AIR POLLUTION

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Health and Development Policy – Air Pollution

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Executive summary

Air pollution represents a **huge burden of disease worldwide**. The problem is particularly marked in some cities and countries in developing regions, such as South Asia and sub-Saharan Africa. Beyond the health impacts, air pollution can contribute to climate change, worsen economic outcomes, decrease subjective well-being, and endanger wildlife. Both household and ambient air pollution can have negative effects. Ambient pollution represents a larger burden of disease and has been increasing in the last few decades, whereas the opposite is true for household air pollution.

A large contributor to ambient air pollution worldwide is vehicle emissions. There are a number of ways to lower vehicle contamination, including but not limited to using low-sulfur fuel, adding emissions control devices, and banning old vehicles.

There is strong evidence that vehicle pollution affects health negatively and that policy changes designed to lower vehicle emissions can indeed improve air quality. Specifically, implementing low-sulfur fuel has been shown to reduce air pollution in London and Hong Kong, and requiring catalytic converters (an emissions control device) improved air quality in India. (Note that decent fuel quality may be needed for catalytic convertors to work.)

The cost-effectiveness of interventions to lower vehicle emissions will depend on the specific intervention chosen for a given country. Interventions to advocate for low-sulfur fuel might be costly if implemented in a refiner country, where technological changes would need to be introduced to the refineries at high cost. However, the same intervention would be much cheaper in an importer country, if it only implies banning imports from countries producing high-sulfur fuel. **The CEA we modeled was advocating for the use of catalytic converters, and it appeared cost-effective at $6 per DALY averted when considering only charity costs and $519 per DALY averted when considering total costs**.

Due to the tremendous impact of vehicle emissions on air quality and health, several organizations are working on this issue and many countries have made commitments and/or implemented changes to lower vehicle emissions. However, there are still many countries in which this issue is a big problem. Funding sources and current efforts are largely focused on a subset of countries (China, India), ignoring a large group of countries (like most African countries and many Asian countries) where vehicle emissions remain a substantial issue.

Experts are supportive of tackling vehicle emissions, as most of them agreed that this is one of the major contributors to air pollution. They did, however, raise important concerns. One concern raised was the cost of these interventions, especially the costs of switching to low-sulfur fuel in countries that refine their own fuel. In these circumstances, the cost to upgrade a refinery could total approximately 1 billion USD. Another widespread concern was policy enforcement. For example, even if the government agreed to require emissions control devices, such a policy might be difficult to enforce as the existing vehicle fleets are huge. An additional concern, not mentioned by experts but worth considering, is that this is a very complex policy area. The main organizations working on these issues are large and have a specialized staff, so it is unclear how successful a small new organization could be in this space.

Besides studying potential interventions to tackle vehicle pollution, we also looked at addressing pollution from static sources such as power plants and industry. **We focused on an idea to use open-source satellite data to improve the monitoring and enforcement of emissions standards**. Emissions standards for static sources are usually present in most countries but are often only poorly enforced. We think that monitoring emissions to identify static polluting sources could be a good way to ensure enforcement and/or improve emissions regulations. A cost-effective avenue to achieve this goal could be through the use of open-source satellite data, provided that technology allows for the identification of individual pollution sources. However, **at this stage, we are unclear about the feasibility of such an intervention** using public satellite data. Private companies have successfully demonstrated that detecting point sources from space is possible for some pollutants. As the resolution of public satellites improves, this intervention will become more feasible.

Overall, we lean against recommending policy work to improve air quality this year, but think it should be revisited in future research cycles.

Abbreviations

DALY	Disability-adjusted life years
NO	Nitric oxide
NO_2	Nitrogen dioxide
SO_2	Sulfur dioxide
CO	Carbon monoxide
$PM_{2.5}$ or	Particulate matter with a diameter of 2.5 microns less
PM_{10} or	Particulate matter with a diameter of 10 microns less
SO_x	Sulfur oxides
CAAA	Clean Air Act Amendments
Ppm	Parts per million
LMIC	Low- and middle-income countries
APPCAP	Air Pollution Prevention and Control Action Plan
CAN	Clean Air Network
CEO	Chief executive officer
CCAC	Climate and Clean Air Coalition
VOC	Volatile Organic Compound
WHO	World Health Organization
WRI	World Resources Institute
CEA	Cost-effectiveness analysis
ICCT	International Council on Clean Transportation
EA	Effective altruism

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1 Introduction

This report has been produced by Charity Entrepreneurship (CE). CE's mission is to cause more effective charities to exist in the world by connecting talented individuals with high-impact intervention opportunities. We achieve this goal through an extensive research process and our Incubation Program. In 2021, our research process focused on the top policy and advocacy interventions within global health and development.

Addressing air pollution was chosen by CE research staff as a potentially promising intervention within this category. This decision was the result of a 9-month process designed to identify interventions that were most likely to be high-impact avenues for future charity entrepreneurs. This process began by listing nearly 250 ideas and gradually narrowing down, examining them in more and more depth.

In order to assess how promising interventions would be for future charity entrepreneurs, we use a variety of different decision tools such as group consensus decision-making, weighted factor models, cost-effectiveness analyses, quality of evidence assessments, case study analysis, and expert interviews.

This process was exploratory and rigorous, but not comprehensive – we did not research all 250 ideas in depth. As such, our decision not to take forward a charity idea to the point of writing a full report should not be seen as a view that the idea is not good.

2 Background

Air pollution kills seven million people every year, and 99% of the world's population breathes air with unhealthy levels of pollution (*Air pollution*, n.d. a).

In 2019, air pollution accounted for 213 million DALYs, 8.4% of the global burden of disease (*GBD results tool*, n.d. a) (Table 1). This makes air pollution the third biggest non-biological health risk factor globally, after child and maternal malnutrition and tobacco use (*GBD results tool*, n.d. b).

The health problems caused by air pollution are varied. Looking at the largest health effects (*GBD results tool*, n.d. c), we see that pollution mostly impacts child mortality and health in later life (age 45+).
Table 1: DALY burden for air pollution parsed by health condition

Health effect	DALY burden in 2019	Percent of total DALYs

Ischemic heart disease (IHD)	45,354,420	1.79%
Stroke	43,474,911	1.71%
Lower respiratory infections (LRI)	37,662,346	1.49%
Neonatal disorders	33,125,927	1.31%
Chronic obstructive pulmonary disease (COPD)	28,309,598	1.12%
Diabetes	12,955,791	0.51%
Lung/tracheal/bronchus cancer	8,951,974	0.35%
Blindness	2,143,472	0.08%
Other	1,306,448	0.05%
Total	**213,284,887**	**8.41%**

The pollutants that have negative health effects include particulate matter ($PM_{2.5}$ and PM_{10}), ozone (O_3), sulfur dioxide (SO_2), nitrogen oxides (NO and NO_2), carbon monoxide (CO), and volatile organic compounds (VOCs) (*Types of pollutants*, n.d.).

A single source of pollution can lead to many additional pollutants; for example, higher levels of sulfur in fuel leads to both SO_2 and increased $PM_{2.5}$.[1] It can be difficult to distinguish between the effects of different pollutants, so studies and interventions tend to either not distinguish between pollutants or focus on $PM_{2.5}$, which is the most commonly measured.

The most substantial health impacts are in South Asia, Southeast Asia, East Asia, Oceania, and sub-Saharan Africa (*GBD results tool*, n.d. d) (Table 2). However, the health impacts, especially for outdoor air pollution, may vary significantly from city to city more so than from country to country.

Table 2: DALY burden of air pollution per region

Location	DALYs per 100,000 (2019)	Total DALY burden (2019)
South Asia	3,954	71,369,584
Southeast Asia, East Asia,	2,794	60,327,721

[1] As SO_2 is a major precursor to $PM_{2.5}$ (*Sulfur Dioxide Emissions*, 2018)

and Oceania		
Sub-Saharan Africa	4,514	48,669,210
North Africa and the Middle East	2,145	13,056,864
Central Europe, Eastern Europe, and Central Asia	1,847	7,716,175
Latin America and Caribbean	1,069	6,249,269
High-income countries	544	5,896,064

Indoor air pollution (accounting for 91 million DALYs in 2019) is caused primarily by the burning of fuels within the home for energy for cooking, heat, and light (*Household air pollution and health*, n.d.).

Outdoor ambient air pollution (accounting for 124 million DALYs in 2019) is caused by a wide variety of sources, including pollutants from: industry (e.g., brick kilns); energy generation (e.g., power stations); transport (e.g., cars); dust thrown up into the air (a main cause of PM_{10}); agricultural practices (e.g., crop burning); and waste burning or poor waste management (Carlisle and Sharp, 2001).

The DALY burden from air pollution has been dropping gradually from 1990 to 2019 (Table 3). This change results from a combination of a large, steady decrease in indoor air pollution as households switch away from solid fuels and, at the same time, a steady increase in outdoor air pollution, driven by more sources of pollution (e.g., factories, cars, etc.).

Table 3: DALY burden from indoor and outdoor air pollution in 2019 and percent change from 1990.

	DALY burden (2019)	% change since 1990
Indoor air pollution (*GBD Results Tool*, n.d. a, *GBD Results Tool*, n.d. e)	91 million	56% decrease
Outdoor air pollution (*GBD Results Tool*, n.d. f, *GBD*	124 million	~62% increase

Results Tool, n.d. g)		
Total air pollution (*GBD Results Tool, n.d. b*, *GBD Results Tool, n.d. h*)	**213 million**	**24% decrease**

Air pollution can also impact economic growth, climate, and other aspects, which are covered in the externalities section. This could make air pollution cost-effective to address, even ignoring the health benefits.

3 Theories of change

As outlined in the introduction, air pollution is a huge problem worldwide. It is also very complex, involving many different sources of pollution that vary depending on the city or country.

The evidence and arguments that led us to focus on lowering vehicle emissions and using satellite data to campaign for stricter industry emissions standards, and/or for the enforcement of existing laws, are as follows:

1) Household air pollution has been decreasing since the 1990s. Additionally, creating change in household air pollution often involves substantial individual efforts (for example, in attempting to change household stove types). These interventions also usually prove to be less tractable. In contrast, outdoor air pollution has largely increased since the 90s. Policies that affect outdoor air pollution might be more difficult to achieve, but once the regulations are in place, they will affect a large number of people. For these reasons, we chose to dive deeper into interventions tackling outside air pollution.
2) Vehicle emissions are one of the biggest sources of outside air pollution across many countries. They have been directly linked to health effects, and policies to lower them have had positive impacts on air quality and human health (see evidence section). We therefore decided to study (and, after seeing their promise, propose) interventions around lowering vehicle emissions.
3) As mentioned earlier, most of the world's population breathes air that is more polluted than the WHO's guidelines. In our initial exploration, research from the UNEP revealed that even though many countries have regulations around emissions from point sources (for example, industry), they do not often enforce those regulations. While interviewing experts, we came across the possibility of using satellite data to measure air quality. We considered it promising to rely on open-source (and therefore low-cost) information to find large emitters/violators and, hopefully, improve enforcement.

4) We had additionally considered other interventions (like advocating for emissions trading schemes), which we ruled out based on their levels of complexity and the low probability of a small organization succeeding at them. You can find additional information about all the interventions we considered in Annex 1.

We outline below the summaries and theories of change of the two interventions we currently think are the most promising.

3.1 Lowering vehicle emissions

Vehicles are big sources of air pollution. One of their main emissions is $PM_{2.5}$. Lowering their PM emissions requires them to run on low-sulfur (<50 ppm) and, preferably, ultra-low-sulfur (<15 ppm) fuel. In addition to cleaner fuel, emissions control systems can be adopted to lower vehicle emissions – these systems generally require low-sulfur fuel.

Cleaner fuels – leads to some reduction in pollution and allows for emissions control systems

↓

Cleaner vehicle standards [help from emissions control systems (e.g., catalytic convertors and diesel particulate filters)] – leads to further reduction in pollution

↓

Cleaner air

Most developed countries have standards that require low-sulfur fuel and several emissions control systems. However, many low- and middle-income countries (LMICs) are still lacking these regulations.

Given vehicles' substantial contribution to air pollution in developing countries and the frequent lack of emission standards, we believe that advocating for stricter vehicle emission policies could be very impactful. Depending on the target country and the extent of its regulations, this could mean several things, including but not limited to: 1) advocating for a transition to low-sulfur fuel, 2) advocating for retrofitting catalytic converters, and 3) advocating for banning the purchase of cars older than a certain number of years. The Climate and Clean Air Coalition put together a global strategy where they outline the state (in 2016) of many of the countries they think should be prioritized (*A global strategy to introduce low-sulfur fuels and cleaner diesel vehicles*, n.d.).

The theory of change for this intervention could be the following:

Charity activities		Charity outputs		Government COM change[2]		Government behavior change		Public COM change		Public behavior change		Benefits
Advocate for policies that lower vehicle emissions and provide capacity support to implement them	→	Plans, policy papers, and meetings with industry on making better technology available Advocacy and meetings to persuade government to take action; Coordinate relevant stakeholders; Help draft recommended standards Advice on enforcement mechanisms	→	Government has the capability to know how to ensure low-emission technologies can be made widely available Government is motivated to make relevant policy changes; Implementation plan created Government has the capability to introduce enforcement mechanisms for the new policy	→	Government acts to ensure low-emission technology is affordable and available Stricter vehicle emission standards introduced Enforcement of standards	→	Increased physical opportunity to pollute less (low polluting fuel and/or vehicles are now available) Increased motivation to pollute less	→	Vehicle pollution is reduced	→	Improved health and wellbeing

The key assumptions, corresponding to each step (i.e., "→") in this theory of change, are:

Campaigners can create policy outputs	Policy outputs are persuasive to decision-makers The plans and advice developed by the charity are fit for purpose	Outputs reach policy makers who have the opportunity to act, despite competing priorities. Government has the physical capability (e.g., sufficient funding) to introduce the	The public has sufficient capability to act (e.g., can afford to change their vehicles or fuels) Laws are sufficiently motivating (e.g., implemented in	The emissions control method (low-sulfur fuel, catalytic converters, etc.) manages to lower pollution	Lower vehicle emissions result in improved health and wellbeing

[2] COM refers to the capability, motivation, and opportunity for change from the COM-B model for behavior change (The Decision Lab, 2021).

		policy.	a way that ensures enforcement) Cultural barriers or lack of understanding do not limit the public's motivation or capability to act.		

Scale: key uncertainty, high uncertainty, some uncertainty, low uncertainty, unconcerning.

3.2 Using satellite data

One significant source of pollution across various cities is industry. Industry actors range from small to large companies. Imposing emissions limits on small companies would be challenging, but it may be effective to impose emissions limits on larger companies that can absorb the costs. In fact, this is what a number of jurisdictions (such as India) have done. However, some experts we interviewed pointed out that governments face a challenge in enforcing these limits. For instance, companies may install coal scrubbers to reduce the amount of harmful pollution but not turn them on (except when being inspected).

One of Charity Entrepreneurship's past successes is the Lead Exposure Elimination Project (LEEP), which directly addresses lack of enforcement. LEEP does this through working with labs that can test the amount of lead in paint and then working with governments and the paint companies to address the problem.

An analogous model can be envisioned to enforce industry standards. In talking with experts, we discovered the existence of public data from satellites that measure some pollutants. The pollutant measured, and the spatial and temporal resolution, vary by satellite and the instrument they carry. It appears as though current systems are able to detect point sources if those sources are large enough (for example, a petrochemical complex). Last year, a new satellite carrying instruments of much higher resolution was launched in Korea. This is part of a triad of satellites that is expected to be functional by 2022 and able to monitor air quality precisely (Atkinson, 2020). As the data will be public, we imagine an intervention where the images would be used to detect large point sources of emissions. The new organization would supply governments with this information and advocate to improve and/or enforce emission standards. The theory of change could be the following:

Charity activities		**Charity outputs**		**Government COM change**		**Government behavior change**		**Public COM change**		**Public behavior change**		**Benefits**
Public satellite data is used to identify point sources of air pollution and to advocate for stricter pollution limits and better enforcement	→	Details of polluting sources Meetings with government and relevant stakeholders Policy advocacy to persuade government Advice for government on designing enforcement mechanisms and standards	→	Government has the opportunity to identify polluters Government becomes motivated to improve standards and enforcement Government has the capability to improve standards and enforcement mechanisms	→	Standards and enforcement mechanisms created/ improved	→	Increased motivation of industry point sources to pollute less	→	Air pollution from point sources is reduced	→	Improved health and wellbeing

The key assumptions, corresponding to each step (i.e., "→") in this theory of change, are:

The resolution of the satellites is high enough to detect point sources of pollution Campaigners can create policy outputs	Policy outputs are persuasive to decision-makers	Outputs reach policy makers who have the opportunity to act, despite competing priorities.	Laws are implemented in a way that ensures enforcement	Industry has the capability to lower emissions (e.g., the technical know-how) Industry has the opportunity to lower emissions (e.g., the costs are not overly burdensome)	Lower point emissions result in improved health and wellbeing

Scale: key uncertainty, high uncertainty, some uncertainty, low uncertainty, unconcerning.

4 Geographic assessment

We conducted an initial geographic assessment on which countries might be most promising for air quality interventions based on their air pollution levels and other relevant factors. However, these results should be taken only as an initial consideration. Additional important points to consider are:

1. **The intervention that one decides to implement**: for example, if deciding to work on improving fuel emission standards, it would only make sense to focus on countries in which a substantial part of the air pollution comes from vehicles and there are not currently adequate fuel standards in place.
2. **How neglected the air quality space is in a given country**: for example, though India ranks at the top of the list due to its high pollution levels and large affected population, many actors and substantial funding are being funneled to these issues there. In contrast, other countries (even neighboring ones with similar issues) are currently more neglected.
3. **The probability that the government will want to change and/or enforce regulations to improve air quality**. To determine this probability, a new organization could 1) talk to government officials and/or lobbyists in the countries in question, 2) look into funding available for environmental issues, and 3) look for commitments made by the country with respect to environmental and/or health issues.

5 Quality of evidence

5.1 If delivered, will this intervention have the expected impact?

To answer this question, we evaluated the evidence linking poor air quality to poor health in general as well as the evidence linking vehicle and industry emissions specifically to poor health.

Link between air quality and health

There are many studies linking air quality to health. A comprehensive review by the WHO summarizes the evidence in >100 studies, including laboratory, field, chamber, and clinical studies (*Review of evidence on health aspects of air pollution – REVIHAAP Project, 2013*). Some main takeaways of the evidence reviewed by this document are as follows:

- Short- and long-term exposure to $PM_{2.5}$ has effects on mortality and morbidity. It has been linked to many conditions, including respiratory illnesses, cardiovascular conditions, atherosclerosis, adverse birth outcomes, and childhood respiratory disease, and potentially linked to neurodevelopment and cognitive function as well as other chronic disease conditions such as diabetes.

- There is evidence for an association between long-term exposure to PM_{10} and health—especially for respiratory outcomes—and for the health benefits of a reduction in long-term mean concentrations of PM_{10} to levels far below the current limits.
- Several cohort analyses have been published on long-term ozone exposure and mortality. Exposure to ozone has been linked to increased respiratory and cardiovascular disease as well as cognitive development and reproductive health problems.
- Many studies have documented associations between day-to-day variations in NO_2 concentration and variations in mortality, hospital admissions, and respiratory symptoms. Additional studies show associations between long-term exposure to NO_2 and mortality and morbidity.
- In single-city studies, positive and statistically significant associations with SO_2 were generally found for all-cause, cardiovascular, cardiac, and respiratory mortality in single-pollutant models. However, those associations tested in multipollutant models were reduced by controls for other pollutants, often substantially.

A chapter on air and water pollution in the book *Disease Control Priorities in Developing Countries* covers evidence on the impact of air pollution on health (Kjellstrom *et al.*, 2011). Some main conclusions:

- The major pollutants emitted by combustion have all been associated with increased respiratory and cardiovascular morbidity and mortality.
- Long-term studies have documented the increased cardiovascular and respiratory mortality associated with exposure to PM (associations were found to be stronger with $PM_{2.5}$).
- PM exposure, SO_2 exposure, or both increased the risk of low birthweight.
- Air pollution increased intrauterine mortality.
- Other effects of ambient air pollution are postneonatal mortality and mortality caused by acute respiratory infections, as well as negative impacts on children's lung function.

There are many individual studies and meta-analyses in this space. Some examples:

- A meta-analysis of 33 studies in China found a significant association between short-term air pollution exposure and increased mortality risks for PM_{10} and $PM_{2.5}$, SO_2, NO_2, O_3, and carbon monoxide (CO) (Shang *et al.*, 2013).
- A paper summarizing the findings of a meta-analysis of studies in 8 Italian cities found a statistically significant association with mortality for natural causes for each pollutant (O_3, SO_2, NO_2, CO, and PM) (Biggeri *et al.*, 2001).
- A meta-analysis of 17 studies shows a positive association between daily levels of ambient air pollution markers (O_3, SO_2, NO_2, CO, and PM) and the hospitalization of children due to pneumonia (Nhung *et al.*, 2017).

As summarized above, there is a huge amount of evidence linking air pollution to poor health.[3]

Link between vehicle and industry emissions and health

Vehicle emissions

One of the questions that the WHO's review of evidence on the health impacts of air pollution set out to answer is the effect of proximity to roads on health. Cardiovascular mortality, respiratory mortality, myocardial infarction, cardiovascular disease, coronary artery calcification, cardiac function, asthma, wheeze, asthma hospitalization, lung function reduction, birth weight, childhood cancer, and lung cancer have all been linked to road proximity and traffic intensity (*Review of evidence on health aspects of air pollution – REVIHAAP Project, 2013*).

These health risks appear to be driven by ultrafine particles, CO, NO_2, black carbon, polycyclic aromatic hydrocarbons, and some metals. The authors mentioned exhaust emissions as an important source of pollution potentially contributing to these effects. They also referred to several epidemiological and toxicological studies that have linked such emissions to adverse effects on health. One of those epidemiological studies compared ambient-pollutant data from "traffic-influenced" sites and "non-influenced" sites and found higher levels of NO_2, nitric oxide, CO, and black smoke at the traffic-influenced measurement sites. This evidence, therefore, confirmed combustion engines as the source of these air pollutants. Black smoke and NO_2 were associated with mortality (*Review of evidence on health aspects of air pollution – REVIHAAP Project, 2013*).

Diesel engine exhaust is rich in $PM_{2.5}$. A large body of evidence describes a wide variety of adverse health effects resulting from exposure to diesel engine exhaust. Recent toxicological studies suggest that both tailpipe and non-tailpipe emissions have toxic properties that are similar to, or sometimes stronger than, those found for diesel engine soot (*Review of evidence on health aspects of air pollution – REVIHAAP Project, 2013*).

Additionally, many studies link vehicle emissions to different conditions. A few of these are the following:

- A meta-analysis of 19 studies evaluated the link between motor vehicle air pollution and asthma in children. They found that exposure to NO_2, NO, and

[3] It is worth noting that people who live in highly polluted areas and are exposed to higher levels of these pollutants tend to have, in general, lower standards of living, which could act as a confounder when assessing health. However, the links are present in many studies across many regions, the relationships are strong, and many of these studies control for additional factors, so this is only a minor concern.

CO was positively associated with a higher prevalence of asthma in children, while exposure to SO_2 was positively associated with a higher prevalence of wheeze (Gasana *et al.*, 2012).
- A meta-analysis of 36 studies assessed the link between exposure to traffic-related air pollution and lung cancer. They found that exposure to NO_2, NO, SO_2, and PM were positively associated with a risk of lung cancer (Chen *et al.*, 2015).

Industry emissions

The WHO's evidence review mentions that coal combustion results in sulfate-contaminated particles, for which epidemiological studies show strong evidence of adverse effects on health (*Review of evidence on health aspects of air pollution – REVIHAAP Project*, 2013). Sources of PM emissions relevant to health also include shipping (oil combustion), power generation (oil and coal combustion), and the metal industry.

There are few studies looking at the specific effects of a given industry on health. Some studies try to assess the impact of different sources on the health and economy of specific countries. For example, a study in Denmark found that the major power plants in Europe and Denmark contribute 24% and 17% of the external health costs in Europe and Denmark, respectively (Brandt *et al.*, 2013).

It is unclear why there is little evidence on this point.

5.2 Can the government effectively deliver this intervention?

Various public policies regulating air pollution have been shown to improve air quality and citizens' health. In this section we analyze some examples, focusing as much as possible on vehicle emissions policies and using satellite data to influence policy, as these are the two interventions we think could be most promising.

In general, we find that there is an important number of cases of vehicle emissions policy leading to lower pollutants and better health. Overall, we think the evidence is reasonably strong for this area.

However, there is limited empirical evidence that public satellite data can be used to identify focal pollution sources, and no evidence that they have been used as a tool to drive policy around enforcement of emissions standards. Currently, it seems that organizations using satellite data are relying on it for coarser city-level data in order to raise awareness around pollution levels. There is some theoretical evidence that existing satellites and soon to be in orbit satellites can be combined with machine learning algorithms to obtain high-resolution air quality data. We think the evidence we found on the feasibility of this approach is weakly positive but, overall, inconclusive.

Below are some examples of policy changes that we investigated and the effects they have had on pollution levels:

USA – 1990 Clean Air Act Amendments

The Clean Air Act Amendments (CAAA) were a set of revisions added to a previous "Clean Air Act" in the United States in 1990. The included legislation was designed to improve the country's environment, particularly focusing on acid rain, urban air pollution, and toxic air emissions (Epa and OAR, 2015).

A paper analyzing the impact of regulations on electricity generating units (EGUs)[4] and on-road mobile sources[5] found that EGU NO_x and SO_2 emissions in the Southeast decreased by 82% and 83%, respectively, between 1999 and 2013. Mobile-source emissions controls led to estimated decreases in Atlanta-area pollutant emissions of between 61% and 93% for various pollutants (Russell *et al.*, 2018). Using health models fit from patient data from the Atlanta area, the authors concluded that emissions reductions resulting from all selected pollution-control policies led to an estimated 55,794 cardiorespiratory disease emergency department visits prevented between 1999-2005 and a prevention of 5.9% of all respiratory disease emergency department visits that would have occurred in the absence of the policies between 2012-2013.

A study using causal inference and machine learning to estimate the health impact of the CAAA found evidence to suggest that approximately 15,000 dementia-related hospitalizations and 15,000–25,000 cardiovascular-related hospitalizations were avoided due to CAAA-attributable changes in pollution exposure each year (Nethery *et al.*, 2020).[6]

Another paper assesses the changes in air quality, as measured by several pollutant concentrations, and children's health in the 20-year period following the CAAA (and additional state-specific regulations) in California. It found that total emissions of NO_x, reactive organic gases, $PM_{2.5}$, PM_{10}, and SO_x decreased in Southern California between 1993 and 2012 (Gilliland *et al.*, 2017). These reductions in pollutants were associated with better health outcomes in children. Specifically,

[4] Through the the Acid Rain Program (ARP), the NOx Budget Trading Program (NBP), and the Clean Air Interstate Rule (CAIR).
[5] Through Tier 2 Gasoline Vehicle Standards and the 2007 Heavy Duty Diesel Rule.
[6] The paper studies the effects in 2000-2001.

decreases in levels of outdoor pollutants—particularly NO_2 and $PM_{2.5}$—were associated with improvements in the growth of children's lung function, and decreases in NO_2, $PM_{2.5}$, PM_{10}, and O_3 were associated with decreases in the prevalence of symptoms of respiratory conditions in children.

China – comprehensive air pollution action plan

In 2013, China introduced the Air Pollution Prevention and Control Action Plan (APPCAP) with a focus on 74 key cities (Tonny XIE *et. al*, 2013).

A study analyzing the effects of the policy on air quality and health found that four years after the policy took place, there were significant reductions in the average annual concentrations of several pollutants ($PM_{2.5}$ decreased by 33.3%, PM_{10} by 27.8%, SO_2 by 54.1%, and CO by 28.2%). The concentrations of NO_2 and O_3 did not change. Analyzing the effects on health showed that there were 47,240 fewer deaths and 710,020 fewer years of life lost in the 74 key cities where the policies took place (Huang *et al.*, 2018).

Another paper focusing on the effects of APPCAP in Beijing between 2014 and 2018 found that APPCAP led to a significant reduction in $PM_{2.5}$, PM_{10}, NO_2, SO_2, and CO concentrations, but an increase in O_3 concentration. The mortalities attributed to $PM_{2.5}$ and O_3 were reduced by 5.6% and 18.5%, respectively (Maji, Li and Lam, 2020).

Dublin – coal ban

Based on health concerns, in 1990, Dublin banned the sale, marketing, and distribution of bituminous coal, requiring people to burn smokeless or other fuels (Kelly, 2015). They obtained measurements of black smoke and SO_2 before and after the coal ban.

A report assessing the effectiveness of air quality interventions in the UK summarizes the effects of this ban (*Assessing the Effectiveness of Interventions on Air Quality*, 2020). The main findings are as follows:

- A first study estimated that in the five years following the ban, black smoke emissions were reduced by 69% and SO_2 by 35%. There was a 16% decrease in deaths from respiratory problems and a 10% decrease in cardiovascular deaths.
- A second, wider study, including 11 additional cities to which the coal ban was extended, found decreases in black smoke of 45-70% but no clear changes in SO_2. The decrease in respiratory deaths found in the initial Dublin study were confirmed and similar changes were found in Cork. The change in cardiovascular deaths found in Dublin was attributed to wider changes in health care.

London – fuel sulfur changes

Ultra-low-sulfur fuels were first introduced in London in 2007 ('The Motor Fuel (Composition and content)(amendment) Regulations 2007', n.d.).

A study found that the airborne particle number concentration in London was reduced between 30% and 59% in different sites over the few months after the policy took place (Jones *et al.*, 2012).

We were not able to find studies assessing the impact of the policy on health.

Hong Kong – fuel sulfur changes

In 1990, Hong Kong introduced regulations restricting sulfur to 0.5% by weight (Wong *et al.*, 2012).

A study found that after the policy, SO_2 levels fell by 45% on average and by as much as 80% in the most polluted districts (Hedley *et al.*, 2002). The intervention led to a significant decline in the average annual trend in deaths and in respiratory and cardiovascular diseases. The study estimated that the average gain in life expectancy per year was 20 to 41 days.

Other studies found a reduction in respiratory symptoms and an improvement in bronchial hyperresponsiveness in children (Peters *et al.*, 1996; Wong *et al.*, 1998).

Catalytic converters in India

Catalytic converters are exhaust emissions control devices that rely on a chemical reaction to convert toxic vehicle emissions to less-toxic pollutants.

In 1995, the Supreme Court of India required that all new petrol-fueled cars in the four major metros (Delhi, Mumbai, Kolkata, and Chennai) be fitted with converters (*Society of Indian Automobile Manufactures*, n.d.). In 1998, this policy was extended to 45 other cities (Wikipedia contributors, 2021).

A study analyzed the impact of this regulation (and others) on air quality and infant mortality using data from 1986-2007. The authors found that requiring new cars to have catalytic converters led to a 19% reduction in PM, 69% in SO_2, and 15% in NO_2 five years after implementation (Michael Greenstone & Rema Hanna, 2011). Additionally, they found that the policy adoption was associated with a decline in infant mortality, but the trend did not prove to be statistically significant (however, they had several concerns regarding the imprecision of this estimate, which they discussed in the manuscript).

Using satellite data to influence policy

There is limited empirical evidence that public satellite data can be used to identify focal pollution sources, and no evidence that they have been used as a tool to drive policy around the enforcement of emissions standards. Instead, we focus on theoretical evidence that satellites could be used in this way and the argument that this would be useful for advocacy.

Several existing satellites are equipped with instruments to measure and/or estimate the concentration of different pollutants (Figure 1). Depending on the satellite, they focus on different compounds and have different spatial and temporal resolutions. The following figure summarizes some characteristics of the different instruments on board these satellites:

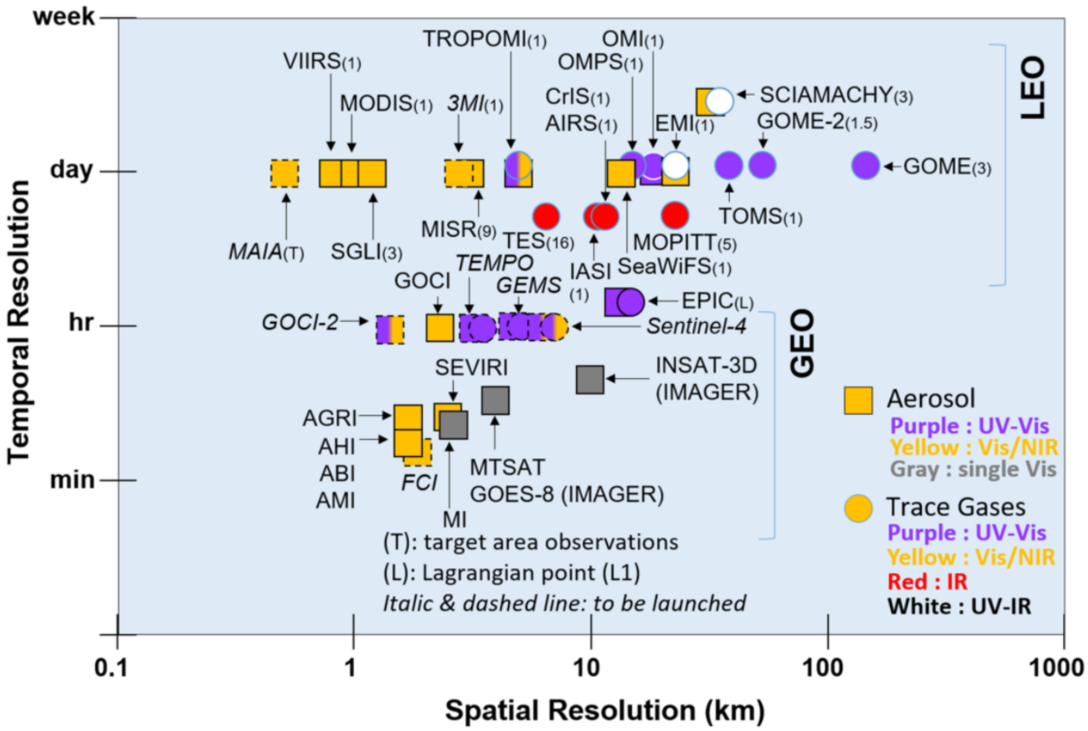

Figure 1: Development of satellite remote sensing instruments for atmospheric composition measurements with respect to temporal and spatial resolution (Kim *et al.*, 2020).

Those with dotted lines indicate instruments that will be functional in the near future. Several of these have high spatial and temporal resolution. A triad of higher-resolution satellites will be live in the near future: the North American TEMPO, the European Sentinel-4, and the Asian GEMS. These will allow researchers and other interested parties to monitor air quality at high resolution.

The satellites currently in orbit have been used to estimate pollution before. A few examples of this can be found in the following studies:

- In one study, data from a 4.4 km resolution Multi-angle Imaging SpectroRadiometer (MISR) AOD was used to estimate $PM_{2.5}$ species concentrations (i.e., sulfate, nitrate, organic carbon, and elemental carbon) using satellite data in Southern California from 2001-2015. The authors seem to have used some of the 4.4 km resolution aerosol data to model different air quality indicators. Their predictions were able to capture some fine spatial gradients and hotspots of $PM_{2.5}$ species, with 60% prediction accuracy (Meng *et al.*, 2018).
- In another study, the authors combined 10 km spatial resolution satellite data with land use regression to estimate daily ground-level $PM_{2.5}$ concentrations in California, United States, from 2006 to 2012 (Lee, Chatfield and Strawa, 2016). The resolution does not seem good enough to identify point sources.
- Researchers at Duke University developed a method combining satellite data and machine learning to find hotspots of heavy air pollution (levels of $PM_{2.5}$) city block by city block (Zheng *et al.*, 2020). However, they seem to have used specific satellite imagery coming from multiple stations in a city, rather than open-source worldwide data from one of the broader operating satellites, so it is unclear how translatable this approach is. It might be possible to use this method to improve the data of existing satellites such that it improves their spatial resolution.

There are companies currently using satellite data to measure emissions from point sources. We interviewed an employee in one of these companies, Lydia Monnington, who works at GHGSat. The company has its own constellation of satellites, which they use to monitor methane emissions and report them back to the industries that hire them for this work.

Nonprofit organizations are also making use of satellite imagery, relying on open-source data. One such organization is the World Resources Institute (WRI). One of their projects, CitiAQ, combines local monitoring data with NASA satellite data and modeling for city-level air quality forecasts (CityAQ, n.d. a).

5.3 Can we effectively advocate for this intervention?

It was difficult to identify cases of nonprofits successfully advocating for changes in air quality. This lack of evidence might be due to a number of reasons:

- This might be a harder area to have an impact on than other policy areas. Indeed, the problem is huge, but so are some of the changes necessary to solve it. Therefore, it might be complicated to persuade governments to change their regulations.

- Existing organizations may not be effective because of the approaches they take (for example, many of them organize protests or take similar actions that perhaps do not result in the desired outcomes).
- Some of these organizations claim to have contributed to certain environmental laws being passed, but there is no evidence of that being true. It might be that the combined action of multiple advocacy organizations and other relevant actors results in these changes in regulation, making it hard to attribute the success to a single program.
- Most of these organizations do not seem very rigorous in how they measure their impact, but rather mention outcomes that are often irrelevant to actual impact.

Several nonprofits, and notably some of the ones that seem to have had some success in this area, rely on the use of lawsuits to sue companies and even various levels of government to enforce environmental regulations.

Most of the seemingly successful strategies appear to be at the subnational level (focusing on cities, for example). Some policies were first implemented in one or a few cities and then expanded more broadly across a given country.

Our overall view is that there is weak-medium evidence that suggests that change can happen here, but it is difficult.

Below are some examples of nonprofit organizations that seem to have successfully advocated for measures to improve air quality.

Clean Air Network

Clean Air Network (CAN) is a green advocacy nonprofit that focuses on air pollution issues in Hong Kong. CAN has been engaging with the government, the business sector, professional groups, and the public on various issues related to air policy (Clean Air Network, 2016).

According to an interview with the ex-CEO of CAN, Ms. Sum-yin Kwong (Loong, personal communication, 2016), the following are the four major policy changes initiated by CAN during its 7-year work:

- Tightening of Air Quality Objectives in 2013 (which is in effect in 2014)
- Implementation of a HK$10 billion subsidy under a diesel commercial vehicle replacement scheme in 2014
- Government publication of $PM_{2.5}$ real-time data in 2014
- Mandatory fuel switch at berth for ocean-going vessels in 2015

EarthJustice

EarthJustice is a nonprofit public interest environmental law organization that helps advocate for and pass laws to protect the environment in the United States. It works on a variety of environmental issues, some of which have to do with clean air (*Clean air*, 2013). It seems to have had success in several areas. For example, in 2012, it secured updated federal rules to control soot pollution (*Obtaining and strengthening national air quality standards*, 2014). Additionally, its litigation led to the first mercury and toxic pollution standards for new and existing coal-fired plants (*Protecting impacted communities*, 2014).

Climate and Clean Air Coalition

The Climate and Clean Air Coalition (CCAC) is a coalition of nonprofits, state actors, and intergovernmental groups. It brings together relevant parties to work in cooperation with key short-lived climate pollutant emitters and other stakeholders from around the world to encourage, enable, and catalyze action to reduce emissions.
Since 2013, the CCAC has helped 16 countries develop national plans that integrate climate and clean air objectives through actions to reduce short-lived climate pollutants (*National planning (SNAP)*, n.d., *Short-lived climate pollutants (SLCPs)*, n.d.). Eight of these plans have received national endorsement and are moving towards implementation.

5.4 Summary of overall evidence

1. As shown by the multiple studies referenced above (and by many more), there is an undisputable link between air quality and health. It is clear that air pollution represents a large burden of disease worldwide, particularly in certain Asian and African cities.
2. Transportation is one of the main sources of air pollution in many cities and has been linked to poor health outcomes in many studies. There is much less evidence for the effect of static pollution sources on health; rather, there is indirect evidence through studies that show that: 1) static pollution sources like energy and industry are some of the main contributors to air pollution through the release of certain pollutants, and 2) being exposed to those pollutants has a negative impact on health.
3. Policy related to air quality can improve citizens' health, as shown by the effects of a number of interventions in different countries. Specifically, there are several examples linking vehicle-emissions-related policy and health improvements. There is no evidence linking the use of satellite data to air quality and health, as this method seems to be rather new, and so our support of it is at this point mainly based on its theoretical applications.

4. There are a few examples of nonprofit organizations successfully advocating for air quality policy changes. However, they are very hard to find, which may indicate that this is an area where it is particularly hard to influence policy makers.

6 Expert views

We contacted a variety of experts, from broad experts working at particular organizations to domain experts focusing on transportation or satellite work.

Although the main contributors to air pollution appear to vary by city and country, the experts agreed that vehicle emissions were one of the biggest contributors. They had positive views about new organizations working to address these issues.

They all raised concerns about poor enforcement of existing regulations, which could also be the case for new regulations, and reported that these problems are usually due to a lack of resources.

A few of them are aware of using satellite data, mainly to raise awareness around pollution, but there is not a very clear consensus on whether it is feasible to use it to detect point sources at this point.

Now we summarize the experts' individual views.

Dr. George Mwaniki

Dr. George Mwaniki is a consultant for the UN Environment Programme (UNEP) on air quality in different countries. He is currently the Head of Air Quality Africa at the World Resources Institute (WRI), an organization with several interesting air quality initiatives. It currently has projects in six different African countries and is looking to expand.

One of the things Dr. Mwaniki shared with us was that a new UNEP report came out in 2021 as a follow-up to a similar report in 2016 analyzing the state of air quality actions globally (*Actions on Air Quality - Policies & Programmes for Improving Air Quality Around the World*, 2016; Soraya Smaoun, Victor Nthusi, Maria Cristina Zucca, Valentin Foltescu and Richard Miesen, 2021). From the report, and from what he shared, little progress has been made to improve air quality in African countries in the last five years. Specifically, 1) a lot of African countries, unlike most of the rest of the world, do not currently have ambient air quality standards; 2) there is a lack of capacity support to track and address pollution (for example, through emissions inventory development); 3) even though 11 countries passed a resolution to improve fuel standards, much of Africa still allows sales of high-sulfur fuel; and 4) most used vehicles exported to Africa do not meet good emissions standards.

He stressed that air pollution is one of the most neglected environmental issues, particularly in African countries, and that most sub-Saharan African countries need support to tackle this problem.

In terms of the main sources of pollution, he mentioned 1) indoor pollution (i.e., using biomass fuel for cooking, which also contributes to outdoor air pollution); 2) vehicles (many second-hand used vehicles, sometimes very old); and 3) waste management. He thinks that in most African countries, industry is not as big a problem because most of them do not have a substantial industrial base.

Emissions control devices for cars are not in place in most African countries. Dr. Mwaniki actually pointed out that when second-hand vehicles are imported, the catalytic converters are removed and disposed of because people think they make it more expensive to maintain the car. In some countries, the fuel is not good enough for catalytic converters.

WRI has a project called cityAQ, which focuses on monitoring pollution by combining satellite data and local monitoring (*CityAQ*, n.d. b). Currently, the smallest grid it can predict is 25 km, so it is difficult to pinpoint and understand the major sources of pollution in African countries.

Dr. Mwaniki thinks it is important to educate citizens about the dangers of air pollution, as some of the main pushback against air quality interventions might come from the overall population considering them unimportant and worrying about the additional costs.

Ahmad Rafay Alam

Mr. Ahmad Rafay Alam is a Pakistani environmental lawyer and activist. He co-founded Saleem, Alam & Co., a firm that specializes in the energy, water, natural resources, and urban infrastructure sectors. He regularly advises the federal and provincial governments, the World Bank, ADB, IFC, and a number of NGOs on issues of policy and strategy in these sectors. He serves as a Member of the Pakistan Climate Change Council, the Punjab Environment Protection Council, and as Advisor to Air Quality Asia.

When asked about regulation on emissions standards, he said that Pakistan has pretty standard environmental regulation. However, enforcement of those standards is complicated. Pakistan regulates nine different air pollutants, and the instruments required to measure them can cost 60-70 thousand USD each. Because of these costs, for a province of about 100 million people, it only has five air quality monitors, of which only three work.

Mr. Alam was the expert who first mentioned satellite data as an alternative tool to monitor air quality to us, bringing up the fact that he had used it in the past to identify some big polluters.

In terms of vehicle emissions, enforcement of emissions control systems is complicated as well. Pakistan does not have a vehicle inspection system, the relevant agencies are short-staffed, and there are millions of cars. There seems to be a will to improve fuel standards, but the cost is too high for the country (about 1 billion USD per refinery to improve the technology.)

Mr. Alam believes that one of the barriers to making progress in air quality is a failure to correctly reach the public. He is working on different initiatives to try to bring awareness about air pollution and its effects on health. He believes that mobilizing people can be a good method of driving policy. This somewhat echoes what Dr. Mwaniki mentioned about African countries as well.

In terms of the main pollution sources in Pakistan, he estimates that about 45% comes from transport, 20% from the energy sector, 15% from industry, and the rest from a combination of sources.

Dr. Bharadwaj Sathiamoorthy

Dr. Bharadwaj Sathiamoorthy is a researcher in the United States who consults for the ICCT. He specializes in vehicle emissions, and his recent work is based on emissions from the transportation sector (heavy- and light-duty vehicles) in India.

Much of his work with the ICCT focuses on heavy-duty vehicles. He mentioned that, globally, these vehicles largely use diesel fuel. Though these fleets are smaller than the other categories in road transportation, they are some of the largest contributors of NO_x and PM. Small percentage improvements to these vehicles can have huge effects given their longevity on-road.

Policies are often drafted to regulate tailpipe or engine-out emissions. It is not often the case that policies demand to include specific emissions control components. In most developed countries, there are regulations in place to ensure the proper use of a certified emissions control system and to deter tampering, but they have not been very effective. In the case of developing countries such as India, there are no such enforcements or practices, which is a larger problem.

The ICCT has several very helpful air quality programs, but the organization does not currently work in African countries, and within Asia, only in India and China. Dr. Sathiamoorthy mentioned that it continues to expand its presence as it acquires more resources to set up in other countries.

Lydia Monnington

Lydia Monnington is an analytics manager at GHGSat, a private company that uses the high-resolution satellite technology it pioneered to monitor industrial methane emissions worldwide. It works with carbon-intensive industries to measure their methane emissions, enabling companies to improve their environmental performance, operational efficiency, safety, and reputation, and to ensure they are complying with regulations. GHGSat also works with governments (for example, it received 20 million USD from the Canadian government to monitor methane emissions) to measure, report on, and reduce methane emissions.

GHGSat has three methane monitoring satellites in orbit and three additional satellites in testing (set to launch in 2022), with six more to follow in 2023. GHGSat uses these proprietary satellites to pinpoint the precise sources of emissions, such as specific oil wells or storage tanks, from space.

It does this using a patented imaging interferometer. By merging multiple sources of light, the payload sensors can create an interference pattern, which enables accurate measurement of industrial methane emissions from individual sites across the world.

For the interventions we are considering, Lydia recommended we investigate the current functionality of existing and future public satellites to detect the gases we are focused on (PM_{10} and $PM_{2.5}$, SO_2, NO_2, O_3 and carbon monoxide (CO)).

She suggested that the key features to consider are spatial and spectral resolution – these can be used to calculate the volume of emissions detectable by each satellite, which can vary by a few orders of magnitude. For example, GHGSat satellites can detect emissions above approx. 100 kg/hr, while Tropomi, an instrument on the public satellite Sentinel 5p, can only detect emissions 30x larger, approx. 3,000 kg/hr.

The spatial and spectral resolution also impacts the satellite’s ability to identify point sources. For satellites with lower resolution, figuring out the specific point sources can be difficult. GHGSat is working on a machine learning system to use wind conditions and global air movements to improve the resolution and, therefore, the ability to pinpoint pollution sources.

Dr. Jhoon Kim

Dr. Jhoon Kim is a professor of atmospheric sciences at Yonsei University in Korea who has published research on satellites.

Dr. Kim said the images from GEMS, the high-resolution instrument on board the recently launched Korean Aerospace Research Institute's Cheollian 2B satellite, are already available (환경위성센터, n.d.), and that the actual data will be made available starting in 2022.

The satellite measures total column concentrations of pollutants. Some of these pollutants (like SO_2) are mostly near the surface of the earth. Depending on this vertical distribution and on the lifetime of these pollutants, it might be easier or more difficult to point to specific sources. For example, if the concentration of a pollutant with a short lifetime appears high, then it indicates the source is near where that measurement is being taken.

There are models that allow you to track back to emission sources after the pollutant concentration data from the satellite has been collected, combining it with weather data (for example, wind) for better estimations. Moreover, using machine learning algorithms, the models can convert column measurements to surface particulate matter measurements. Professor Kim has published this machine learning model for other satellites (Park *et al.*, 2019) and has now developed a model to use with the GEMS instrument as well.

7 Cost-effectiveness analysis

7.1 Lowering vehicle emissions

As we mentioned in the Theories of Change section, there are several possible interventions that could lower vehicle emissions. The intervention choice will likely depend on the city or country selected.

As a starting point, we decided to focus on policy around catalytic converters, which has proven successful in the past (see the India case study in the Evidence section). We generated a first version of a cost-effectiveness analysis (CEA) to assess the potential cost-effectiveness of installing catalytic converters into all cars and motorized two- and three-wheel vehicles. We focused on Pakistan,[7] where outdoor air pollution is very high and one of the main sources of pollution is vehicle emissions.

In this first estimate, the intervention appears to be cost-effective, at $6 per DALY averted when considering only charity costs and $519 per DALY averted when considering all costs.

7.2 Using satellite data

We think that there are too many uncertainties around using satellite data to recommend it at this time, so we did not complete a CEA for this intervention this year.

8 Implementation

8.1 Talent

This area of policy seems complicated. From our research, some of the most successful organizations tackling this issue, particularly for vehicle emissions, are relatively large and have many domain experts. Ensuring that a vehicle expert be part of a new organization's co-founding team would likely be very difficult, but might not be necessary.

If we conclude that this recommendation is worth pursuing, finding a co-founder with policy experience in any area, or the right personality to approach policy makers, might be enough.

8.2 Access

Information

The Global Sulfur Strategy has information on the status of fuel and vehicle standards for several of the countries it considers a priority (*A global strategy to introduce low-sulfur fuels and cleaner diesel vehicles, n.d.*). Its information is from 2016 and has not been updated, but the current information on fuel standards seems somewhat easy to find for most countries. The current standard can be

[7] Pakistan might not actually be the best country to implement this intervention in, as the expert mentioned the current government would like to leapfrog the fuel issues and acquire an electric fleet. However, even if they go forward with that plan, their goal is to have 30% of the fleet be electric in the next ~15 years, which still means that much of the fleet would not be. Given the concerns around catalytic converters that the African expert mentioned, we thought it made more sense to focus on an Asian country for this intervention and, therefore, we chose Pakistan.

usually found in news reports, policy briefs, and Ministry websites, for example, in the Ministry of Petroleum and Natural Gas reports in India (Ministry of Petroleum and Natural Gas, Government of India, n.d.).

It has been very difficult to find information related to emissions control devices, and even some of the experts consulted were unaware of the status of specific countries on this issue. This might be related to the fact that, as one of the experts mentioned, it is rare for there to be specific legislation around an emissions control device (like catalytic converters). Rather, it is usually incorporated into a vehicle emissions standard regulation.

It has also been very difficult to find information on the feasibility of using satellite data to identify point sources of emissions.

Government

From our conversations with experts, it seems like the primary limiting factor in getting the government involved with these interventions has to do with the resources they would have to provide. Certain interventions, like updating refineries to produce lower-sulfur fuel, are very costly, especially for LMICs. For other interventions, like changes to all cars, enforcement would require money and staff.

8.3 Funding

Funding from donors connected to effective altruism (EA)

Air quality could be an area that EA donors are open to funding. Open Philanthropy has done research on Air Quality in South Asia (*South Asian air quality*, 2021). Founders Pledge has a Climate Change Fund that could potentially be interested in funding some of these initiatives (*Climate Change Fund*, n.d.). GiveWell has identified ambient air pollution as an area for possible future interest (*Public health regulation update*, n.d.).

Other funding

There seems to be various other sources of funding to improve air quality, making this a promising idea. Some of the potential sources of funding for these interventions could be:

- Bloomberg Philanthropies: It explicitly supports international efforts to improve air quality.
- Clean Air Fund: It assists current funders in their grantmaking and also provides direct grants and other kinds of support to organizations. The Clean

Air Fund itself is funded by the following organizations, which may also be interested in funding a new organization:
    - Bernard van Leer Foundation, Bloomberg Philanthropies, Children's Investment Fund Foundation, FIA Foundation, IKEA Foundation, Impact on Urban Health, OAK Foundation, and the ELMA Foundation
- USAID (later in the nonprofit's life): USAID has and is supporting several air quality initiatives.

Moreover, a report from the Clean Air Fund that assessed the current funding landscape for global air quality claimed that, in 2019, about $1.4 billion in official development spending was disbursed to projects related to improving air quality (*The State of Global Air Quality Funding 2021*, 2021). This, however, represents less than 1% of total aid spending. About 80% of this funding is currently going to Asia (much of it specifically to China), and very little of it (~5%) goes to Africa. In terms of foundations, their donations favor work in the US as well as in Asian countries, particularly China and India. Some of the funders the report mentions are:
    - Public funders: the Asian Development Bank and World Bank are the most active, providing the bulk of the spending as loans.
    - Foundations: FIA Foundation, ClimateWorks Foundation

8.4 Scale of the problem

According to the WHO's estimates, >99% of the world's population breathes air with unhealthy pollution levels (*Air pollution*, n.d. b). A large part of the contribution seems to come from vehicle emissions.

There are still many countries with inadequate fuel and vehicle emissions standards that could benefit from this intervention. This is particularly true for many African and Asian countries.

8.5 Neglectedness

Vehicle emissions seem to remain a big problem in many of the most polluted countries, suggesting work in this space is neglected.

8.6 Externalities

For this report, we focused on the health impact of air quality to determine its importance and the potential cost-effectiveness of interventions addressing this issue. However, there are several significant externalities related to air quality that should be considered as well.

Climate change

Many air pollutants contribute significantly to climate change, such that improving air quality could impact climate positively.

The Global Sulfur Strategy states that one of the main components of $PM_{2.5}$, black carbon, is a potent climate forcer that absorbs sunlight and releases heat, causing warming (*The global sulfur strategy*, n.d.). It additionally states that some of the vehicle emissions control mechanisms, especially particulate filters, can reduce $PM_{2.5}$ emissions by up to 99% and black carbon by over 99%, indicating that such an intervention could have a positive effect on climate. Other vehicle-related interventions such as, for example, advocating for a more modern fleet, can have additional climate-related benefits. Indeed, more modern vehicles are generally more fuel-efficient, often lowering their CO_2 emissions.

A study modeling the potential effects of the interaction between climate change and air pollution on water availability in the United States suggests that air pollution could aggravate regional climate change impacts on water shortage (Duan *et al.*, 2017).

Economic

Several studies suggest that air pollution negatively impacts economic growth. Below are some examples:

- A 2019 study on the impact of air pollution estimated that a 1 µg/m³ decrease in annual mean $PM_{2.5}$ in Europe would increase Europe's GDP by 0.8% (*The economic cost of air pollution: Evidence from Europe*, 2019). This would primarily be due to lower work absenteeism and increased labor productivity.
- A study linking air pollution to productivity in Hebei province, China found that there were large (15%) reductions in productivity over the first 200 µg/m³ rise in $PM_{2.5}$ concentrations in a factory, with this drop leveling off for further increases in pollution (Li, Liu and Salvo, 2015). From their analyses, they concluded that "labor productivity across 190 Chinese cities could rise by on average 4% per year were the distributions of hourly $PM_{2.5}$ truncated at 25 µg/m³."
- A 2014 study analyzed the economic impact of the 1970 Clean Air Act in the United States (Isen, Rossin-Slater and Walker, 2014). The analysis suggests that exposure to cleaner air in utero and before age 1 improves an individual's adult labor market performance measured 30 years later (more specifically, they found a 1 percent increase in age 29-31 earnings). This seems like a modest increase in earnings compared to other variables (for example, a high-experience kindergarten teacher is associated with a 7 percent increase in age-27 earnings (Chetty *et al.*, 2011)). However, it is still a significant

increase that, when considering all the population in a city or country, may represent substantial numbers.

- A study from 2000 analyzed the cost-benefit of an NO_2 air pollution control program in Tokyo, using data from 1973-1994 as a basis for the calculations. The results suggested an average cost-benefit ratio of 1 to 6. The estimated economic benefits of reductions in nitric oxide and NO_2 emissions between 1973 and 1994 were US$6.78 billion for avoided medical costs, US$6.33 billion for avoided lost wages of sick adults, and US$0.83 billion for avoided lost wages of mothers with sick children (Voorhees *et al.*, 2000).

In addition to these studies, conversations with researchers at other Effective Altruism organizations working on this topic led us to believe that the impact of air quality on economic well-being could be quite large. Therefore, we believe that this should be explored further in future research and could be incorporated into the cost-effectiveness analysis.

Well-being

Some studies suggest that air quality can affect well-being.

- A meta-analysis assessing the relationship between ambient air pollution and depression suggested that increases in long-term exposure to $PM_{2.5}$, PM_{10}, and NO_2, as well as short-term exposure to $PM_{2.5}$, PM_{10}, and O_3, were not significantly associated with depression. However, it did find a significant association between short-term NO_2 exposure and depression (Fan *et al.*, 2020).
- Another paper estimated the effects of six main air pollutants on subjective well-being in China by matching a nationally representative survey with local air quality data. They looked into three different subjective well-being metrics and found that $PM_{2.5}$ exposure reduced hedonic happiness and increased the rate of depressive symptoms, but did not affect life satisfaction (Zhang, Chen and Zhang, 2019).

Animal welfare

Air pollution harms wild animals in two main ways: 1) it degrades the environment or habitat in which they live, and 2) it affects the availability and quality of their food supply (Environment and Canada, 2004).

Air pollution can also directly cause animal mortality. For example, nitrogen in air pollution acts as a fertilizer, making conditions too rich for many wild fungi and plants. This endangers many animals, including pollinating insects, that depend on wild fungi and plants (Guardian staff reporter, 2017).

8.7 Additional considerations

Policy in this area seems harder to change than in others: the changes required are sometimes large and costly, and they may be difficult to enforce. Good political access will be important to achieve change, as well as working in cities and/or countries that seem committed to improvements in air quality.

There are also some considerations that are specific to the two types of interventions considered.

Lowering vehicle emissions

- Enforcement in this area seems particularly difficult, as vehicle fleets are very large and depend mostly on citizens. This seems particularly true for an intervention like retrofitting catalytic converters, which would require people to actively take their cars somewhere to make this happen (and likely absorb the cost).
- Experts mentioned that in some countries, the citizens are largely against catalytic converters (one expert explained that people in some African countries actively remove them from second-hand cars they purchase because they believe the converters will make it more expensive to maintain their cars).

Using satellite data

- Satellite technology is improving all the time. While it is difficult to identify point sources with the current generation of public satellites, private companies have demonstrated that it is possible to identify point sources for some gases (e.g., methane).
- Governments might not want to enforce the emissions standards even if the data is brought to them.

8.8 Remaining key uncertainties

There are several gaps in the research that should be addressed before recommending an air quality intervention.

One such gap is the lack of a reliable estimate of the probability of success in pushing for air quality policy as a nonprofit. It would be helpful to interview policy makers, lobbyists, and other relevant experts who might provide some clarity in this regard, given the lack of evidence from nonprofits themselves.

Next are some gaps concerning the specific interventions we chose to focus on for in-depth analysis.

Lowering vehicle emissions

One of the interventions to lower vehicle emissions we believe could be most promising is the use of catalytic converters. However, there are several questions that should be addressed before deciding to push for this intervention:

- Are catalytic converters already in place in some of these countries and, if so, is their use properly enforced? It is surprisingly difficult to find policy documents on this question, and even some of the air quality experts interviewed were not aware of whether regulation on this issue existed in their countries.
- Once focused on a specific location, one would need to determine whether the existing fleet (given the vehicles' characteristics and the fuel used) is suitable for catalytic converters at all. If so, one would then need to figure out what percentage of the country's fleet could have what model of converter installed. Then, the extent to which these changes would lower pollution would need to be calculated.

Another promising intervention might be to push for cleaner (lower-sulfur) fuels. One of the reasons we did not choose to focus exclusively on this intervention was because the world seems to have made more progress on this front in the last few years. However, a seemingly recurrent consideration regarding air quality issues when reading notes or consulting experts is that even though regulations may exist, they many times fail to be enforced. It would be useful to talk to country-specific experts to figure out the status of low-sulfur fuel implementation in those areas and which actors, if any, are helping with the process.

Using satellite data

One of our main concerns regarding this intervention is its feasibility, given the novelty of the method and the related little evidence that it can be successfully employed to identify sources of pollution. Some of the relevant questions to answer are the following:

- Is the temporal and spatial resolution of existing or soon-to-be public satellites good enough for this purpose?
- How high above the emissions limits do the sources need to be for their emissions to be detected as "above the limit" by the satellite?[8]
- How far apart do the sources need to be for the satellites to be able to detect them as point sources?

[8]Some answers to this question can be found for particular pollutants (e.g., methane, Varon *et al.*, 2018), but we are unsure about most pollutants.

Additionally, even if this were indeed feasible, there is the question of whether the government or relevant authorities would be willing to use this information to enforce air quality regulations and/or improve existing policy. It might be difficult to answer this question.

9 Conclusion

Air pollution represents a huge burden of disease and affects many countries. Therefore, it is an important area to make progress on. However, we believe that more research needs to be conducted to determine the most promising interventions for a small organization to tackle, as well as the feasibility of those interventions in different countries. Considering the main interventions we chose to focus on in this report: there are many doubts about enforcement of standards, both for mobile and static sources; it is unclear which vehicle emissions control mechanisms are in place in different countries; and we are uncertain that at this point, satellite data can be used to accurately detect point sources. Overall, we lean against recommending policy work to improve air quality this year, and we propose to conduct further research into this area in future years.

Annex 1 - Intervention choice

In this report, we focused on interventions addressing vehicle emissions and interventions using satellite data to identify point source emissions. Below are notes on other interventions we looked into, the reasons we chose to pursue them (or not), and the main remaining uncertainties:

-**Coal scrubbers**: Experts considered this intervention impactful if used correctly but difficult to enforce, so we did not explore it in depth. That being said, enforcement seems to be a prevalent issue across most of these interventions, so it might be worth looking into this option further.

-**Emissions trading schemes**: This intervention is being implemented in several countries for greenhouse gases, but much less so for other pollutants. It is now happening for $PM_{2.5}$ in parts of India, after research from J-PAL found promising results (JPAL, 2021). However, this seems like a very complex area where much larger stakeholders have had problems. Additionally, there is not much precedent for the types of pollutants that we are looking into, which would make implementation more difficult. It might be more promising in a few years once the results from the larger implementation in India come in.

-**Tax on emissions**: Most examples of this method are carbon taxes, and this is something that relevant stakeholders frequently consider as a way to mitigate climate change. We only performed shallow research into this idea, but the main uncertainties we identified are:

- Can a small organization succeed at this? It seems like it is something that large groups are already tackling, and they often fail.
- Even if a small organization could be successful, sometimes the problem with this intervention seems to be that the tax is set too low, and so the incentives to pollute less are not there.

-**Retrofitting and building efficient brick kilns:** We only looked into this idea very briefly. The main uncertainty in this subspace might be neglectedness, as CCAC and the International Centre for Integrated Mountain Development (ICIMOD) appear to be working on this issue and are introducing a better technology in several countries.

-**Reducing crop burning:** We did not have sufficient time to look into this intervention. One of the experts mentioned it as a significant contributor to pollution in Pakistan. The main uncertainty around an intervention in this space is likely enforcement.

-**Other ideas:** We also very briefly considered organizations advocating for and providing support to government on: stricter emissions limits on industry, improving regulatory and enforcement policy, improving enforcement with cheap portable air quality monitoring, better waste collection and management, bans on burning waste, promotion and subsidies for solar lighting, paving roads or road dust binding, promotion and subsidies for cleaner cookstoves, and increasing the use of renewable energy sources (rather than coal). We also considered organizations carrying out more research, and a general approach where a new charity would do a bit of everything as needed.

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