CLEAN AIR FUND

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 a "Improved Air Quality" (IAQ) scenario. It then compares the estimated impact in terms of premature deaths, 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 pollution and its impacts across Africa following best-practice modelling approaches.

STAGE 1 – Estimating the 2019 baseline

A. Health impacts of air pollution in the six 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 (2019). In the absence of city-level data, the method uses country-level information and scales this down to the city-level based on the city's share of the total population.[1] We recognize that the relationship between premature deaths caused by air pollution is likely not proportional to population share, however the precise relationship is unclear.[2]

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). Data on global workdays lost to all sources of air pollution was scaled down from the global number of workdays lost to air pollution from fossil fuels, based on the ratio of global deaths from all sources of air pollution to the global deaths from air pollution from fossil fuels. This was then scaled to each country based on its share of years of healthy life lost due to disability (YLD) 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 six 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

[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] Most studies suggest air pollution related deaths in cities are higher than rural areas (and likely the country average). However for the only city where GBD dataset is available (Nairobi), air pollution related deaths occur at a lower rate than the rest of the country.

(ii) **absenteeism**: the loss of economic value from workdays lost due to high levels of air pollution[3].

Both these parameters rely on the **economic value of a work year**. This is computed based on the labour share of GDP – taking into account labour force size[4] and labour force participation rates[5] - to find the average economic output per capita.

ii. **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). This is calculated by multiplying the number of premature deaths attributable to air pollution within each reported age bracket by the sum of the net present economic value of all future working years lost from the age of death until age 80 (accounting for lower labour force participation rates between the ages of 65-80). 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. The discount rate refers to the rate of interest that is used to discount all future economic value to derive its net present value in 2019.

These values are calculated at the country level in 2019 and then scaled down to city-level based on the city's share of the total population.

ii. Economic impact of absenteeism: The economic value of a working year in each of the cities was applied to the estimated cost of working days lost. The economic impact of absenteeism 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. These values are similarly calculated at the country level and then scaled down to city-level based on the city's share of the total population.

C. Excluding informal sector in economic impact

The primary analysis is based on formal GDP estimates for each of the cities. Capturing the informal economy raises the annual economic costs of air pollutions by approximately 45% average across the six cities. Cost estimations that include the informal sector are based on two-step approach:

(i) Integrating informal sector share in countries' GDPs[7], and
(ii) Using the total GDP, including informal sector share, to calculate the economic value of a working day or year

Including the informal sector provides a more realistic perspective of the costs, given the size of the informal economy in each city. However reported data on informal GDP and the size of the informal workforce carries a high degree of uncertainty and has therefore been omitted from primary estimates. Across the report, informal sector activities which impact air

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[3] 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.
[4] World Bank Data
[5] For ages 15-64 the labour force participation rates were taken from the World Bank Data, while for ages 65+ a constant value was applied from all countries from UN, world population ageing 2013
[6] World Bank, The global health cost of PM2.5 air pollution, 2022
[7] World Economics, Informal Economy

pollution in the cities have been clearly highlighted.

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

To account for the greater impact of air pollution in cities and the faster growth rates of cities compared to the national population, urbanization rates for each city were included in the projections of premature mortality and working days lost to 2040.

All baseline estimates in 2019 were projected to 2040 based on a ten-year Compound Annual Growth Rate (CAGR). This includes projected values for premature mortality, population size, urbanization rate and PM2.5 pollution concentrations[8]. CAGRs were calculated based on the ten-year period between 2009 and 2019. Two exceptions were made to historical CAGRs: (i) GDP forecasted growth rates were taken from 2017-2027 based on projections by the IMF; (ii) projection of GHG emissions were calculated using a 2020-2030 CAGR based on baseline estimates (i.e., current policy scenarios) from National Determined Contribution reports.

Economic impacts for the whole time period (2023 – 2040) were calculated by projecting the 2019 values accounting for the growth in the population size, urbanization rates, GDP, and PM2.5 levels . Despite the existence of more recent air pollution data in some instance, we defaulted to 2019 recorded levels to remove any variation due to the COVID-19 pandemic.

This methodology was compared against the World Bank's income and welfare-based estimates to ensure that the projections were of similar magnitudes.

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 1) 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 meant this was not possible in all cases. The percentage reductions for implementing each policy is combined with the percentage contribution each source to total PM2.5 and GHG levels.

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 six cities growing to reach 100% impact by 2033 or 2038. All policy interventions were assumed to have 10 year implementation timeframe from 2023 except the one related to road transport. This was to account for the lower institutional capacity, policy constraints, and the generally longer timeframe for implementation of infrastructure projects. 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 deaths reduced is based on studies that estimate the impact of higher or lower air pollution concentrations on premature

[8] PM2.5 CAGRS were taken from 2009 – 2019 for Kenya and Cameroon. For the other four countries, the CAGR was calculated from 2010 – 2019 due to data gaps from the State of Global Air database.

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**[9]**.**

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

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

Table 1: Impact of clean air policies in reducing air pollution when applied at full potential[10]

Clean air policy	Example mechanism *(not exhaustive)*	Impact on air pollution	Impact on GHG	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 • 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 CO2e emitted by on-road traffic	PM2.5: (i) International Growth Centre, From car-free days to pollution-free cities - Reflections on clean urban transport in Rwanda, 2021 ; https://www.theigc.org/sites/default/files/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 GHG: USA facts, Carbon emissions dropped in 2020. Much of the decrease was due to less driving and fewer flights, Section 3, paragraph 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 cooking appliances and alternative fuel sources for household energy requirement	• Increase availability and reduce price of clean appliances (LPG cookstoves or electric induction plates) that replace biomass appliances • Reduce subsidies on biomass • Support entrepreneurship models that expand use and access to clean cooking appliances	Replacing cooking appliances using biomass fuels leads to 25% reduction in PM2.5 concentration in ambient air.[11]	Replacing all feasible cooking appliances reduces solid fuels GHG emissions by 45%.[12]	PM2.5: Conibear et.al., (2021), A complete transition to clean household energy can save one-quarter of the healthy life lost to particulate matter pollution exposure in India, Abstract https://iopscience.iop.org/article/10.1088/1748-9326/ab8e8a GHG: Clean cooking Alliance	

[10] 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
[11] Revised from 2022 analysis from 55% in previous report to 25% based on updated source listed
[12] Revised from 2022 analysis from 44% in previous report to 45% based on updated source listed

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 25%[13,14].	Switching to BATs reduces industrial activities GHG emissions by 34%.[15]	PM2.5 & GHG: Aerosol and Air Quality Research, PM2.5 Emission Reduction by Technical Improvement in a Typical Coal-Fired Power Plant in China, 2016 ; https://www.nature.com/articles/s41893-020-00669-0#data-availability; Abstract.	% for GHG reduction obtained by taking the midpoint of the range stated (i.e., 18% to 50%) % for PM2.5 change is taken as the lower bound of the range provided for a conservative figure in applying the PM2.5 emissions reduction to PM2.5 concentration reduction
Implement support systems to switch from slash-and burn to sustainable land- clearing practices[16]	• 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 reduces 99% of the PM2.5 concentration attributable to land clearing.	Switching away from slash-and-burn practices reduces land clearing GHG emissions by 76% assuming composting with solid wastes from land-clearing emits in the same average proportion as for any other waste.[17]	PM2.5: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). https://www.thenationalnews.com/mena/2022/03/25/cairo-trying-to-shake-off-tag-as-one-of-the-worlds-most-polluted-cities/ GHG: Replacing slash and burn practices with slash and composting to reduce carbon dioxide emissions from degraded peatland , Abstract	% GHG reduction calculated as the difference between the emission from slash and burn (4.98 t CO_2 ha^{-1}) vs slash and compost (1.20 t CO_2 ha^{-1})

[13] 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, 25% represents the lower bound of estimations to account for lower impact on concentration than on emissions.

[14] Revised from 2022 analysis from 47% in previous report to 25% based on rationale in footnote 13

[15] Revised from 2022 analysis from 29% in previous report to 34% based on the updated source listed

[16] Slash and burn applies to all land clearing including post-harvest, land clearing for construction, etc.

[17] Revised from 2022 analysis from 69% in previous report to 76% based on updated source listed

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 94%[18] of PM2.5 concentration attributable to waste.	Cessation of waste burning practices save 50% of GHG emissions generated[19]	WHO Urban Health Initiative, Solid waste management and health in Accra, Ghana, 2021 ; https://www.who.int/publications/i/item/9789240024250; PM2.5:Pg 20 GHG: Pg: 18	

[18] Revised from 2022 analysis from 99% in previous report to 94% based on updated source listed
[19] Cessation updated to include only reduction in open burning and does not including any other measures such as composting or gas capture

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, as well as World Bank methodology to project insights into the future, and across different regions with different concentration levels and local contexts (e.g., relationship between PM2.5 concentration change and premature mortality).

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 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.

- **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. Scaling from country data to city data which most likely underestimates health effects from air pollution although relationship is unclear. The methodology also does not account for agglomeration economics - namely the higher average economic output per worker attained in urban areas - hence the economic value of urban workers in our calculations may be underestimated.

- **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 six selected cities do account for linear differences in air pollution concentration, real GDP, and population.

- **The impact of the clean air interventions, in terms of reduced levels of PM2.5 are derived largely from data collected in other countries, sometimes including high-income countries and is more likely underestimated**. Our estimates also assume that clean air policies will have 50% impact in 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).

- **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.

- **Focus on PM2.5 as the primary driver of air pollution related mortality and morbidity in Africa**. This study focused on PM2.5 as the primary driver of mortality and morbidity due to limited information and inconsistent data available for other pollutants types in Africa. It does not take into account the health impacts of other air pollutants (e.g., NO_2 or O_3)

- **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.

- **Estimates on the burden of disease and death sourced from the Global Burden of Disease data set are likely to undercount full impact on health**. 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.
- **The correlation between reduction in PM2.5 concentration and reduction in mortality rates is unlikely to be linear at all air pollution concentration levels**. 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 $\mu g/m^3$ of increase in PM2.5 levels.[20] 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 primary estimates of the economic impact do not include data on presenteeism due to a lack of evidence from Africa**. 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.

- **The primary estimates of the economic impact do not include informal estimates of GDP**. While the alternative analysis does include estimates of the scale of potential, data on informal GDP and the size of the informal workforce are estimates, and have limited data on the impact of air pollution. Additionally, the annual economic output of informal economy workers is likely to be underestimated. Due to limited data on informal economies, informal economy estimates assume labour income accounts for the same percentage share of GDP as formal estimates. This likely underestimates the economic value of a working year for informal workers given a greater share of informal GDP comes from waged labour than the formal economy

- **PM2.5 figures record ambient pollution levels only.** Estimates consider all deaths attributable to air pollution (ambient, indoor and ozone) but PM2.5 concentrations are only regularly reported for ambient air pollution sources. The impact of levers are therefore applied to ambient PM2.5 levels only, but are used to compute the change in mitigated premature deaths from all sources of air pollution (ambient, indoor and ozone). The methodology also therefore captures the effect of intervention #2 "deploying clean cooking appliances and alternative fuel sources for household energy requirement" on premature mortality and absenteeism via a reduction in ambient air

[20] Long-term exposure to PM and all-cause and cause-specific mortality: A systematic review and meta-analysis

levels only. This may lead to an underestimation of the health impact of clean cooking interventions, which is known to have a high direct impact on deaths attributable to indoor sources of air pollution.

- **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.

- **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.

- **The estimates of savings through levers are to be treated as the potential scale of savings rather than inputs to an investment case**. The potential scale of impact assumes immediate implementation and no time lag before the impact to provide the potential scale of savings. The cost of implementation of levers is also not considered. The cost of implementation of levers 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 (including health benefits for future generations)

- **There are likely time lags between the implementation of clean air interventions and the positive impact on health outcomes**. 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.

- **Improved air quality scenarios assume that there is no contribution from transported natural or anthropogenic aerosol from upwind regions**. Given the research's interest in local-level interventions that can be undertaken to change pollution outcomes, we have sought to remove major exogenous sources of air pollution to ensure the comparability of measures. This includes taking PM2.5 estimates outside of the Harmattan season to remove the influence of wind-blown Saharan dust on air pollution in Western and Central African cities. The sources used for Nigeria and Ghana measured PM2.5 concentrations outside the Harmattan season. In Cameroon, the main source reports annual PM2.5 averages, including dust from the Harmattan. To adjust for this, additional sources reporting PM2.5 contributions outside the dry season months are used to scale-down share of PM2.5 share attributable wind-blown dust. It should be acknowledged that some cities may be subject to high levels of regionally transported aerosols (e.g., cities strong prevailing winds).

- **The potential toxic effects of the combination of natural dust and traffic emissions is not included**. Due to a lack of reported data on this phenomenon, this model assumes no interaction effect between two variables.

FUTURE REFINEMENTS

This report uses best public data and techniques available at the time of publishing. Nonetheless, as outlined elsewhere in this section, the methodology relies on strong assumptions and imperfect data. We have summarized below some main areas of improvement that could be pursued in future exercises:

- Include estimation of cost of air pollution on health expenditures to further increase comprehensiveness of analysis (Croitoru, et. al., (2020), The cost of air pollution in Lagos)
- Consider conducting a COVID-specific analysis that looks at the effect of vehicular emissions on PM2.5 concentrations using pre, during and post-COVID data, and links effect to disease burden in Global Burden of Disease datasets.
- Utilize more local data – including monitoring sites, source apportionment studies and impact assessments. In the future comprehensive impact analyses using reduced complexity and/or chemical transport models and local health cohorts could be used to generate more precise estimations.