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Methods and approach

The study does not model the relationships between emissions, concentrations, exposure and impacts in the same way as a typical impact assessment study. Instead, it draws on parameters and relationships established in existing literature and expert interviews, to give a "Business-As-Usual" (BAU) and "Improved Air Quality" (IAQ) scenario. It then compares the estimated impact in terms of lives lost, economic costs and greenhouse gases emitted in each scenario.

The study represents an initial step towards the more in-depth and targeted analyses that are needed to robustly quantify air quality and its impacts across Africa following best-practice modelling approaches

STAGE 1 – Estimating the 2019 baseline

A. Health impacts of air pollution in the four cities

The number of premature deaths and workdays lost per year due to air pollution are estimated for each city in 2019 to form baseline numbers, using available information.

Data on premature deaths caused by air pollution is collected from the Global Burden of Disease dataset. This study estimated the city-level health impact by scaling from country to city based on the city's share of the total population.[1]

The number of workdays lost in each country is based on a global report by the Center for Research on Energy and Clean Air (CREA).[2] Data on global workdays lost to fossil fuels was scaled to account for all sources of air pollution based on proxy mortality data by air pollution source[3], and scaled to each country based on each country's share of years of healthy life lost due to disability (YLD)[4] as a proxy for the disease burden that would be in direct proportion to the number of working days absent due to air pollution.

B. Economic impact of air pollution in the four cities

The economic impact of air pollution is based on these two main health parameters:

(i) **premature mortality:** the loss of economic value from lives lost caused by air pollution, and
(ii) **absenteeism:** the loss of economic value from workdays lost due to high levels of air pollution[5].

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[1] This approach is in line with the World Bank's method to estimate city-level mortality in their report, "The Cost of Air Pollution in Lagos"
[2] Center for Research on Energy and Clean Air (CREA), "Quantifying the Economic Costs of Air Pollution from Fossil Fuels", 2020
[3] https://www.healthdata.org/gbd/2019
[4] Premature deaths data is available at the national level and is adjusted to the city-level in direct proportion to greater metropolitan area population. Source: (1) Global Burden of Disease dataset; State of Global Air; Dalberg analysis
[5] This study does not consider the economic impact of presenteeism, health expenditures, impact on agricultural yields and/or ecosystem disruptions attributable to air pollution given limited data in the African or similar country contexts.

Economic impact of premature mortality: The economic impact of premature mortality is based on the World Bank's income-based approach (the net present value of income of current and future working years lost). For each city, the economic value of a working year lost is based on the labour share of GDP - taking into account labour force size and labour force participation rates - to find the average economic output per capita.

Economic impact of absenteeism: The economic value of a working year in each of the cities was applied to the estimate cost of working days lost. The economic impact of premature mortality is based on the World Bank's income-based approach[6] i.e. the net present value of income of current and future working years lost.

C. Including informal sector in economic impact

The primary analysis is based on formal GDP numbers for each of the cities. Capturing the informal economy raises the annual economic costs of air pollutions by approximately 55% average across the four cities. Cost estimations to include the informal sector are based on two-step approach:

(i) integrating informal sector share in countries' GDPs, and
(ii) using the GDP with informal sector share to calculate the economic value of a working day or year.

Informal sector data is shown in approximations of the financial costs to the individual cities and aggregate financial costs for the four cities for 2019 and 2040. The financial benefits resulting from delivering the policy levers use formal economy data only. Use of informal sector economic impacts across the report is clearly highlighted in the text.

Including the informal sector provides a more realistic perspective of the costs, given the size of the informal economy in each city. However data on informal GDP and the size of the informal workforce are estimates, as there is limited data on the impact of air pollution in the informal sector.

STAGE 2 – Estimating the business-as-usual (BAU) scenario

BAU projections of premature mortality and working days lost to 2040 account for greater rates of urbanization forecast for the greater metropolitan area populations of each city. Baseline estimates in 2019 were projected to 2040 based on a ten-year Compound Annual Growth Rate (CAGR) – noting all four countries had linear and consistent trends in mortality caused by air pollution since 2000.

Economic impacts for the whole time period were calculated following a similar approach as outlined above for the baseline 2019 data. The net present value of all future working years lost was applied to premature mortality data by age group. In line with the World Bank's approach for project economic analysis for low and middle-income countries, a discount rate of 6% and real income per capita growth rate of 3% was used.

6 https://openknowledge.worldbank.org/bitstream/handle/10986/36501/9781464818165.pdf?sequence=4&isAllowed=y

STAGE 3 – Estimating the improved air quality (IAQ) scenario

The IAQ is estimated by approximating the change in premature deaths, workdays lost and greenhouse gas emissions due to the implementation of five clean air policies over the considered time period, building off the BAU.

Each policy (listed in Table X) is associated with a corresponding percentage reduction in sector-attributable PM2.5 concentration and greenhouse gas (GHG) emissions. The reductions for each policy are obtained from recent literature. Studies from countries with similar air pollution and development contexts were used where possible although the lack of air pollution impact assessments across Africa made this not possible in all cases.

To account for feasibility constraints, the analysis assumed that by the first year of implementation (2023), clean air policies will have 50% impact in the four cities growing to reach 100% impact by 2033 or 2038 to account for the lower institutional capacity and policy constraints in the African context along with a longer timeframe for certain lever implementation (e.g., public transport infrastructure). The percentage reduction in PM2.5 (applied to concentration levels in each city) was translated to corresponding reductions in premature deaths and workdays lost using an assumed linear relationship. Based on literature review and studies in multiple country contexts, the potential lives saved is based on studies that estimate the impact of higher or lower air pollution concentrations on premature mortality – **the key input used was that a 10 μg/m^3 reduction in PM2.5 concentration is associated with a 7.4% reduction in premature mortality**[7].

Avoided GHG emissions, comparing IAQ and BAU, are calculated by summing the GHG reductions provided by each policy measure for each city.

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[7] Long-term exposure to PM and all-cause and cause-specific mortality_ A systematic review and meta-analysis | Elsevier Enhanced Reader

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Table 1: Impact of clean air policies in reducing air pollution when applied at full potential[8]

Clean air policy	Example mechanism	Impact on air pollution[9]	Impact on GHG[10]	References	Comments
25% reduction in gasoline and diesel fuel road traffic	• Strengthen public transport infrastructure; for example, extend bus routes for last mile connectivity to key destinations • Provide free public mobility services • Introduce odd-even scheme for private vehicles • Increase parking fees within the city and/or introduce city toll	Reducing traffic by 25% could lead to 15% reduction in PM2.5 concentration attributable to on-road traffic.	Reducing car traffic by 25% could lead to 42% reduction in CO_2e emitted by on-road traffic	(i) International Growth Centre, From car-free days to pollution-free cities - Reflections on clean urban transport in Rwanda, 2021 ; https://www.theigc.org/wp-content/uploads/2021/08/Kalisa-et-al-June-2021-Policy-Brief.pdf; Page 8 ; (ii) Aerosol and Air Quality Research, Assessing the Impact of Traffic Emissions on Fine Particulate Matter and Carbon Monoxide Levels in Hanoi through COVID-19 Social Distancing Periods, 2021 ; https://aaqr.org/articles/aaqr-21-04-oa-0081 ; Section 3.4.2 "Potential effects of the changing of transportation volume on pollutants' concentrations" Paragraph 3 & 4	% obtained by: (i) calculating arithmetic average of the ratio of PM2.5 reduction for Kigali (56%) and for Hanoi (62%) ; and (ii) multiplying the arithmetic average by PM2.5 reduction hypothesis for the four focus cities (25%).
Deploy clean cookstoves and alternative fuel sources for household energy requirement	• Increase availability and reduce price of clean cookstoves (LPG cookstoves or electric induction plates) that replace biomass cookstoves • Reduce subsidies on biomass	Replacing cookstoves using biomass fuels leads to 55% reduction in PM2.5 concentration in households.	Replacing all feasible cookstoves reduces solid fuels GHG emissions by 44%.	United Nations Climate Change, Zero Carbon Clean Cookstoves for Africa - Benin, Ghana, Nigeria, 2022; https://unfccc.int/climate-action/momentum-for-change/activity-database/zero-carbon-clean-cookstoves-for-africa ; "Fast Fact" section, second bullet point	% obtained by averaging the highest (80%) and the lowest (30%) indoor PM2.5 reduction potential observed.

[8] Replacing slash and burn practices with slash and composting to reduce carbon dioxide emissions from degraded peatland; Second Pollution Abatement Project, World Bank, 2016; The state of the global clean and improved cooking sector, ESMAP, 2015; Greenhouse Gases Equivalencies Calculator - Calculations and References, US Environmental Protection Agency; Reducing transport GHG emissions: Opportunities and Costs, OECD, 2010

[9] Multiple sources detailed in the model

[10] Multiple sources detailed in the model

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Switch to cleaner industrial technologies	• Using best available technology (BAT) that is feasible in developing country contexts • Move from natural resource-based, low technology industries to medium to high technology industries • Develop eco-friendly industrial zones	Switching to BATs reduces industrial activity PM2.5 emissions by 47%[11].	Switching to BATs reduces industrial activities GHG emissions by 29%.	Aerosol and Air Quality Research, PM2.5 Emission Reduction by Technical Improvement in a Typical Coal-Fired Power Plant in China, 2016 ; https://aaqr.org/articles/aaqr-16-05-2015aac-0200.pdf; Page 640 "Discussion" section.	
Implement support systems to switch from slash-and burn to sustainable land-clearing practices[12]	• Implement policies and programs to raise awareness and incentivize sustainable land clearing practices • Incentivising use of Best Available Technology for agriculture land clearing	Switching away from slash-and-burn practices saves 99% of PM2.5 concentration attributable to land clearing.	Switching away from slash-and-burn practices reduces land clearing GHG emissions by 69% assuming composting with solid wastes from land-clearing emits in the same average proportion as for any other waste.	https://www.thenationalnews.com/mena/2022/03/25/cairo-trying-to-shake-off-tag-as-one-of-the-worlds-most-polluted-cities/ In a few years only, the Egyptian government claims to have set a collect & recycle mechanism capturing 90% of the rice straws produced. We assume a longer timeline to get to 99% to reflect the diversity of needs (e.g. different crops resulting in different waste).	
Implement integrated waste management systems that improve waste collection, prevent open burning and improve incineration practices	• Improve the infrastructure for waste collection • Implement penalties for open burning of waste • Introduce large scale recycling, reuse, and composting centres for waste generated • Facilitate processing of pollution generated through waste incineration	Avoiding waste open burning saves 99% of PM2.5 concentration attributable to waste.	Recycling and composting with wastes along with improved incineration practices save 69% of GHG emissions generated by wastes.	WHO Urban Health Initiative, Solid waste management and health in Accra, Ghana, 2021 ; https://www.who.int/publications/i/item/9789240024250; Page 19/Fig 4.4	

[11] https://www.nature.com/articles/s41893-020-00669-0#data-availability. Note- this source references to potential reduction in PM2.5 emissions not concentration. In the absence of alternative sources, we have used the data on emissions. To account for the difference in emissions vs. concentration, we have taken the lower band average emission/concentration proxy. Note: As data is available only for emissions and not concentration, 47% represents the lower bound of estimations to account for lower impact on concentration than on emissions.
[12] Slash and burn applies to all land clearing including post harvest, land clearing for construction, etc.

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LIMITATIONS

The study results represent first-of-their-kind estimates, requiring more in-depth analysis to robustly calculate these impacts via best practice modelling approaches. The study uses credible data from sources such as the Global Burden of Disease, Health Effects Institute, CREA and others, and further processes it to extrapolate out into the future (e.g., BAU) and across different regions with different concentration levels and local contexts (e.g., relationship between PM2.5 concentration change and premature mortality).

The study does not directly model the relationships between emissions, concentrations, exposure and impacts and instead relies on parametrisations and assumed relationships gathered from desk-based research and expert interviews. The results represent an initial step towards the more in-depth and targeted analyses required to robustly quantify health, economic and climate impacts across Africa.

Several of the assumptions made are conservative in nature (e.g., omission of presenteeism, healthcare costs, impact on crop yields from economic costs) and are therefore likely to lead to an underestimation overall.

Other key considerations and simplifications include:

- **The estimates of savings in the IAQ should be treated purely as an indicative of the potential scale of savings rather than inputs to an investment case.** The potential scale of impact assumes near-immediate implementation (50% in 2023).
- **The cost of policy implementation is not considered in the scope of this work.** The cost of policy implementation will be lower on an annual basis in the longer term, with higher costs in the short term. Benefits, on the other hand, continue to accumulate as the lever is maintained. Data up to 2040 underestimates longer term benefits.
- **City-level data is limited across African cities and therefore key figures are scaled down from national values.** Data available at the country level is scaled down to the city level based on metropolitan area populations and estimates of city GDP as appropriate. Projections to 2040 also accounted for greater rates of urbanization projected in each city.
- **The financial cost of premature mortality is highly sensitive to the selected discount and growth rates.** The model used the World Bank discount rate (6%) and growth rate (3%) for low- and middle-income countries, used for their income-based estimation of the global cost of air pollution
- **Projections using available historical data were made based on ten-year CAGRs.** These linear estimates assume consistent trends in the short/medium term to 2040 – corroborated by reviewing historical trends for each datapoint. Previous reports on air pollution projections have used both linear as well as non-linear projections as an alternative projection.
- **Estimates on the burden of disease and death due to air pollution in Africa are sourced directly from the Global Burden of Disease, 2019, dataset.** These estimates are likely to be conservative and undercount air pollution's full impacts because they are based solely on diseases known to be directly caused by air pollution. Research and evidence on understanding and defining the health impacts of air pollution is growing and hence, it is likely that new evidence will reveal additional links between air pollution and diseases, thereby increasing future estimates of the premature mortality and disease burden attributable to air pollution.
- **Estimates undercount the total economic costs of air pollution without accounting for health expenditures, agricultural yields or ecosystem disruptions attributable to air pollution**. Impact

estimation is limited only to the health impact and reduction in greenhouse gas emissions given a lack of studies in the African context or similar contexts that could be extrapolated to the selected cities.

- **This study relies on extrapolations from existing studies and datapoints from other countries given limited to no primary research in African contexts.** As far as possible, country contexts with similar levels of air pollution and development were used, as well as studies across multiple contexts. However, some data was sourced from higher income countries with similar pollution levels, or countries with similar levels of development but higher levels of air pollution – the two contexts where more primary research has been conducted. Extrapolations to the four selected cities do account for linear differences in air pollution concentration, real GDP, and population.
- **Burden calculations do not consider the effects that changes in numbers of deaths has on the size and age of the population in subsequent years**. Burden calculations provide snapshot of the extent of air pollution and its impact without considering that population size and age affect the number of deaths.
- **This study focused on PM2.5 as the primary driver of mortality and morbidity** due to limited information and inconsistent data available on other pollutants in Africa. It does not account for the wider range of air pollutants which harm human health such as ozone and nitrogen dioxide.
- **The correlation between reduction in PM2.5 concentration and reduction in mortality rates is unlikely to be linear at all levels of air pollution concentration**. The 7.4% reduction in premature mortality is based on a summary estimate of 25 studies that estimates an average of 8% increase in mortality rate through 10 µg/m3 of increase in PM2.5 levels.[13] In reality, the correlation is unlikely to be linear, especially for much larger changes in air pollution concentrations. Scientific studies have taken both a linear and non-linear approach to estimating the impact of air pollution.
- **The impact of clean air policies in terms of reduced levels of PM2.5 are derived largely from data collected in other countries, sometimes including high-income countries.** Our estimates also assume that clean air policies will have 50% impact icon the first year of implementation (2023) growing to reach 100% impact by 2033 or 2038 to account for the lower institutional capacity and policy constraints in the African context along with a longer timeframe for certain lever implementation (e.g., public transport infrastructure).
- **There are time lags between the implementation of clean air policies and the positive impact on health outcomes that have not been considered.** The impact of clean air policies on long-term exposure is hard to distinguish in initial years, as results are generally seen over 5-10 years. Hence, there is a limitation in the assumption that impact will start in the same year as implementation.
- **The primary estimates of the economic impact do not include data on presenteeism due to a lack of evidence in the African context.** Presenteeism, or lower productivity while at work, is another mechanism of air pollution's economic impact that was not included as existing studies have focused on the world's most polluted cities, mainly in China and India, or in developed economies such as the United States.

[13] Long-term exposure to PM and all-cause and cause-specific mortality_ A systematic review and meta-analysis | Elsevier Enhanced Reader