling component of the investment case (see Section 2 and Section 3). The modelling involves different steps: the first step is to estimate the current health and economic burden of air pollution. The second step estimates the impact of scaling-up interventions to decrease this burden. Finally, a return on investment analysis is conducted to compare the costs and benefits of scaled-up action.

Report writing and investment case deliverables

Led by the policy specialist, the investment case team writes and assembles the deliverables, including a final report, PowerPoint presentation, advocacy strategy, and one-page infographic that effectively communicates the main findings. National partners should provide direct input on relevant sections of the report, and help define the list of government representatives, non-profits, civil society, media, and other institutions that would benefit from learning about the results of the analysis and schedule a date to present the final investment case deliverables.

2

Household air pollution (HAP) methodology

2. Household air pollution (HAP) methodology

Air pollution investment cases need to be split into two components, indoor or household air pollution (HAP) and outdoor or ambient air pollution (AAP). The impact on human health from both is critically important, and HAP can also be a key factor in AAP in many countries. This section focuses on the approach to estimate the economic burden, and returns from addressing HAP, while the subsequent section will discuss AAP, concluding with how to combine the two if looking to have a comprehensive air pollution approach.

HAP is caused by burning 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 [1]. HAP has also been cited as one of the major barriers to low- and middle-income countries (LMICs) achieving the Sustainable Development Goals (SDGs) [2].

The aim of a HAP investment case is to estimate the current health and economic burden of HAP due to cookstove use and determine the impact of scaled-up action, at the country level. The HAP investment cases use WHO's Benefits of Action to Reduce Household Air Pollution (BAR-HAP) Tool. The BAR-HAP Tool was developed by researchers at Duke University and funded by WHO, with the aim of analyzing the impact of cookstove transitions, including the social, economic, and environmental outcomes. The tool is available online [3].

To adapt the tool for UNDP investment case analysis, RTI International built a module onto BAR-HAP that estimates the economic burden of HAP due to cookstove use. RTI attached the module to version 1.4 of BAR-HAP (the enhanced file may be found below in **Table 2**) and shared the enhanced version of the tool with Duke University researchers, who have subsequently incorporated the RTI structure into updated versions of the tool. RTI also created several supplemental Excel workbooks to facilitate data collection, offering proxy data and recommending sources, including the HAP data collection workbook available in Table 2.[2]

Since the BAR-HAP's operations manual [4] thoroughly describes the steps required to operate the tool and the methods underlying its calculations, this report focuses on assisting investment case economists to acquire the data necessary to populate BAR-HAP and customize an investment case analysis to a given national context.

2 All the workbooks and resources developed by RTI were current for version 1.4 of the WHO BAR-HAP Tool. With updates to the BAR-HAP Tool, there may be additional data needs not covered by the data collection workbooks and/or the location of specific data points mentioned in this document may have changed.

Table 2. Investment case tools

BAR-HAP – Primary investment case tool	Supplemental workbooks
1. The *WHO BAR-HAP Tool, Version 1.4* with RTI adaptations to facilitate the HAP burden analysis	1. RTI data collection workbooks
2. *WHO BAR-HAP Tool instruction manual* [4]	2. Accompanying parameter estimation workbooks (see data collection section)
3. Published article describing the tool [5]	
	

Data collection workbook

The workbook defines and describes each needed data point and provides default data for reflection. It is divided into six sections, listed below, each laid out on a separate tab.

Introduction		Introduces the workbook and provides instructions for the investment case team on how to review and replace data with country-specific values. It lists all of the relevant parameters in the analysis.
Step 1: Baseline and intervention	1	Describes current cookstove use in the country of interest. The tab also walks users through how to select the cookstove transition scenarios that the investment case will examine.
Step 2: Cookstove parameters	2	Provides space to enter information on the context surrounding cookstove use, including the prices of different stove types and fuels, use rates, and time costs to collect biomass fuel and cook.
Step 3: Estimating the health impacts	3	Provides space to enter country-specific values on morbidity, mortality, and treatment costs related to five diseases attributable to HAP (COPD, acute lower respiratory infection (ALRI), ischemic heart disease (IHD), lung cancer, and stroke).
Step 4: Setting economic, environmental and other parameters	4	Lists the economic, environmental, and demographic parameters needed to conduct the analysis.
Step 5: Parameters for analyst consideration	5	Describes additional parameters used in the analysis where country-specific information may not be available. Parameters should be considered and adjusted where possible, but it is most likely that the default data provided within the BAR-HAP Tool is the best available data for the analysis.
Step 6: Generating the results	6	The tool will generate the estimates on the cost and benefits of scaled-up action to reduce HAP.

After populating the workbook, it can be shared with the investment case team, which may then confirm use of the default data or provide other more appropriate data. Once confirmed, the economist can upload the data collection workbook to the BAR-HAP Tool to automatically generate the results of the economic analysis.

1 Step 1: Baseline and intervention

The WHO BAR-HAP Tool requires the economist to provide information on existing cookstove use in the country of study (baseline scenario), as well as to set goals for household transition rates up the energy ladder over a 15-year time horizon (intervention scenario). The data used for the baseline scenario provides information on the current level of cookstove use and allows the tool to conduct the economic burden analysis.

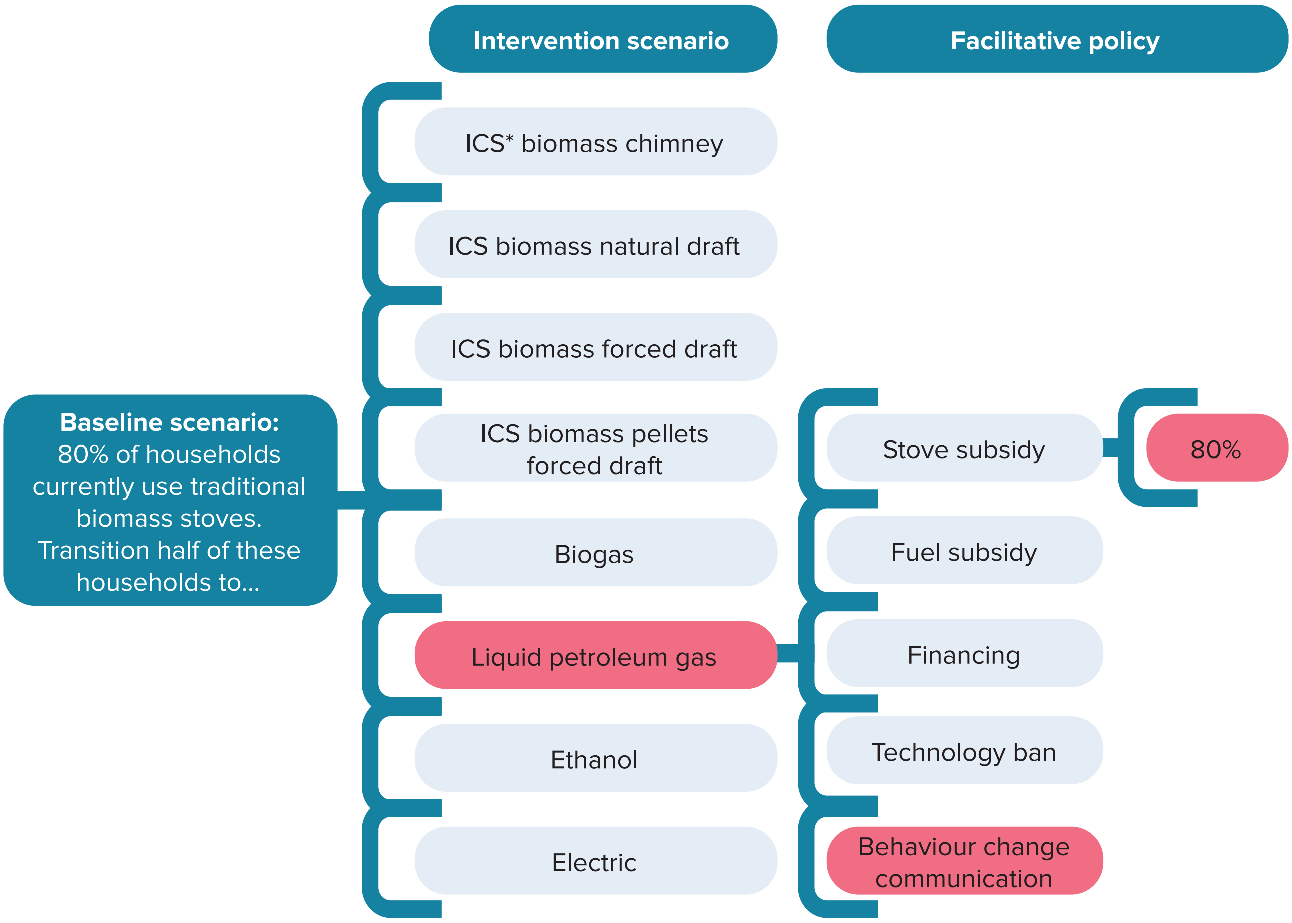
In the baseline scenario, the percentage of households in the country that currently use cookstoves powered by biomass fuel, charcoal fuel, kerosene, liquid petroleum gas, or electricity is entered in the tool. Some households may cook with multiple cookstoves, a process known as "stacking". However, the tool simply seeks information on the primary cookstoves used by households. Data on cookstove distribution and use can commonly be obtained from USAID's Demographic and Health Surveys (DHS) or the World Bank's LSMS. In addition, the WHO collects national estimates in its Household Energy Database. The economist can review the database for surveys conducted in the country of interest and should consult national experts to understand whether more recent information—or other available data sources—are available.

The intervention scenario is a projection of national goals for transitioning households to more efficient cookstove types over the next 15 years. Two pieces of information are required to set the intervention scenario: 1) estimates of the percentage of households that will transition from one cookstove type to another; 2) selection of any facilitative policies that will assist in the transition. There are five types of facilitative policies that may be selected, including stove subsidies, fuel subsidies,[3] financing, technology bans, and behaviour change campaigns. Policies may be modelled as being enacted individually, or in combinations.

Figure 1 provides an example of a potential transition wherein the government chooses to examine the impact of moving half of all households that currently use traditional biomass stoves to cookstoves powered by liquid petroleum gas. The transition will be facilitated by a stove subsidy provided by the government, covering 80 percent of the stove cost, and a behaviour change communication campaign to increase awareness about the benefits of transitioning.

3 Note: BAR-HAP does not allow subsidies to be placed on biomass fuels.

Figure 1. Hypothetical intervention scenario



*ICS = improved cookstove

As part of the ICA interviews (see Section 1), the investment case team should engage with country partners to understand and identify existing national goals for transitions and should identify relevant government reports and strategies that may shape the transitions examined within the investment case. In some cases, government institutions such as the Ministry of Energy may have purview over goals for cookstove transition rates. Existing plans and goals should inform the intervention scenario examined in the investment case analysis; however, in cases where strategies do not yet exist, the investment case national team may need to select goals for the intervention scenario.

When assisting country partners to set subsidy rates for the intervention scenario, the economist should keep in mind that for the cookstove subsidy to have an effect, the subsidy must draw the cost of the cookstove down far enough to influence household demand for the product. For example, if a cookstove costs US$80 and demand for the cookstove is zero at US$20 (i.e. no household will buy the cookstove at a price greater than US$20), then the subsidy must be greater than 75 percent of the cost of the cookstove (US$60 of US$80).[4]

4 Note: if a stove subsidy is enacted in tandem with financing options or a behaviour change campaign, then the subsidy rate may be slightly less, given that the effect of financing mechanisms is to raise households' ability to pay for large capital expenses and the effect of the behaviour change campaign is to increase demand through internalization of awareness of the social, economic, and

In the BAR-HAP Tool, in addition to setting the subsidy amount, the economist can adjust the price at which demand is zero (detailed information is provided in the "Price intercept" parameter in the analyst only section of the Excel Data Collection workbook).

2 Step 2: Cookstove parameters

Data describing the environment surrounding cookstove use in the country of interest should be collected here. The BAR-HAP Tool asks users to input data on costs; behaviour surrounding cookstove use; time allocations for cooking and cooking-related chores; and other social and environmental concerns related to cookstove use.

While national data is preferred, local information for all parameters listed in the data sheet may be unavailable. In such cases, the investment case team can rely on proxy indicators from reliable global sources. National-level surveys, such as the World Bank's LSMS, provide valuable insights, including time spent collecting wood and other natural resources, as well as the proportion of respondents reporting expenditure on wood fuel. Summary data is available in the final LSMS report; and its underlying dataset provides more precise estimates necessary for the investment case analysis.

Published literature—especially studies evaluating the impact of programmes facilitating cookstove transitions—may provide additional information specific to the context of the country of interest. Managers of cookstove programmes operating in the country may also serve as a resource, given their potential access to any data that the investment case team has not been able to uncover through online desk research.

3 Step 3: Estimating the health impacts

The BAR-HAP Tool examines the health impacts of five diseases attributable to HAP: ALRI, stroke, IHD, lung cancer, and COPD. The tool requires information on existing disease morbidity and mortality, and data on health expenditures to treat these diseases.

Ministries of Health may have estimates of disease incidence and prevalence attributable to HAP; otherwise, modelled national estimates of disease morbidity and mortality related to HAP can be downloaded from the Institute for Health Metrics and Evaluation's Global Burden of Disease (IHME GBD) Results database. Where country specific values do not exist, the values of the GBD should be updated to reflect official statistics, where possible.

environmental harms of inefficient cookstoves. In the BAR-HAP Tool, the extent to which these two policies increase demand (i.e. the effect size of the interventions) is governed by two parameters: "Effect of financing on demand" and "Effect of behaviour change communication on demand". See this report's Parameters for analyst consideration section for more information.

For instance, even in places where there are no mortality estimates for any of these diseases in general, the values should be adjusted by a ratio of the demographic data for the country in the GBD to official demographic estimates. In addition, the BAR-HAP Tool asks for users to specify the average age of death among those who die due to HAP-attributable causes, information that is unlikely to be available from national sources. A workbook developed by RTI is provided in the Appendix of this report (Table A1), which calculates remaining life expectancy using mortality data from GBD and national life expectancy data from the UN's Population Prospects.

The BAR-HAP Tool calculates health expenditures attributable to HAP, and the extent to which cookstove transitions can reduce health expenditures. To inform the tool's estimates, users are asked to input average health spending per disease case. The first option should be to refer to estimates of the financial costs of treating the diseases in question, often calculated as part of national costing exercises. Some countries may apply complex costing approaches for reimbursement purposes, that would provide particularly accurate values to use as an input for this component. If no such costing estimates are available, the economist can take a normative costing approach, identifying the costs expected to treat every case of disease, following clinical guidelines of medical inputs and staff time. This is a time-consuming exercise, which also requires finding country-specific price information on all required inputs, and comparing a standard treatment approach for NCDs, such as in the OneHealth Tool, with treatment guidelines in the country. When this is not an option, a calculation of per-case treatment cost can be made from reported health spending data.

Ministries of Health may produce health expenditure information disaggregated by individual diseases. If so, the total health expenditure for a given disease can be divided by total prevalence to obtain average expenditures per disease case. However, many countries may not have health expenditure data disaggregated by disease. In Table A1 (Appendix), RTI provides a workbook that follows methods developed by Ding et al (2016) [6] to extrapolate average cost–per-case estimates in OECD countries to countries around the globe. The workbook facilitates the estimation of stroke, IHD, and lung cancer costs; however, ALRI and COPD costs are not part of these estimates, due to insufficient expenditure data in the OECD countries surveyed in the study.

Assuming that the values above, from national costing and reimbursement data, national health expenditure data or from the extrapolated estimates, are representative for public and private health spending, there is a need to identify the public spending for HAP-attributable diseases only. For each disease, the tool breaks down the share of health expenditures borne by the public sector versus the private sector. Where national information is unavailable, estimates from the WHO Global Health Expenditures Database (GHED) can be used to estimate the share of spending likely to be covered by public sources.

4 Step 4: Setting economic, environmental and other parameters

The BAR-HAP Tool requires additional information from users on economic, environmental, and demographic parameters. Many of the data inputs for the model are required in order to place a monetary value on health outcomes. For instance, the BAR-HAP Tool uses the "unskilled" wage rate to place a value on the time household members spend cooking or gathering fuel for firewood. Ministries of Labour may track wage rates by skill type, though where disaggregated information is unavailable, the minimum wage rate may serve as a proxy for this parameter.

The "Value of a statistical life" (VSL) metric is used to place a monetary value on premature death due to ill health. Some government agencies—especially regulatory agencies that perform regulatory impact assessments—have standard national values for VSL. Where approved government values do not exist, searching academic literature to uncover whether a VSL has been elicited from stated or revealed preference studies, and/or wage risk studies, locally or regionally, is recommended. In the case that no information is found, the RTI-provided workbook may be used to obtain a VSL estimate for the country of interest (Table A2 of the Appendix). Following methods published in the Harvard Reference Case Guidelines for Benefit-Cost Analysis in Global Health and Development [7], the workbook extrapolates country estimates of VSL from United States estimates, using gross national income (GNI)-per capita ratios to adjust for differences in gross national incomes, and their related differing typical risk profiles.

Negative externalities as a result of the use of biomass cookstoves are also monetized, including carbon emissions and environmental degradation. Values for the social cost of carbon (SCC) , which place a monetary value on all damages associated with one additional ton of carbon emission, are an intense subject of research and are continuously being updated to incorporate new learning, as methods for quantifying the SCC[5] are refined and tested. Recent research and recommendations from trusted global sources should be reviewed, but using accepted standards such as those employed by the United States Environmental Protection Agency—US$51 dollars per ton of carbon emissions [8], may be considered.

Conceptually, the "tree replacement cost" parameter in the tool can be challenging to comprehend and requires some background. The replacement cost represents the intrinsic value of wood that is sustainably gathered to fuel biomass cookstoves [9]. When wood is gathered as fuel for biomass stoves, some portion is sustainably harvested (i.e. the natural

5 Note: Social cost of carbon figures generally refer to the global harms caused by the emission of one additional ton of carbon. While regional and domestic (i.e. national social costs of carbon) exist, the global consequences of carbon use (i.e. inability to sequester the emitted carbon and its consequences to the airspace of the emitting country), global agreement on social imperative to act (e.g. wide adoption of the Paris Agreement), and the nature of the problem—in which one country acting alone cannot avert global disaster—suggest use of the global social cost of carbon over national or regional estimates.

growth rate of the forest will replace what has been gathered), and often some other gathered portion is unsustainable (i.e. is gathered at a rate higher than the forest can naturally replenish itself, contributing to deforestation). Sustainably harvested wood will be replaced by natural afforestation, and thus consumption of the wood does not ostensibly contribute to environmental degradation. However, there is inherent value in its existence – as without the wood (or forest), the ecosystem services it provides would collapse.

A proxy estimate of tree replacement costs is the cost per kilogram to purchase sustainably grown timber. In many locations, this estimate may not be available; in which case, the workbook provided in Table A2 (Appendix) may assist the economists to estimate the cost of tree replacement. The workbook provides two reported estimates of costs to plant trees (one from a private business and one from a non-profit organization). As an example, it then shows estimates of the merchantable volume of wood in native trees, before proceeding to estimate the cost per kilogram of wood produced. Economists may use this workbook or rely on the default estimate provided within the BAR-HAP Tool.

Finally, there is a "HAP spillover" variable, which is a measure of how much HAP flows out of households, contributing to AAP. A WHO database on local source apportionment summarizes studies that have examined the percentage of AAP in a given country due to natural sources (e.g. dust, sea salt), traffic, industry, domestic fuel burning, or other unspecified sources of human origin. However, the WHO database does not contain information for all countries. In addition, some studies are relatively old and as such may be outdated. The database also has not been updated since 2015, so searching for more recent source apportionment studies is recommended [10].

5 Step 5: Parameters for analyst consideration

The BAR-HAP Tool relies on several other parameters to conduct the analysis. However, many are parameters for which country partners are unlikely to provide data and/or are parameters for which the default data is likely to suffice. These include several parameters related to the mechanical operation of cookstoves (e.g. fuel use and efficiency, pollution emission), health parameters (e.g. disability-adjusted life-years weights for HAP-attributable diseases), and information on facilitative policies (e.g. leakage rates of subsidies, effect sizes of interventions, administrative costs of providing financing options for cookstove purchase). The default data underlying these parameters is backed by an extensive literature review by Jeuland et al (2018) [9].

The parameters may be selectively reviewed, and attempts can be made to obtain information when and where deemed appropriate. For example, if a country specifies that they want to examine a transition to a particular cookstove brand with known fuel efficiency, pollutant emissions, etc., the existing default data can be replaced to reflect the known attributes of that specific stove. Or, if a history of subsidy programmes exists in the country, it may be useful to review whether there are published studies examining subsidy leakage rates.

One exception to reliance on default parameters is for the "demand parameters" category. The BAR-HAP Tool contains underlying cookstove demand functions that govern estimates of the number of households that adopt cookstoves. There are three parameters that the economist has control over for each cookstove type: 1) the "price intercept where demand reaches zero for a given cookstove" (i.e. the price at which no household will buy the cookstove); 2) the percentage of all households that would adopt the cookstove if the cost were zero; and 3) the price at which the maximum quantity of households would purchase the cookstove.
Consideration of these parameters is complicated - though essential - for the analysis. It is likely that few studies explicitly examine demand for cookstove use in the country of interest, and judgements will need to be made about suitable and reliable estimates.

By default, under the assumption that removal of the capital cost to purchase a given cookstove would remove any barriers or inhibitions that households have about purchasing it, the default value for the percentage of all households who would adopt a given cookstove at a price of zero is set at 100 percent for all cookstoves. This estimate may be suitable to keep. However, in some cases, other constraints (e.g., cultural norms, or access to particular fuel types) may prevent a certain portion of the population from desiring a certain cookstove, even when free of charge. Adjustments should be made where relevant according to the local context.

Step 6: Generating the results

Once the data from the workbook has been gathered, the workbook should be uploaded into the BAR-HAP Tool, and the tool will generate the estimates on the cost and benefits of scaled-up action to reduce HAP.

Through RTI's built-in burden module, synchronized with the BAR-HAP Tool's existing structure, the tool will provide estimates on the economic burden of HAP due to cookstove use. The economist may simply follow the BAR-HAP Tool's standard data entry requirements detailed above, and the tool will automatically quantify the health and economic burden of HAP (see results in the tool's "Burden tables" and "Burden summary" tabs).

Limitations

The limitations of the BAR-HAP Tool have been extensively covered in published research [3] and are comprehensively detailed in the WHO's BAR-HAP operations manual [2]. As these discussions are readily available in the existing literature, they are not further elaborated upon in this report.

3

Ambient air pollution (AAP) methodology

3. Ambient air pollution (AAP) methodology

AAP is one of the most pronounced global environmental hazards posing a major threat to economic development and health [11]. It is primarily driven by emissions from the transport sector, as well as industrial facilities and power plants, among other sources [12]. Although there is no truly safe level of $PM_{2.5}$ exposure [11], the WHO's Air Quality Guidelines recently reduced the recommended maximum exposure level from an annual average of 10 µg/m^3 (10 micrograms per cubic meter) to an annual average of 5 µg/m^3, to minimize AAP-attributable diseases [12].

AAP investment cases aim to support advocacy efforts to scale-up action to mitigate and abate AAP. To conduct AAP investment cases, an AAP Tool was developed by RTI. This section outlines the assumptions, methodology, and steps involved in developing the AAP Tool, offering insights into the appropriate data to utilize and the sources to consult when conducting an investment case on AAP. It also includes practical instructions for using the tool.

Perspectives and time horizon

Costs and benefits of health interventions are sensitive to the perspective used. Potential perspectives include that of healthcare providers, patients and their families, whole of society, and donors, among othes. For AAP investment cases, a societal perspective is suggested, in line with the AAP economic burden approach where the economic benefits of proposed interventions that avert health expenditures and productivity losses accrue to the wider society rather than a specific payer (e.g., government, donor, private sector, etc.) Additional societal losses are estimated through premature mortality and enumerated using the value of a statistical life (VSL).

The AAP Tool is currently set to examine the economic burden and economic and social returns over three time horizons; (1) 7 years to estimate the short term economic cost of AAP and cost/benefits from reducing exposure to $PM_{2.5}$; (2) 12 years to estimate medium-term estimates; and (3) 32 years to estimate the life cycle and longer-term economic burden and cost/benefits of interventions. All costs and benefits are estimated as being the 'net-present value'of the US$-value of the baseline year by discounting future costs and benefits with a default 3 percent discount rate.

The default time horizons in the AAP Tool start in 2019, and are 7-, 12-, and 32-years long, however, future investment cases should use relevant starting years and time horizons that align with possible policy windows or initiatives. After adjusting this in the AAP Tool, the timeframe of the analysis (i.e., the year the analysis begins) can be updated depending on when the investment case is being prepared.

Step 1: Data collection	1	Filling out the data request form.
Step 2: Estimating the baseline burden	2	To understand how AAP exposure drives health outcomes, the first step is to identify the relative risk (RR) of a disease when exposed to AAP.
Step 3: Computing the economic burden	3	Using the excess cause-specific disease burden estimate, the AAP Tool calculates the annual total economic costs incurred by the country that are attributable to excess ambient $PM_{2.5}$ exposure.
Step 4: Modeling the interventions	4	The population effects of emission reductions from interventions are ascertained in relation to the local share of emissions exposure which are attributable to the intervention's sector.

1 Step 1: Data collection

Filing out the data request form

A data request form was developed alongside the AAP Tool and provides the definition of each data point required as well as default data if national data is not available. The request form is divided into five sections:

1. **Economic burden parameters**. This section requires data on disease morbidity and mortality, and health expenditure to treat AAP-related diseases.
2. **Intervention return-on-investment parameters**. The data request form includes matrices where parameters may be entered for interventions. These sections are pre-populated with data from academic publications and grey literature which provide key parameters around intervention costs and effect sizes.

3. **Additional queries.** This section asks a few questions about selected parameters to get a sense of what type of resources may be available to inform the investment case. These parameters include government purchasing prices for clinical intervention materials, number of visits to health systems and hospitals, and coverage of clinical interventions.
4. **Parameters (for the analyst only).** These are a list of parameters that inform the analysis but are unlikely to be changed by national estimates, such as presenteeism, absenteeism and pollutant exposure level coefficients, which are readily inputted in the model.
5. **Country-specific baseline epidemiology.** This section requires data on the annual incidence and mortality of the six diseases of interest linked to AAP, which can be obtained from IHME GBD if national estimates are not readily available.

Another essential data component for conducting an AAP investment case is information on the risk of developing selected diseases, which can be obtained through an AAP exposure assessment. If national annual average $PM_{2.5}$ exposure levels are available from published studies, government reports, or reliable environmental monitoring databases, the economist can input this data directly into the AAP Tool. However, if such data is unavailable, one approach, outlined below, is to conduct at AAP exposure assessment.

Conducting an AAP exposure assessment

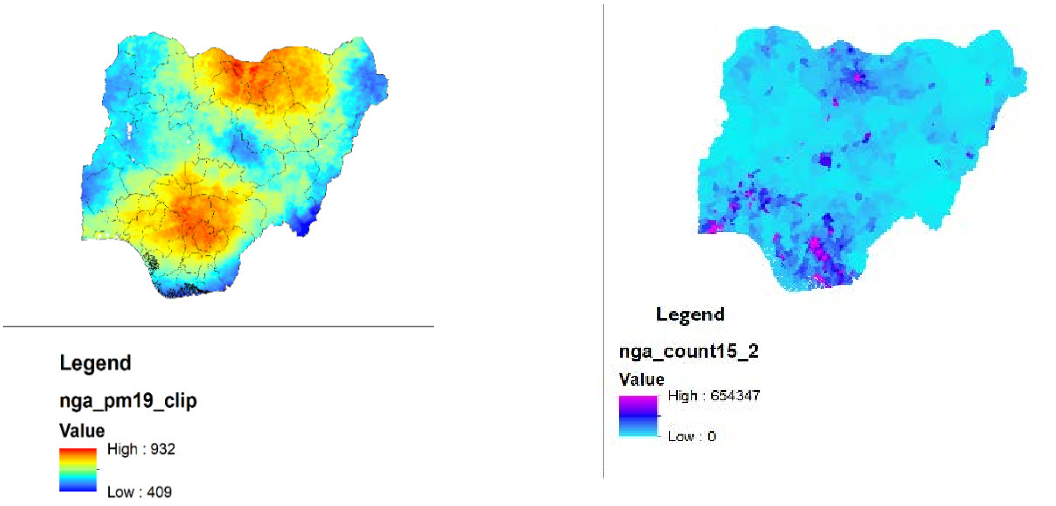
Country AAP levels can be extracted from the most recent five-year satellite-derived estimates of annual mean all-composition $PM_{2.5}$. The model uses $PM_{2.5}$ levels at 0.01° X 0.01° grids for the country of interest, which are constructed by the Atmospheric Composition Analysis Group [13]. All-composition $PM_{2.5}$ estimates include pollution from both natural sources (e.g., dust, sea salt, etc.) and anthropogenic “humanmade” sources (e.g., manufacturing, transportation, etc.)

Spatial and temporal variability in human exposure is captured by calculating the most recent population-weighted annual mean $PM_{2.5}$ exposure levels for the country and each subnational area (e.g., state, province, etc.) [14]. Using ArcMap 10.8, the Atmospheric Composition Analysis Group’s constructed annual average $PM_{2.5}$ pollution estimates for each 1 km^2 area can be extracted within the country or subnational-level administrative borders (see Figure 2A) [15]. A similar process is then performed to identify the population for each of these 1 km^2 areas with the country’s population count data (see Figure 2B) [14]. The annual average $PM_{2.5}$ concentration estimates for each 1 km^2 area are subsequently overlayed onto the population density map. The Global Administrative Area database’s template (also referred to as “shapefiles”) is used, that defines a country’s national and subnational-level borders to identify the exposed population by state, province or other administrative boundary [16].[6]

6 The formula for calculating the population-weighted average annual exposure levels by geographical unit (country or state) is $\textit{Population Weighted Exposure}_i = \frac{\Sigma_g (P_{gi} * C_i)}{\Sigma_g P_{gi}}$

where P is the population, C is the outdoor ambient $PM_{2.5}$ concentration, g refers to the corresponding 1km^2 grid area, and i refers to a geographical unit.

Figure 2A-B. Example of Nigeria's National Annual Ambient $PM_{2.5}$ (2019) and Population (2015) by 1 km^2 Gridded Cells



Source: Nigeria's $PM_{2.5}$ data are from the Atmospheric Composition Analysis Group; population data were constructed by the Center for International Earth Science Information Network - CIESIN - Columbia University; shapefiles are from the Global Administrative Area database (GADM). Images were generated with ArcMap 10.8.

2 Step 2: Estimating the baseline disease burden

Exposure concentration response functions

To understand how AAP exposure drives health outcomes, the first step is to identify the relative risk (RR) of a disease when exposed to AAP. The RR is the ratio of the probability of disease in an exposed population to the probability of disease in an unexposed population (Formula 1). In this case, the "unexposed population" are those who are exposed to the theoretical minimum risk exposure level (TMREL). The TMREL represents the level below which AAP does not contribute to long-term health issues. The globally recognized TMREL for $PM_{2.5}$, applicable to all ages and sexes is 2.4 μg/m^3 [17].

Formula 1. Relative risk

$$\text{Relative Risk (RR)} = \frac{\text{Probability of disease in exposed population}}{\text{Probability of disease in unexposed population}}$$

An exposure concentration response function depicts the relationship between different age-specific and cause-specific RRs of disease incidence or mortality across a spectrum of pollutant exposure levels. These functions are steep at low pollutant exposure levels and typically plateau at higher exposure doses.

Excess mortality estimates can vary due to a diverse choice of estimators, data inputs, and methodologies, which affect scientific and public health interpretations [18]. Two prominent models were compared, to choose the best method to model the relationship between $PM_{2.5}$ exposure and the risk of mortality and incidence: the Integrated Exposure Response Model (IER) [19] and the Global Exposure Mortality Model (GEMM) [20].

These two validated models of exposure concentration response functions are commonly used in AAP disease burden studies because of their ability to predict the health risks associated with the full range of AAP exposure levels seen globally [20]. After carefully assessing the advantages and limitations of each model (full comparison analysis available upon request), the IER model was selected as the foundation for the base estimates.

Integrated Exposure Response (IER) model

Few large-scale cohort studies closely evaluate the linkage of outdoor air pollution to health outcomes in highly polluted countries [17]. The AAP model uses IHME's IER Relative Risk model to estimate $PM_{2.5}$ attributable mortality and incidence. The IER model assumes that the RR from a specific pollutant does not vary by source or daily variation in dose. Based on epidemiological evidence, the IER model also adjusts the RR for IHD and stroke by age, with the understanding that risk linearly declines with age [17], [21].[7]

The model uses the TMREL as a counterfactual concentration of $PM_{2.5}$ (at which the RR of disease mortality/incidence is one) to compare the risk of higher exposure levels of $PM_{2.5}$. The TMREL concentration in the model ranges between a minimum of 2.4 and 5.9μg/m^3, which is consistent with the lowest concentrations observed in long-term epidemiological studies [22].

7 Although potentially counterintuitive, the IER model's age-based adjustment of RR for IHD and stroke reflects that, while the overall risk of these conditions increases with age, the proportion of risk specifically attributed to air pollution diminishes as other health risk factors become more significant in older populations. This adjustment applies only to IHD and stroke, while RRs for other diseases are assumed constant across age groups. Further explanation can be found in Singh et al., (2023) [22].

Formula 2. The IER model's functional form

IER's Models Functional Form

For $z < z_{cf}$,RR=1

For $z \geq z_{cf}$,RR=1+ α {1-exp [-y(z-z_{cf})$^{\sigma}$]}

where,

z - Concentration

z_{cf} - Counterfactual concentration below which there is no additional risk

α - Maximum RR (For very large z, RR approximates 1 + α)

γ - Ratio of the RR at low to high exposures

σ - Power of $PM_{2.5}$

Source: Global Burden of Disease Collaboration Network, 2019 [19].

Estimating the cause-specific mortality or incidence attributable to AAP

The investment case uses a long-term (30+ years) time horizon to illustrate a life cycle approach to the burden of AAP and intervention costs and benefits. To estimate a country's total national or subnational cause-specific mortality and incidence attributable to ambient $PM_{2.5}$, exposure concentration response curves and baseline levels of mortality and incidence from the AAP-related diseases should be applied to the national/subnational population distribution.

Baseline cause-specific mortality and incidence data

The AAP Tool uses IHME's modeled national age-specific estimates of the number of mortality and incident cases (i.e., newly onset cases of an illness) of IHD, stroke, COPD, lung cancer, Type 2 Diabetes (T2D), and ALRI as the baseline numbers for the country's overall disease burden attributable to air pollution from these six diseases. The baseline context of ambient air pollution serves as the main driver of the economic burden of air pollution in a country, and this baseline scenario is projected forward, to provide a comparison of the burden if scaled-up action is not taken. Projections of mortality and incidence of illnesses associated with AAP can be linearly forecasted using a five-year average from the IHME's GBD Results tool's historical data [23]. The APP Tool is set up to estimate the projected burden in a status quo or no action scenario, projecting the burden of 32 years. The tool can and should be adapted to different time horizons to align with national context and priorties (e.g, strategic plan objectives).

Calculating the excess burden of cause-specific mortality or incidence

The analysis calculates national and subnational-level excess mortality and incidence of diseases associated with each year's expected $PM_{2.5}$ exposure levels as compared to the counterfactual if the country's exposure levels met the WHO recommended levels (5µg/m^3) in that same year [24]. A country's AAP Population Attributable Fraction (PAF) should be calculated for the six different diseases. The PAF depicts the proportion of mortality and incidence of an illness in the population that is attributable to exposure levels of $PM_{2.5}$ above the reference levels. To calculate the national disease-specific PAFs and for each state by 5-year age groups, the disease-specific RR for mortality and incidence if the population was exposed to the country's 5-year average concentration levels (x µg/m^3) and the WHO recommended levels of 5 µg/m^3 should be used. The following formula depicts how to calculate this for each subnational unit (i.e., at the state, provincial, or regional level).

Formula 3. Calculating the AAP attributable fraction by subnational unit and 5-year age groups.

Formula for Calculating the Disease Burden Attributable to AAP by Subnational Unit and 5-year Age Groups:

AAP Population Attributable Fraction (PAF) for Subnational Unit$_i$ by 5-year age groups = $1-1 / RR_{(x \text{ or } 10)}$

where,
RR_x - represents the age and cause-specific RR of the outcome at an exposure of x **µg**/m^3 in each subnational unit i compared to the counterfactual exposure
RR_{10} - represents the age and cause-specific RR of the outcome at an exposure of 5 **µg**/m^3 (WHO guidelines) concentration compared to the counterfactual exposure

The excess cause-specific mortality and incidence by 5-year age cohorts at the national and subnational levels should then be computed for each year over the modelled period, to track the size of the economic burden of AAP if no further action is taken to combat AAP. This is done by finding the proportion of disease burden in the population that is attributable to exposure above the reference level (see Formula 4). In other words, the calculation uses the difference in the PAF when the population is exposed to the 5-year average subnational/national $PM_{2.5}$ exposure levels (x µg/m^3) compared to the WHO's $PM_{2.5}$ exposure standard of 5 µg/m^3. By multiplying this value by the corresponding number of cause-specific deaths or incident cases for each 5-year age group in state (i), the excess cause-specific mortality or incidence for each state by 5-year age groups will be determined.

Formula 4. Excess cause-specific mortality or incidence by subnational unit and 5-year age groups.

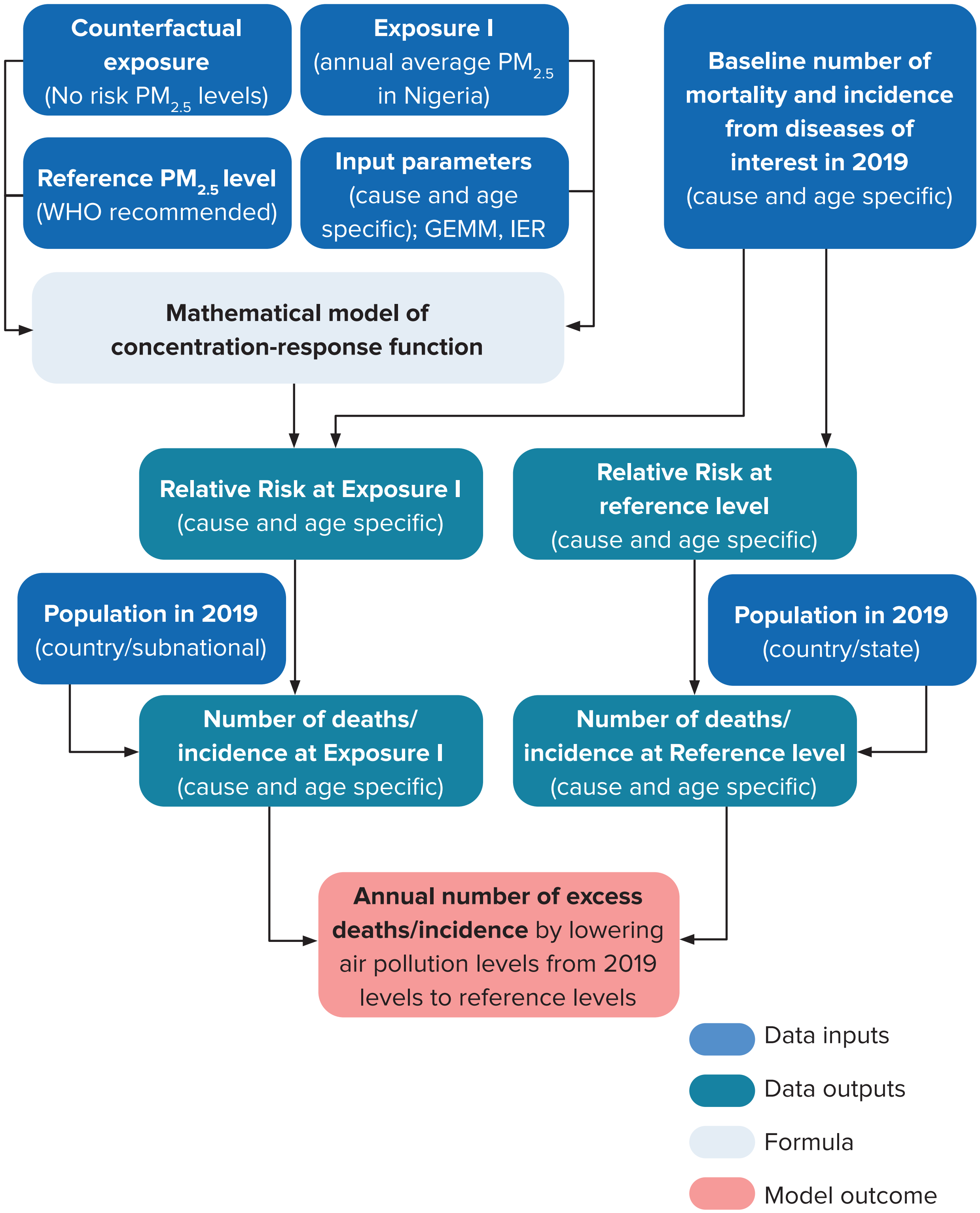
Formula for Excess Cause-Specific Mortality or Incidence by Subnational Unit and 5-year age groups:

Number of Excess Cause-Specific Cases of Mortality or Incidence for Subnational Unit$_i$ by 5-year age group $(PAF_x - PAF_5) * P_i * I$

where,
PAF_x - represents the age and cause-specific proportion of the outcome that are attributable to an exposure concentration of x μ g/m^3 (i.e., 2019 $PM_{2.5}$ levels)
PAF_5 - represents the proportion of the outcome that are attributable to the reference exposure concentration of 5 μ g/m^3 (WHO guidelines)
P_i - represents the proportion of the total population in subnational unit (i) (Subnational Unit$_i$ population in 2019 / National population in 2019)
I – represents the country's age and cause-specific number of deaths and incidences in the corresponding year

Figure 3 illustrates the conceptual framework for calculating the disease burden attributable to ambient $PM_{2.5}$ pollution using 2019 baseline pollution levels compared to the WHO's global standard. It depicts the model's data inputs (e.g., baseline disease burden data), its intermediate outputs (e.g., the country's estimated RR at current exposure levels), and the outcome of the excess disease burden attributable to AAP based on the country's current pollution exposure level.

Figure 3. Conceptual framework for calculating the disease burden (mortality and incidence) attributable to AAP ($PM_{2.5}$).



3

Step 3: Computing the economic burden

Using the excess cause-specific disease burden estimate, the AAP Tool calculates the annual total economic costs incurred by the country that are attributable to excess ambient $PM_{2.5}$ exposure. The total economic cost of ambient $PM_{2.5}$ air pollution is the sum of the direct and indirect costs related to exposure to ambient $PM_{2.5}$.

Direct costs include healthcare expenditures to treat AAP-attributable diseases, while indirect costs include the economic value of lives lost due to AAP-attributable diseases, and the productivity losses from AAP-attributable disease (absenteeism and presenteeism)[8]. The following sections describe methods to calculate the direct costs and indirect costs.

Direct costs

Direct costs refer to the money that is spent on medical care related to a particular risk factor, in this case AAP. Direct costs can consist of the cost of hospitalizations, physicians, medications, and other medical expenses, and in this analysis, refer to healthcare spending financed by public means to treat AAP-attributable diseases, thus taking a government perspective.

To calculate the direct costs associated with AAP-related diseases, several alternatives are available. One approach follows a 'normative costing' exercise. This looks to estimate the per-person cost to treat a given AAP-attributable disease, assuming all treatment follows clinical guidelines. ALRI, COPD, IHD, and stroke, treatment regimens - consisting of medications and a prescribed number of outpatient visits to clinics or hospitals (and/or inpatient stays) - are based on those in the WHO OneHealth Tool. These treatment regimens and their costs may vary based on the severity level of the disease. The default cost of inpatient and outpatient stays are sourced from WHO CHOICE [25] and can be converted to the country's local currency unit.

To estimate the cost of medications and supplies to treat a specific AAP-attributable disease, in-country representative prices of medications and supplies should ideally be collected, with a representative country-specific markup applied to account for supply chain costs to ship and distribute medicines and ensure that they are widely available [25]. In the absence of in-country representative medication and supply prices, default data from the OneHealth Tool can be used.

8 Absenteeism refers to individuals unable to attend work and presenteeism refers to individuals being less productive at work due to illness or health conditions, in this case AAP-attributable.

As the OneHealth Tool does not provide treatment regimens for T2D and lung cancer, the default per-patient treatment cost for these diseases can be derived from a targeted review of global or national studies that provide the average total healthcare costs per patient [26], [27], [28].

After identifying the per-person treatment cost for different treatment regimens used to address the specific AAP-attributable diseases, the following should be identified:

1) The proportion of those affected by the AAP-attributable disease who will need each treatment regimen. 'Disease severity splits' may be used to estimate this (e.g., ALRI has a disease severity split where 80 percent of cases are moderate and 20 percent are severe).
2) Baseline country-specific healthcare coverage levels, which should approximate the proportion of the population with a given disease which is currently receiving care at a given level of the health system.

To find the average treatment cost to treat a given AAP-attributable disease while considering the need for, and access to, different treatment regimens, the per person cost for each treatment regimen can be multiplied by the proportion of those affected by the disease who will need that treatment regimen and the baseline country-specific healthcare coverage level for that regimen. These costs can then be summed up to estimate the average treatment cost per case of AAP-attributable disease.

Another approach looks to estimate the treatment cost per case, without disaggregating by severity. In many countries, estimates of financial costs to treat diseases have been carried out as part of national costing exercises. Where this has not been the case, average treatment costs per case of disease can be obtained by dividing actual expenditure data, for a specific disease, by the number of cases of that disease in the country. This average treatment cost per case can then be multiplied by the estimated disease incidence to estimate the total current cost of providing treatment to a population of individuals with a given AAP condition. Along with the cause-specific total cost of providing treatment, the AAP Tool calculates the excess annual healthcare expenditures associated with the disease incidence attributable to a country's baseline $PM_{2.5}$ exposure AAP compared to the WHO's standard level.

Indirect costs

Indirect costs include productivity and social losses due to premature mortality as well as productivity losses due to absenteeism from work and reduced productivity while at work (Formula 5). Within the AAP economic burden model, indirect costs include premature mortality (number of deaths and economic cost of premature death from AAP-related diseases) and the economic costs from productivity losses attributable to the incidence of AAP-attributable disease.

Formula 5. Indirect costs

Indirect Cost = Economic Cost of Premature Mortality + Economic Cost of Productivity Losses

where
Economic Cost of Premature Mortality = the monetized economic value of the years of life lost due to AAP
Economic Cost of Productivity Losses = absenteeism from work and reduced productivity while at work (i.e., presenteeism) due to AAP-attributable illnesses during the same year that the incident occurred.

Economic value of premature mortality due to AAP

Mortality has both labor and social costs. It decreases the quantity of available labor and, consequently, the economic output of a country, as well as the economic activity of individuals. Additionally, it represents an intrinsic loss of the inherent social value of each life that is lost. Such economic costs are represented by converting units of human life (years lost due to disease) into economic values. This process monetizes each year of life by reflecting its economic value to society. Alternatively, it assesses what society would be willing to forgo in terms of economic resources to preserve those years of life.

AAP-attributable mortality is monetized by multiplying the expected number of life years that would have remained to an individual had they not died due to AAP (i.e., Years of Life Lost) by the value of a statistical life year (VSLY) (Formula 6). VSLY is a monetary measure of a society's willingness to pay for an individual to avoid one expected year of life loss. It is derived by dividing the VSL with the life expectancy of the median aged worker in a given country.

Formula 6. Monetizing AAP-attributable mortality

$$\text{Mortality Value} = (YLL_{Year,Disease1} + YLL_{Year,Disease2} \ldots) * VSLY_{Year}$$

where YLL = Years of Life Lost
VSLY = Value of a Statistical Life Year

The AAP Tool calculates the economic costs associated with premature mortality attributable to AAP by estimating the total number of years of life lost due to increased exposure levels of $PM_{2.5}$. This calculation is based on the methods outlined in the World Bank's Methodology for Valuing the Health Impacts of Air Pollution and the Harvard Reference Case Guidelines for Benefit-Cost Analysis in Global Health Development [29], [30].

By multiplying the overall YLL by the monetary VSLY, the AAP Tool quantifies the excess economic losses from premature mortality the country incurs by maintaining $PM_{2.5}$ levels at their current baseline compared to WHO standards.

AAP-exposure related workplace productivity losses

The productivity losses attributable to AAP exposure are derived from the excess absenteeism and presenteeism among those in the workforce who experience AAP-attributable illnesses. As the model estimates AAP-attributable incidence and not prevalence, the economic costs from productivity losses highlight the absenteeism and presenteeism among new cases of AAP-attributable diseases during a single year.

Productivity losses due to excess absenteeism

Absenteeism is when sick employees miss work due to illness or health conditions. Excess absenteeism refers to the average additional days of work missed from the incidence of an AAP-related illness (i.e., sick days due to an AAP-related illness). Formula 7 illustrates the calculation for the cost of lost productivity due to excess absenteeism among those with AAP-attributable illnesses.

Formula 7. Calculating absenteeism

Employees with AAP-attributable illness x Excess Days Absent X Average Daily Wage

where,
Employees with AAP-attributable illness = Employment rate × Number of AAP-attributable disease cases
Excess Days Absent = Additional days absent among those with AAP-attributable illness compared to those without the illness
Average Daily Wages = Calculated from annual gross minimum wage data

The average daily wages and employment rate represent national averages for a country's general population, inclusive of those in the formal and informal sectors. A literature review of absenteeism associated with each AAP-related disease informs the data on the cause-specific excess days absent [31], [32], [33]. Absenteeism costs only include those who experience an acute case of AAP-attributable illnesses (i.e., incident cases) and survive.

Productivity losses due to excess presenteeism

Presenteeism refers to lower on-the-job productivity resulting from experiencing a disease attributable to AAP exposure. This is when sick employees (i.e., those who experience an acute incident of an AAP-attributable disease and survive) attend work but are less productive while at work due to AAP-related impairment and disability. Formula 8 illustrates the calculation for the cost of lost productivity due to excess presenteeism among those with AAP-attributable diseases.

Formula 8. Calculating presenteeism

Presenteeism Cost = Employees with an AAP - Attributable Disease × Excess Presenteeism Rate × Average Daily Wages

where,
Employees with AAP-attributable illness = Employment Rate × Number of those with an AAP-attributable illness
Excess Presenteeism Rate = Rate of Reduced Productivity among employees with an AAP-attributable illness
Average Daily Wages = Calculated from annual gross minimum wage data

Like the calculations for excess absenteeism, the average daily wages and employment rate generally reflect national averages. In contrast, the excess presenteeism rate was derived from a review of the literature on presenteeism associated with the same diseases [34].

4 Step 4: Modeling the interventions

Sectoral contributions to AAP

The population effects of emission reductions from interventions are ascertained in relation to the local share of emissions exposure which are attributable to the intervention's sector. Contributions to $PM_{2.5}$ exposure primarily come from the sectors of agriculture, road transport, waste, energy, and industry, and vary across regional, national, and subnational contexts. Table 3 presents the definitions of these six key sectors of anthropogenic emissions used in the modelling of intervention effects.

Table 3. Definitions of selected emissions sectors

Sectors	Definitions of selected emission sectors applied in the modelling of intervention effects
Agriculture	Includes manure management, soil fertilizer emissions, rice cultivation, enteric fermentation, and other agricultural emissions. Does not include open fires from agricultural waste burning.
Energy	Includes electricity and heat production, fuel production and transformation, oil and gas fugitive/flaring, and fossil fuel fires.
Industry	Includes industrial combustion (iron and steel, non-ferrous metals, chemicals, pulp and paper, food and tobacco, non-metallic minerals, construction, transportation equipment, machinery, mining and quarrying, wood products, textile and leather, and other industry combustion) and non-combustion industrial processes and product use (cemewnt production, lime production, other minerals, chemical industry, metal production, food, beverage, wood, pulp, and paper, and other non-combustion industrial emissions).
Residential	Includes residential heating and cooking.
Road transport	Includes cars, motorcycles, heavy and light duty trucks and buses
Waste	Includes solid waste disposal, waste incineration, waste-water handling, and other waste handling.

Table 4 presents a subset of anthropogenic sectoral sources that contribute to AAP by region. The impact of natural sources of AAP on $PM_{2.5}$ exposure may also be found in the dataset created by McDuffie et al., (2021) [35]. The estimates integrate 24 global atmospheric chemistry transport model sensitivity simulations, high-resolution satellite-derived $PM_{2.5}$ exposure estimates, and disease-specific concentration response relationships.

Table 4. Sample sectoral source contribution of ambient air pollution

Regions	Sectoral source contributions to $PM_{2.5}$ exposure estimates (%)					
	Agriculture	Road transport	Waste	Industry	Energy	Residential
Central Asia	5.1	5.3	6.1	6.9	10.9	10
Central Europe	18.6	7.7	1.5	6.5	16.4	19.9
Eastern Europe	11.5	6	3.2	6.8	16.6	10.4
Australasia	9.3	4.3	0.4	7.4	8.1	2.6
Latin America – South	5.8	7.7	2.6	11.9	5.8	7.9
Caribbean	2.8	5.5	5.4	9.5	11.2	15.2
North Africa/ Middle East	5.7	7	3.4	5.2	11.8	3.2
South Asia	9.5	6	4.4	14.3	12.0	26.3
Sub-Saharan Africa – West	0.1	2.2	0.9	1	1.7	7.8
Sub-Saharan Africa – East	0.5	3.5	2.0	6.4	6.9	19.6
Global	8.3	6	4.8	11.7	10.2	19.2

Source: McDuffie et al., (2021). Sources of industrial and energy-attributable pollution include coal and non-coal-related sources. Sources of residential-attributable pollution include combustion of residential coal, residential biofuel, and other sources of residential combustion [35].

Intervention selection

The primary consideration for selecting interventions to model within an AAP investment case is their suitability and applicability to the national context. Additionally, empirical evidence supporting the effectiveness of these interventions is essential, along with data on their costs and expected impact. Key components for including intervention studies to inform the economic analysis include:

- Emission source corresponding to agriculture, road transport, waste, industry, energy, or residential sources of $PM_{2.5}$.
- Description of intervention and the specific emissions source it addresses, with enough detail for the economist to ensure suitability to the AAP context in the country of interest, the interventions' associated costs, including upfront investment and ongoing costs as relevant.
- The effect size of interventions must be provided in weight of emissions reduced, or percentage of emissions reduced by weight. Weight of emissions reduced per intervention unit (cars retrofitted, houses electrified, filters applied, etc.) or per year are also acceptable.
- Ensure the intervention's relevance and appropriateness within the specific national context, ensuring alignment with local needs and priorities.

In addition to costs and effect sizes, in order to accurately represent the impacts of action on AAP, additional data must be inputted to scale-up and model a given intervention within the geographic area of interest. Intervention effect sizes which are framed as reduction of emissions per intervention unit or a percentage of total source emissions can be scaled to appropriate coverage levels within the target context.

For instance, if modelling the impact of an intervention to use improved fertilizer on maize-producing cropland, the current and target coverage of the proposed intervention should be researched. These terms are defined below, drawing on an example from Zhang et al., (2020), which found that in China, an investment between US$0.40-2.00 in efficient fertilizer production and placement practices could avert 1kg of ammonia emissions per year for every hectare of maize farmland [36]. Two critical questions must be addressed regarding the coverage levels of this specific intervention, as well as for all other interventions considered. Current coverage: What proportion of maize farmland in the country of interest is already using proposed improved fertilizer practices?

Target coverage: What coverage is achievable and desirable in the country of interest? For countries with an existing coverage of a proposed intervention, the target coverage will be incremental. For instance, if about 20 percent of maize farmland is already using proposed improved fertilizer practices, and the economist wants to scale this up to 100 percent, the incremental cost and benefits would be for an 80 percent increase in coverage.

Intervention effects may also be framed as reductions in the percentage of emissions from a source of pollution. Howard et al., (2019) found that the installation of electrostatic precipitators in Brazilian coal power plants reduced emissions of primary $PM_{2.5}$ by 98 percent [37]. If looking to model the implementation of this coal power plant intervention, the percentage-based effect size applied to the emissions produced by coal power plants in the target context will be needed.

Economists may wish to model the implementation of broader policy changes such as the regulation of a particular industry or emissions source. For example, a country may want to model a 25 percent reduction in emissions from its entire waste management sector, in which case the economist would input 25 percent effectiveness in reducing total $PM_{2.5}$ emissions over a target coverage of 100 percent.

The AAP Tool has readily available data for costs and effectiveness of various interventions targeting emissions from specific sources within the agriculture, energy, industry, residential, road transport, and waste sectors. An example intervention for each of these sectors and key data points are provided in the Appendix (Table A3). Economists are welcome to incorporate other interventions in the AAP Tool for which data is available. However, caution should be exercised when modeling multiple interventions targeting the same specific emission source within a given sector. This approach may lead to double-counting and an overestimation of the health impact of these combined interventions unless the overall effect on emissions from their combined use is estimated first.

The pattern of scale-up in each country is intervention-specific and country-specific. The investment case team should ideally collect feedback from stakeholders on the current status of selected intervention and target coverage levels.

Countries may want to scale-up existing interventions in the country or model any number of interventions which are not included in the AAP Tool. The tool will flexibly accommodate interventions so long as there is data available for the intervention, including effect size, cost, and coverage levels. However, the interventions should fit into the six sectors included in the model.

Economists should explore the Global Emissions Inventory and the $PM_{2.5}$ Source Apportionment data sources to identify which of the six selected source sectors of pollution are most relevant to their context [35], [38]. Lastly, interventions centered around improved cookstoves to reduce residential pollution should not be applied to the AAP Tool. Rather, cookstove interventions should be entered into the BAR HAP Tool, as described in Section 2 of this report. These results can then be plugged into the residential sector component of the AAP Tool (further details on combining results from the HAP Tool and the AAP Tool are provided in Section 4).

Estimating the impact of an AAP intervention

To determine the impact of the selected interventions on the economic burden of AAP, the excess mortality and incidence of stroke, lung cancer, ALRI, COPD, T2D, and IHD that could be prevented by each intervention are estimated. These calculations consider sectoral source contributions of direct $PM_{2.5}$ exposure, attributable mortality estimates, and fractional disease contributions. Disease incidence and mortality figures are linked to $PM_{2.5}$ exposure, which can be attributed to source sectors pertaining to selected interventions.

Figures 4-6 illustrate the steps taken to estimate an intervention's impact in reducing the economic burden attributable to AAP. The first step is to obtain the share of national annual ambient $PM_{2.5}$ economic burden per sector. To do so, the economic burden from sector $PM_{2.5}$ exposure is divided by the economic burden from overall $PM_{2.5}$ exposure. The economic burden from sector $PM_{2.5}$ exposure is calculated by multiplying the proportion of historical sectoral $PM_{2.5}$ exposure contributions by the economic burden from overall $PM_{2.5}$ exposure. Data on historical sectoral $PM_{2.5}$ contributions by country were obtained from McDuffie et al., (2021) [35].

City-level calculations are possible within the tool but will require additional input from the economist. At a minimum, estimates of the share of national emissions from each sector which are generated within that city, and the share of national population which that city represents, will be required. Where available, city-specific $PM_{2.5}$ concentration exposure and sector-attributable exposure contributions are recommended.

Figure 4A. National Economic Burden from $PM_{2.5}$ is divided by mean $PM_{2.5}$ concentration exposure (micrograms per cubic meter)

Data sources	**National Economic Burden Analysis**		**Ambient Air Pollution Exposure Assessment**		
	Economic Burden from Anthropogenic $PM_{2.5}$ of Country Y	**/**	**Number of micrograms per cubic meter in mean national concentration exposure in Country Y**	**=**	**Economic Burden per cubic meter in mean national concentration $PM_{2.5}$ exposure in Country Y**
Examples	*US$450 billion from overall $PM_{2.5}$ exposure*		*50 micrograms per cubic meter mean national concentration exposure*		*US$9 billion Economic Burden per microgram per cubic meter*

Figure 4B. Apportioned according to Sector-Specific Pollution Contributions

Data sources	**Ambient Air Pollution Exposure Assessment**		**Global $PM_{2.5}$ Exposure Inventory Data by Sector**		
	Number of micrograms per cubic meter in mean national $PM_{2.5}$ concentration exposure levels in Country Y	**/**	**Sectoral source contribution to national $PM_{2.5}$ concentration exposure levels in Country Y**	**=**	**Number of micrograms per cubic meter of national $PM_{2.5}$ exposure evels by sector in Country Y**
Examples	*50 micrograms per cubic meter*		*Road transportation contributes to 10% of national $PM_{2.5}$ concentration exposure levels*		*Road transportation contributes to 5 microgram per cubic meter of national $PM_{2.5}$ exposure*

Figure 4C. National Economic Burden by sector

Data sources	**Ambient Air Pollution Exposure Assessment**		**Global $PM_{2.5}$ Exposure Inventory Data by Sector**		
	Economic Burden per cubic meter in mean national concentration $PM_{2.5}$ exposure in Country Y	**X**	**Number of micrograms per cubic meter of national $PM_{2.5}$ exposure levels by sector in Country Y**	**=**	**Cost of Illness of $PM_{2.5}$ exposure by sectoral source in Country Y**
Examples	*US$9 billion Economic Burden per microgram per cubic meter*		*Road transportation contributes to 5 microgram per cubic meter of national $PM_{2.5}$ exposure*		*Exposure to $PM_{2.5}$ from road transportation contributes to US$45 billion of the national Economic Burden*

The Community Emissions Data System (CEDS) provides the weight of directly emitted $PM_{2.5}$ for the agricultural, industrial, waste, energy, residential and road transport sectors by country. These emissions data are classified into primary $PM_{2.5}$ pollutants (black carbon and organic carbon) and secondary $PM_{2.5}$ precursor pollutants (CO, NOx, NH_3, SO_2, and non-methane volatile organic compounds (NMVOC)) [38].

The regional shares of sector-specific $PM_{2.5}$ exposure concentration which are attributable emissions of primary and secondary $PM_{2.5}$, are estimated based on statistical analysis of historical trends in emissions and exposure, as well as estimates of primary and secondary sectoral contributions in 96 global cities from Tessum et al. [39]. Using estimated proportions of AAP attributable to primary $PM_{2.5}$ for each region and sector, as well as the national weight of primary $PM_{2.5}$ emissions (black carbon and organic carbon), the national weight of total $PM_{2.5}$ produced by each sector is computed (see Formula 9). Then, reductions in emissions of primary $PM_{2.5}$ and total $PM_{2.5}$ are indexed to sector-attributable exposure to determine the resulting reduction in population $PM_{2.5}$ exposure and economic burden estimates.[9]

Formula 9. Calculating the proportion of AAP attributable to primary $PM_{2.5}$ by sector and region

Formula for Calculating the Proportion of AAP Attributable to Primary $PM_{2.5}$ by Sector and Region

Regional proportion of sector emissions attributable to primary $PM_{2.5}$ /100 = Country Weight of BC+OC*/ Country Weight of total $PM_{2.5}$ from sector

*BC =black carbon and OC = organic carbon

The above method of estimating sector-specific AAP contributions from primary and secondary $PM_{2.5}$ is applied to the energy, industry, road transport, residential, and waste sectors. For the agricultural sector, CEDS data only reports emissions of NOx and NH_3, neither of which contribute to primary $PM_{2.5}$. Using an analysis from Gu et al. (2021) [40] , which estimates the regional shares of 2013 $PM_{2.5}$ exposure attributable to NOx and NH3 emissions, CEDS data is applied for the respective shares of regional NOx and NH_3 emissions which come from the agricultural sector. Regional contributions to $PM_{2.5}$ exposure from agricultural NOx and NH_3 are derived, which are similarly indexed to the weight of agricultural emissions and the national share of agriculture-attributable $PM_{2.5}$ exposure to determine health benefits from modeled interventions.

Because CEDS data for the agricultural sector omits emissions of black carbon and organic carbon, the model does not account for reductions of primary $PM_{2.5}$ emissions from agriculture, which might result from interventions such as reduced agricultural burning. However, this limitation is relatively minor, as AAP contributions from the agricultural sector are overwhelmingly attributable to NH_3 emissions, which are produced through activities such as soil fertilization, animal feeding, and manure management. For this reason, it is

9 Supplemental files, available upon request, provide further information on the calculation of region- and sector-specific proportions of total $PM_{2.5}$ constituted by primary $PM_{2.5}$, including underlying data.

recommended that the economist input agricultural interventions which target NH_3.
The health-related economic impact of each proposed intervention is determined using the following steps: (1) estimate the quantity or proportion of ambient $PM_{2.5}$ emissions averted per sector and pollutant using the effect sizes of each intervention (Figure 5A); (2) apply this figure to the CEDS data on total direct $PM_{2.5}$ emissions by sector estimating the total intervention effect on $PM_{2.5}$ exposure (Figure 5B); (3) multiply the total number of emissions averted with the economic burden per emission to obtain the economic value of averted emissions (Figure 6).

Figure 5A. Intervention effects on sector-specific primary $PM_{2.5}$ (Intervention Effects are measured against National Sectoral Emissions Data to derive notional prapartions of sector-specific primary $PM_{2.5}$ which could be averted)

Data sources	**Intervention Literature**		**Global Emissions Inventory Data by Sector and Pollutant**		
	Number of Primary $PM_{2.5}$ Emissions Averted by Sector-specific Intervention in Country X	**X**	**Number of sector-specific emissions of primary $PM_{2.5}$ in Country Y**	**=**	**Intervention's Effect on Sector-Specific Primary $PM_{2.5}$ in Country Y**
Examples	*Road transportation intervention averts 1,000 tons emissions from primary $PM_{2.5}$ in Country X*		*Road transportation emits 50,000 tons of primary $PM_{2.5}$ emissions in Country Y*		*2% of primary emissions from road transportation $PM_{2.5}$ reduced*

Figure 5B. Emissions reductions are indexed to regional trends in exposure, primary $PM_{2.5}$ emissions, and secondary $PM_{2.5}$ precursor pollutant emissions to estimate national $PM_{2.5}$ exposure response to redudions in primary emissions

Data sources			**$PM_{2.5}$ Primary Contribution Regression Analysis**		
	Intervention's Effect on Sector-Specific $PM_{2.5}$ in Country Y	**X**	**Primary $PM_{2.5}$ Emissions Contribution to Sectoral $PM_{2.5}$ Exposure in Country Y**	**=**	**Intervention's Effect on Sector-Specific Total $PM_{2.5}$ Exposure in Country Y**
Examples	*2% of primary $PM_{2.5}$ emissions from road transportation reduced*		*Primary $PM_{2.5}$ emissions accounts for 40% of national road transportation $PM_{2.5}$ exposure in Country Y's region*		*Intervention is estimated to reduce total $PM_{2.5}$ exposure from road transportation by 5%*

Within the analysis of region- and sector-specific primary and secondary $PM_{2.5}$, a sensitivity analysis was performed based on the variance of sector-specific primary and secondary $PM_{2.5}$ observed in the analysis of 96 cities performed by Tessum et al [41].[10] Rather than a single estimate of the region- and sector-specific contributions of primary and secondary $PM_{2.5}$, the AAP Tool allows users to select low, medium, and high estimates of this figure when inputting interventions. Adjusting this setting will change the final health impacts of an intervention depending on how that intervention's effect size is framed.

Figure 6. Economic burden averted by intervention

	Intervention's Effect on Sector-Specific $PM_{2.5}$ in Country Y	X	Economic Burden of $PM_{2.5}$ exposure by sectoral source in Country Y	=	Economic Burden Averted by Intervention in Country Y
Examples	*Intervention reduces exposure to total $PM_{2.5}$ from road transportation by 5%*		*Exposure to total $PM_{2.5}$ from road transportation contributes to US$45 bilion of the national Economic Burden*		*Road transportation intervention averts US$2.25 billion of Country Y's national Economic Burden*

Intervention benefits and costing

Intervention benefit lag time

The lag between intervention implementation, reduction in emissions, and the impact on health through reduced mortality and morbidity is intervention specific. The tool assumes that adaptation interventions have an immediate reduction in emissions, and thus, health impact, whereas mitigation interventions have a one-year lag period before emission reductions, and benefits accrue. The distinction between adaptation and mitigation interventions is described by Woollacott et al. as reducing emissions (mitigation) and avoiding exposure (adaptation) [42]. For instance, the proposed advanced environmental policy for reducing energy emissions would have a one-year lag before benefits accrue, while waste management interventions would have an immediate impact on reducing emissions and related health burdens. Based on country needs and assumptions, the lag time can be changed to estimate the differential impacts of proposed interventions.

Intervention costing

As mentioned in the previous section on costing perspective, the AAP investment case takes a whole-of-society perspective for costs, and looks across three different time horizons. The AAP Tool has preset values for prices of different costing components used across the different interventions, and assumptions around the quantity of each ingredient needed. Where possible, local prices should be incorporated, and quantity assumptions may need adjustment, particularly when applied in contexts that are exceptionally large or small, or in highly urbanized or non-urbanized settings.

10 Further details on the sensitivity analysis and its implications are available in the supplemental files (available upon request).

The estimation of costs for each intervention are derived from the literature, identifying successful programs and resource needs associated with a specific effect size. All costs are currently converted in the tool to US$ using appropriate exchange rates from the World Bank [43]. Cost estimates are also inflated/deflated to latest US$ values using appropriate inflation rates from the International Monetary Fund (IMF) [44]. An official, or more recent, exchange should be selected to better reflect local prices.

Calculating the net present value and ROI

All intervention benefits and costs are currently discounted using a three percent discount rate to arrive at the net present value (NPV) of estimates. However, the discount rate can be adapted to reflect local needs and forecasts, as in many cases factors like inflation, or national interest rates, may vary significantly from this value. The return on investment (ROI) for each intervention is computed using Formula 10 below.

Formula 10. Return on Investment (ROI)

$$\text{ROI} = \frac{\text{Intervention benefit}}{\text{Incremental Intervention cost}}$$

From a financial perspective, an ROI is typically considered worthwhile if it's value isabove one. In some cases, the ROI for an intervention may come out to less than one where the implementation costs outweigh the estimated monetized benefits. Despite this, it is still valuable to highlight and discuss the health, environmental and social benefits gained through implementing the intervention. For example, the non-economic benefits of action may still make the case that investments are worthwhile, such as the estimated number of AAP-attributable deaths averted or emissions that are mitigated by taking action on AAP. Aligning the discussion of these benefits with stakeholder goals can contribute to supporting priority-setting initiatives.

Practical application of the AAP Tool

Excel tool platform, structural layout, and navigation

The AAP Tool was created by RTI in Microsoft Excel (Version 2202 Build 16.0.1.1431.20648). The tool is contained in one Excel workbook with 11 active worksheets. The worksheets fall into three functional categories: the Main worksheets with descriptive information about the tool (1), Input (1), and Data & Analysis (9).[11]

11 The AAP Tool may be available upon request.

Figure 7. *Excel* tool structure – worksheet categories.

Main	Welcome
Input	Input parameters
Data and analysis	Emissions analysis
	Global source apportionment
	Full data forecast
	Economic burden
	Summary – Economic burden
	Energy intervention – Impact
	Transport intervention – Impact
	Agriculture intervention – Impact
	Economic returns

- Welcome worksheet provides background information about the tool;
- Input parameters worksheet shows input parameters, descriptions, assumptions, and sources;
- Data and analysis worksheets lay out the economic burden of AAP and summarize the costs, benefits, and economic returns of implementing selected interventions.

The next sections describe each worksheet in detail, starting with the Input worksheet.

Input Parameters worksheet

The Input Parameters worksheet provides space for users to enter parameters from the data request form and intervention studies into the model. The parameters are split into three sections:

1) sociodemographic,

2) intervention parameters, and

3) model parameters (stroke, IHD, COPD, lung cancer, ALRI, and T2D).

Cells in each section should be updated with country-specific data. In the sociodemographic section, users should input data in the value and average life expectancy columns. In the model parameters and intervention parameters sections, users should input data in the value columns. The data entered into this worksheet is used in the data and analysis worksheets to calculate the economic burden of AAP and the costs, benefits, and economic returns of implementing interventions targeting AAP reduction. The definitions of these parameters can be found in the data request form.

At the top of the worksheet, a dropdown menu allows a country to be chosen from a list of 166. This feature applies only to the calculation of intervention effectiveness and does not automatically populate any sociodemographic or health parameters. No cells other than the country-specific calculations of intervention effectiveness in subsequent worksheets are affected. The worksheet accommodates parameters for up to six interventions, three of which are currently modeled in the subsequent intervention impact worksheets. Before entering intervention parameters, the economist is prompted to choose the appropriate intervention sector from a drop-down menu. Sector drop-down selection, along with the country drop-down selection at the top of this worksheet and the drop down-section of primary $PM_{2.5}$ estimates on the intervention impact worksheets, are used to calibrate intervention effect sizes to specific country emissions and ambient pollution.

The health-related economic effects from interventions are calculated by comparing the emission reductions to the entire body of national emissions from that sector. On the top right of each intervention impact worksheet, the economist will find that intervention effect sizes are shown relative to country-specific and sector-specific emissions (and using low, medium, and high estimates of primary $PM_{2.5}$ as a proportion of total $PM_{2.5}$). For these fields to calculate correctly, weight-based reductions entered into the first row of the intervention input boxes must equal the total desired reduction based on target scale-up, and percentage-based reductions entered into the second row should represent the percent of total sector emissions abated. This requires an estimation of the proportion of total sector emissions which are represented by their specific emissions source.

Data and Analysis worksheets

The Data and Analysis Worksheets lay out detailed data needed to estimate the economic burden of AAP, summarize the economic burden of AAP, and summarize the implementation costs, benefits, and economic returns of implementing interventions targeting AAP reduction.

- The Emissions Analysis worksheet contains information for 166 countries which were sufficiently represented in datasets of emissions volume from CEDS and exposure from McDuffie, et al. On the leftmost side of this worksheet, estimates for the regional proportions of sector-attributable AAP which consist of primary $PM_{2.5}$ compared to secondary $PM_{2.5}$ can be found. These estimates underpin the calculated effectiveness parameters in the intervention input table and improve the accuracy of effect size translations from one context to another.
- The Global Source Apportionment worksheet includes data of sectoral source contributions to $PM_{2.5}$, total attributable mortality estimates, and fractional disease contributions for 204 countries.
- The Full Data Forecast worksheet presents the comprehensive data analyses used to estimate the economic burden of AAP. Results from the IER program should be incorporated in this section. Guidance for running the program in R Studio and obtaining the required data for this worksheet is provided in Table A4 in the Appendix.

- The Economic Burden worksheet provides a concise layout of the economic burden of AAP. This page presents the parameters entered by the economist and calculates the morbidity and mortality attributable to AAP in the desired country and selected regions for each of the six selected diseases. These summaries are broken down into healthcare, economic value of mortality, presenteeism, and absenteeism costs.
- The Summary – Economic Burden worksheet includes summaries of the projected number of incident cases and deaths, the total economic burden over the projected period, the economic burden as a share of national GDP, the economic burden disaggregated by direct and indirect costs, and the economic burden disaggregated by source sector for each disease.
- The Energy Intervention – impact worksheet provides the health impact, cost, and overall economic benefit of installing electrostatic precipitators in all coal powerplants in a country.
- The Transportation Intervention – impact worksheet shows the health impact, cost, and overall economic benefit of introducing low-sulfur diesel fuel for all diesel-burning vehicles in a country.
- The Agriculture Intervention – impact worksheet lays out the health impact, cost, and overall economic benefit of improved fertilization practices for maize farmland, including reduced urea-based fertilizer, promoting enhanced efficiency nitrogen fertilizer, and implementing deep placement of fertilizer.
- Finally, the Economic Returns worksheet summarizes the total costs, total benefits, and ROI for all included interventions.

Limitations

The following section details the limitations of the AAP Tool, underscoring key factors that may impact the accuracy of the results estimated.

- The evidence on the impact of AAP on various health outcomes is continuously evolving. Assessing the impact of interventions is significantly more complex than for most other health areas, as it requires precise information on AAP exposure levels and involves multiple pollutants and parameters related to their production. Consequently, accurately estimating both the economic burden and the return on investment for addressing AAP is particularly challenging and depends on the precision of numerous parameters—more so than in other health investment cases conducted by UNDP. This increases the likelihood of relying on default values, which can contribute to potential inaccuracies in the final results.
- The estimation of healthcare-related costs attributable to AAP may be overestimated or underestimated, depending on the approach used. If the primary suggested approach—using treatment-regimen costs sourced from the OneHealth Tool—is applied, it reflects a normative approach to treatment and costing, which may be especially inaccurate in

resource-limited settings. On the other hand, not accounting for case severity and relying on averages fails to incorporate this crucial factor into cost estimation.

- The costs and effect sizes of interventions are likely to be influenced at the regional level by several factors. The magnitude of emission reductions from implementing a policy or technology improvement depends on the status quo in the country, including the existing local coverage level of selected interventions. Reliable data related to this can be difficult to obtain.
- As the AAP Tool focuses on measuring the economic burden of AAP based on the burden model associated with AAP-attributable illnesses, it does not consider the impact of AAP on other economic areas, such as agricultural crop outputs or climate change.
- Secondary $PM_{2.5}$ formation is influenced by a number of geographic, environmental, and seasonal factors [45]. The relation between precursor gas emissions and the formation of secondary $PM_{2.5}$ is not linear and estimating the generation of secondary $PM_{2.5}$ with greater precision would require complex chemical transport modelling or atmospheric simulations.
- Since the AAP Tool's estimates of local primary and secondary $PM_{2.5}$ contributions are based on global city data, some sectors may overestimate their share of national exposure. Urban areas, with closer proximity to emission sources, tend to have higher primary $PM_{2.5}$ exposure. As a result, sectors like energy, industry, and road transportation might overrepresent their national impact. Additionally, intervention effects could be overestimated in countries with significant cross-border pollution compared to domestic emissions.
- The AAP Tool assumes immediate health impacts from adaptation strategies and a one-year lag for mitigation interventions, though this likely overestimates the speed of benefits. While intervention-specific delays between implementation, emission reductions, and health impacts exist, these lags are not well-documented in the literature.
- The model addresses only $PM_{2.5}$ and its precursor pollutants, excluding CO_2 and CH_4. $PM_{2.5}$ is a short-lived climate pollutant, and scientific consensus suggests that reducing such pollutants primarily offers economic benefits by lowering morbidity and mortality. However, the broader economic benefits of reducing short-lived climate pollutants remain uncertain, which limits their inclusion in the analysis. This can lead to the underestimation of impacts, as for the same cost, some interventions may have effects on health that are not captured, and thus, not reflected in the economic benefits.
- Limited data on the cost and effectiveness of interventions for $PM_{2.5}$ sectoral sources makes it difficult to include them in the ROI analysis. Without data on emission weight and composition, effects must be estimated as a percentage of total sector emissions. Consequently, the ROI modelling excludes interventions for agricultural residue burning, fugitive road dust, and construction dust.

- While including multiple interventions from a single sector would double-count their respective impact on emissions reductions, not including such interventions significantly limits the scope of action, which can be particularly large in countries where one sector is a particularly large driver of AAP. This can lead to the interpretation that other interventions in this same sector, besides the primary one chosen, should not be pursued, due to their exclusion in the analysis.
- The use of both the economic cost of premature mortality and economic productivity outcomes can result in some double counting. Monetizing the years of life saved by an intervention as a social cost is typically inclusive of output-related economic impacts, such as reduced productivity (presenteeism) and decreased labor supply (absenteeism). However, this approach does not account for the economic or social value of morbidity not captured by absenteeism and presenteeism. A more comprehensive approach would include the social value of morbidity and disability through monetized healthy life-years, and the economic value of morbidity and disability by estimating the lost economic output due to disease-related premature retirement.
- Finally, limitations exist when combining the results from both tools due to the differing methodologies used for AAP and HAP. One issue is that the AAP analysis typically employs a different time horizon than the HAP analysis, although extracting relevant years for comparison is still feasible. Another limitation arises from the lack of differentiation in relative risks for a 10 $\mu g/m^3$ concentration between HAP-related $PM_{2.5}$ from biomass burning and ambient $PM_{2.5}$ from more industrial sources.

4

Combining results from AAP and HAP investment case analyses

4. Combining results from AAP and HAP investment case analyses

If both an AAP and a HAP investment case are being conducted and the economic burden and ROI results will be collectively reported in the form of a combined report, the economist must ensure that the impact of AAP from cookstove-related HAP is not double-counted.

The HAP investment case uses the BAR-HAP Tool, which has a health spillover variable, that calculates the spillover health effects of cookstove use on AAP. It does so by assuming the health burden is an additional 13 percent of that from the HAP from cookstove use. This is a default parameter in the BAR-HAP Tool, which may be useful for conducting a HAP investment case on its own. However, the BAR-HAP Tool's estimated impact of current cookstove use practices on AAP may differ from the total health burden attributable to total AAP from residential sources, which should include emissions from cookstove use.[12]

To avoid double counting and improve the accuracy of the impact of cookstove interventions on AAP, the following directions should be applied:

1) The BAR-HAP Tool's spillover health effect value must first be set to zero to find the economic impact of cookstove use on HAP alone. The economic burden of AAP from cookstoves should not be included in the HAP part of the analysis and should instead be part of the AAP economic burden as a part of residential AAP.
2) Then, rather than using the health spillover variable, estimating the benefits of the household cookstove intervention on AAP can be outsourced to the AAP Tool. To evaluate the impact of the cookstoves on AAP, the effect size of the BAR-HAP Tool's intervention (i.e., percentage reduction on HAP emissions, which can be gathered from the Burden tab in the BAR-HAP Tool) can be applied to the AAP Tool as a residential AAP intervention, making sure it is applied to the AAP contribution from cookstoves, which is a certain percent of residential pollution.
3) The intervention costs calculated by the BAR-HAP Tool can be used so that a new set of costs do not have to be calculated in the AAP Tool.
4) Once the economic benefits from reducing residential AAP through the cookstove interventions in the AAP Tool are identified, this value should be added to the total HAP benefits from the BAR-HAP Tool (N.B. it is important to ensure the time-horizons for estimating the benefits are the same).
5) From there, the economist should be able to report the economic impact measures of the cookstove intervention both on HAP by itself (using the BAR-HAP Tool's zero percent health spillover scenario) and/or HAP and AAP (using the BAR-HAP Tool's zero percent health spillover scenario benefits and costs and the AAP benefits from the AAP Tool).

12 The BAR-HAP Tool also does not include T2D in its disease burden estimates.

5

Considerations

5. Considerations

The significance of health as a driver, outcome, and indicator of sustainable development is frequently under-recognized and undervalued. This is partly due to decision-makers often lacking access to reliable, context-specific data on the secondary health impacts of economic activities.

Investment cases support countries to advocate for greater and more effective investments in addressing a health challenge. By providing countries with national estimates of the burden of a disease or risk factor (in this case of air pollution) and measuring the costs and benefits of scaling-up interventions to reduce this burden, UNDP and partners can assist decision-makers in making strategic choices about resource allocation in the face of competing demands.

Policymakers in countries around the world are harnessing UNDP investment cases to boost attention, investment and action for health as an accelerator of sustainable development. A review of the impact of investment cases on NCDs in 13 countries found that a substantial number of actions and/or policy changes attributable in whole or in part to the investment cases were identified, across (i) governance, including laws, policies, plans, coordination and public communications; (ii) financing, including budget allocation, leveraging additional partnership support, and health taxes; and (iii) health service access and delivery, including health system strengthening, universal health coverage and service provision [46].

By framing action as an investment rather than a cost, investment cases can be a useful tool to elevate the priority of addressing air pollution and advocate for sustainable financing, including increased budget allocation.

Photo credit: Zsuzsanna Schreck

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6

Appendix

HAP model
AAP model

6. Appendix

HAP model

Table A1. Epidemiology and health expenditures data

Epidemiology			
Morbidity of select diseases	Incidence of ALRI in children ≤ age 5, and prevalence of stroke, IHD, lung cancer, and COPD all ages	DCW[13] – Health tab C15:T31 BHT[14] – Assumptions_ InputSheet tab AJ6:AJ17	***Potential data sources:*** Ministries of Health may have access to or produce official national estimates ***Default data source(s):*** modeled estimates from the Global Burden of Disease database. Follow the links below, change the location to the country of interest, and select "*Search*". 1. ALRI 2. Other diseases - Stroke, IHD, Lung cancer, COPD
Mortality of select diseases	Mortality among incident cases of ALRI in children ≤ age 5, and in prevalent cases of stroke, IHD, lung cancer, and COPD	DCW – Health tab C33:C49 BHT – Assumptions_ InputSheet tab AB12:AB16	***Potential data sources:*** Civil death registries may have information, but low-quality records are common in LMICs and even in cases where quality information exists, significant time may be required to obtain and sort data. ***Default data source(s):*** modelled estimates are available from the Global Burden of Disease database. Follow the links below, change the location to the country of interest, and select "search" to acquire death rates per 100K, by disease. 1. ALRI 2. Other diseases - Stroke, IHD, Lung cancer, COPD

13 Data Collection Workbook (DCW).
14 BAR-HAP Tool (BHT).

Life expectancy remaining	Remaining expected life if children ≤ age 5 had not died from ALRI, and if individuals of all ages had not died from stroke, IHD, lung cancer, and COPD	DCW – Health tab C52:C67 BHT – Assumptions_ InputSheet tab AB42:AB46	***Potential data sources:*** Civil death registries may have information, but low-quality records are common in LMICs and even in cases where quality information exists, significant time may be required to obtain and sort data. ***Default data source(s):*** Modelled estimates from the Global Burden of Disease database. Use the following workbook to calculate remaining life expectancy.
Healthcare expenditures			
Cost per disease case	Total healthcare expenditures (public and private) to treat the designated diseases	DCW – Health tab C74:C89 BHT – Assumptions_ InputSheet tab AB18:AB22	***Potential data sources:*** The Ministry of Health may have data on total health expenditures broken down by disease. Totals by disease can be divided by the prevalence (# of people) to estimate the total cost per case. ***Default data source(s):*** Use the following workbook to calculate the cost per case of stroke, IHD, and lung cancer. Default estimates are not currently available for ALRI and COPD, though Jeuland et al (2018) has compiled estimates in Supplemental Appendix B20.
Public health expenditures	The percent of healthcare expenditures for the designated diseases that are public health expenditures	DCW – Health tab C93:C108 BHT – Assumptions_ InputSheet tab AB24:AB28	***Potential data sources:*** The Ministry of Health may have data on the sources of expenditures to treat the designated diseases ***Default data source(s):*** The WHO Global Health Expenditures database [47] Public health expenditures divided by total healthcare expenditures provides an estimate for use in the analysis

Table A2. Economic, environmental, and demographic data

Economic			
Unskilled wage rate (US$/hr)	The average wage rate among unskilled workers, where "unskilled" is defined as having limited or no training (either in education or in trade)	DCW – Other tab C13:T24 BHT – Assumptions_ InputSheet tab AJ6:AJ17	***Potential data sources:*** Ministry of Labour data on wages by skillset ***Default data source(s):*** The minimum wage rate (see ILO data) [48] may be used in lieu of other data, though with care given that some countries have low minimum rates that may not be reflective of the average paid value of unskilled labour.
Mortality of select diseases	Mortality among incident cases of ALRI in children ≤ age 5, and in prevalent cases of stroke, IHD, lung cancer, and COPD	DCW – Health tab C33:C49 BHT – Assumptions_ InputSheet tab AB12:AB16	***Potential data sources:*** Civil death registries may have information, but low-quality records are common in LMICs and even in cases where quality information exists, significant time may be required to obtain and sort data. ***Default data source(s):*** modelled estimates are available from the Global Burden of Disease database. Follow the links below, change the location to the country of interest, and select "search" to acquire death rates per 100K, by disease. 1. ALRI 2. Other diseases - Stroke, IHD, Lung cancer, COPD

Life expectancy remaining	Remaining expected life if children ≤ age 5 had not died from ALRI, and if individuals of all ages had not died from stroke, IHD, lung cancer, and COPD	DCW – Health tab C52:C67 BHT – Assumptions_ InputSheet tab AB42:AB46	***Potential data sources:*** Civil death registries may have information, but low-quality records are common in LMICs and even in cases where quality information exists, significant time may be required to obtain and sort data. ***Default data source(s):*** Modelled estimates from the Global Burden of Disease database. Use the following workbook to calculate remaining life expectancy.
Value of a statistical life	A measure of how much individuals are willing to pay on average so that one less expected death occurs in a given year	DCW – Other tab C27:T38 BHT – Assumptions_ InputSheet tab BH28	Potential data sources: IC national team members may have awareness of standard values used by government agencies. VSL values may also be available from published stated or revealed preference studies, and/or wage risk studies Default data source(s): VSL values by country can be obtained using the following workbook
Social discount rate	The social discount rate is a measure of time preference, reflecting the present value of costs and benefits that occur in the future	DCW – Other tab C41:T51 BHT – Assumptions_ InputSheet tab BH23	Potential data sources: IC national team members may have awareness of standard values used by government agencies. Default data source(s): Haacker and colleagues (2020) [49] recommend a 5 percent social discount rate for low- and middle income countries. Country-specific discount rates may also be calculated following methods detailed by Addicott and colleagues (2020) [50]

Environmental			
HAP spillover	A measure of the percent of all pollution attributable to HAP due to cookstove use	DCW – Other tab C56:T67 BHT – Assumptions_ InputSheet tab AB48	***Potential data sources:*** Published literature, government databases ***Default data source(s):*** Karagulian and colleagues (2015) [51] provide regional estimates of pollution by source, though data for some regions is thin and outdated. The studies underlying the regional estimates may be viewed in the WHO database on local source apportionment studies of particulate matter in air.
Social cost of carbon	The social cost of carbon is a monetary estimate of all of the costs of emitting one ton of carbon	DCW - Other tab C70:T81 BHT - Assumptions_ InputSheet tab BH30	***Potential data sources:*** IC national team members may have awareness of standard values used by government agencies. ***Default data source(s):*** UN high-level commission on carbon pricing and competitiveness
Tree replacement cost	The cost of purchasing one kilogram of wood from timber companies that produce renewably harvested wood (US$/kg)	DCW - Other tab C84:T95 BHT - Assumptions_ InputSheet tab BH29	***Potential data sources:*** Cost from local sustainable timber companies. ***Default data source(s):*** BAR-HAP Tool assumption; other estimates can be made using the following workbook.

Demographic			
Household size and composition	The average household size (# of people) and the average # of children under age 5 in each household [52]	DCW - Other tab C99:T110 BHT - Assumptions_ InputSheet tab BH24:BH25	***Potential data sources:*** National Census data; [53]; Living Standards Measurement Studies [54] ***Default data source(s):*** UN Household size & composition data table [52]

AAP Model

Table A3. Examples proposed interventions for $PM_{2.5}$ reduction

Source contribution	Intervention[15]	Effectiveness	Cost	Setting	Source
Waste management	Improved solid waste management and sanitation practices to reduce burning	1 ton of $PM_{2.5}$ removed	Region specific (US$ 9,800-US$28,00/ton)	Region specific	Larsen [55]
Energy	Electrostatic precipitators for coal power plants	98% of primary $PM_{2.5}$ emissions averted	US$47,170 capital costs US$0.8083 Per mwh*(2017)	Brazil	Howard et al. [56]
Energy	Fabric filters for coal power plants	99.7% Of primary $PM_{2.5}$ emissions averted	US$56,780 capital costs US$0.9152 Per mwh* (2017)	Brazil	Howard et al. [56]
Road transport	Diesel oxidation catalyst, active and passive diesel particulate filter for local transportation buses (1998 – 2006)	Combined effect of 80.47 kilograms of $PM_{2.5}$ averted per vehicle per year*	Total cost of US$3,990 Per vehicle per year*	Mexico city	Evans et al. [57]
Road transport	Diesel oxidation catalyst, active and passive diesel particulate filter for long-haul tractor-trailer (1998 – 2006)	Combined effect of 23.04 kilograms of $PM_{2.5}$ averted per vehicle per year*	400 Million new Taiwan dollars (2019)*	Taiwan	Evans et al. [57]
Industry	Improve control of smoke from 7000 restaurants				Lai et al. [58]
Agriculture	Reduced urea-based fertilizer, promotion of enhanced efficiency nitrogen (n) fertilizer, and deep placement of fertilizer for rice farming				Zhang et al. [59]
Residential	Electric heating installed in 200,000 traditional houses				World Bank [60]

15 Some interventions, such as the examples included for energy and road transport sectors, require additional data input to calculate costs and effect sizes according to the country of interest. Economists will have an opportunity on the data workbook to provide units such as total number of cars, total number of coal power plants, and total number of megawatt hours generated, which will help determine total intervention costs and effects.

Table A4. Introduction to the IER model program

To run the IER program, users should gather the information provided in Table A4 below. The IER program was developed in RStudio (2022.07.2 Build 576; R version 4.2.1 2022-06-23 UCRT) and is an R Markdown file (.Rmd). The program is set to estimate the disease incidence and mortality cases attributable to AAP in the years 2019 through 2050 for the six selected diseases.

For the program to run smoothly, the information documents should be placed in specific locations on the users' computers. Once the data is collected and saved to the appropriate location, the IER program should be opened. Instructions on how to run the program are included in the program itself.

Table A4. Data inputs for IER program

Information documents	Location
Data_Inputs.xlsx; sheet = "IHME"	"Country_IER Model" folder; Data_Inputs.xlsx file *(folder with RStudio code)*
Data_Inputs.xlsx; sheet = "Population_Weighted"	"Country_IER Model" folder; Data_Inputs.xlsx file *(folder with RStudio code)*
Data_Inputs.xlsx; sheet = "Population_Full"	"Country_IER Model" folder; Data_Inputs.xlsx file *(folder with RStudio code)*
IHME Risk Summaries for each disease (COPD, IHD, Stroke, Diabetes, ALRI, & Lung Cancer)	"Data Inputs" folder *(folder inside "Country_IER Model" folder)*