WORKING PAPER

Integrating Air Quality Management and Climate Change Mitigation

Achieving Ambitious Climate Action by Cleaning the Air We Breathe

Ernesto Sánchez-Triana, Drew Shindell, Marcelo Mena, and Santiago Enriquez

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ACRONYMS

AR6	Sixth Assessment Report of the Intergovernmental Panel on Climate Change
BC	Black carbon
CCAC	Climate and Clean Air Coalition
CCAP	World Bank Group's Climate Change Action Plan
CH4	Methane
CO	carbon monoxide
CO_2	carbon dioxide
COP	Conference of the Parties to the UNFCCC
GAINS	Greenhouse Gas-Air Pollution Interactions and Synergies model
GRID	Green, Resilient, and Inclusive Development
GWP	Global Warming Potential
HFC	Hydrofluorocarbons
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
LLGHGs	long-lived greenhouse gases
LMICs	Low- and Middle-Income Countries
LTS	Long-Term Strategies
PforR	Program for Results
$PM_{2.5}$	particulate matter with a diameter less than 2.5 microns, fine particulate matter
NDC	Nationally Determined Contributions
OC	organic carbon
OECD	Organization for Economic Cooperation and Development
SDGs	Sustainable Development Goals
SLCP	Short-lived climate pollutants
SNAP	Supporting National Action and Planning
SO_2	Sulfur dioxide
UNFCCC	United Nations Framework Convention on Climate Change

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Executive Summary

Tackling air pollution and climate change at once is crucial for humanity's short-, medium-, and long-term wellbeing. Air pollution kills around 7 million people every year. It also causes multiple illnesses with significant consequences, including reduced labor and agricultural productivity. The deaths and illnesses caused by air pollution have an estimated cost of 8.1 trillion dollars per year, equivalent to 6.1% of global GDP (World Bank, 2022). The impacts of climate change are already evident and expected to rise, causing losses that could be equivalent to almost 25% of global GDP by the end of the century and confirming that it is the biggest environmental threat towards the planet's future (Germanwatch, 2021).

Mitigating emissions of short-lived climate pollutants (SLCP) offers opportunities to build synergies between air pollution and climate mitigation solutions. The primary SLCPs are methane (CH_4), black carbon (BC), and many hydrofluorocarbons (HFCs). They have much shorter atmospheric lifetimes than long-lived greenhouse gases, such as carbon dioxide (CO_2), but are much more powerful as climate warmers and have significant effects human health and the planet.

Reducing SLCPs is a fast-response, near-term measure to curb climate change. Long-lived greenhouse gases stay for centuries in the atmosphere. Also, aerosols that cool the planet are co-emitted alongside large CO_2 emission sources (e.g., coal). Consequently, decarbonization strategies focusing on long-lived GHGs will take a very long time to deliver climate benefits. In contrast, SLCP reductions can result in observable climate benefits in much shorter timeframes and are the strongest lever available to slow the rate of warming and the mounting toll of extreme weather events in the first half of this century.

Integrating the air quality and climate change mitigation agendas also offer opportunities to build wider support for climate action. Decarbonization strategies that include mitigation of SCLPs can lead to near-term benefits in terms of improved air quality for human health, labor and agricultural productivity, and food security. Emphasizing that these benefits will occur "here and now" can help to reduce the mismatch between the perception of climate as a risk distant in time and space, and the need for rapid action to mitigate long-term climate change. Low- and Middle-Income Countries (LMICs) stand to benefit the most from SLCP mitigation; 90% of air pollution-related deaths occur in these countries.

Climate change can seem a distant threat but coupling it with air pollution can help bring the problems and solutions to the forefront in developing countries. Take energy poverty, for example. Almost 90% of the population in lower-income countries use dirty solid fuels that pollute. In contrast, in upper-income countries, more than 99% of the population has access to clean fuels. Also, 90% of air pollution-related deaths occur in these countries, largely because of poor air quality and limited access to adequate health services. Integrated policies to achieve energy access and climate and air-quality goals foster simultaneous achievement of Sustainable Development Goals and significant co-benefits.

Designing Interventions to Mitigate SLCPs and their Linkages with Air Quality Management

Most countries have not explicitly committed to mitigate SCLPs. Methane and HFCs are covered under the UNFCCC; however, less than half of the countries mentioned HFCs in their first Nationally Determined Contributions (NDC). The Global Methane Pledge was launched in November 2021 as a global effort to reduce 2030 emissions by at least 30% relative to 2020. This Pledge is separate from, but complementary to NDCs. Out of the 119 countries that had endorsed the pledge by October 2022, 96 included methane as part of their overall GHG reduction target, but only 15 had set specific methane mitigation targets. Black carbon is not part of the GHGs covered by the UNFCCC. As of April 2022, less than 10 countries explicitly mentioned black carbon in their NDC (Fransen et al, 2022).

Many net-zero emission targes do not have mandatory legal frameworks that go beyond the international commitments in the context of the UNFCCC. In contrast, air pollution management has stronger regulatory frameworks that were adopted in most countries before climate action frameworks. These frameworks generally set limits on the concentrations of air pollutants (including $PM_{2.5}$, PM_{10}, and ozone). When they are exceeded, attainment plans are designed to reduce emissions of the pollutants and their precursors, with the objective to meet the standard. Because these plans focus on controlling emissions from sources that also emit SLCPs and GHG, they have large coincidences with decarbonization strategies and can be an excellent entry point to promote SLCP mitigation.

Different policy instruments are available to mitigate SLCP emissions, which have been tested in low-, middle- and high-income countries. At one extreme, such instruments include fines or sanctions that are linked to traditional command-and-control regulations. At the other extreme, they include laissez-faire approaches that require consumer advocacy or private litigation to act as incentives for improving environmental outcomes. Reforming subsidies in agriculture and energy sectors could reduce methane and other GHG emissions, while also freeing resources that could be used to support climate action.

Economic instruments have been used to tackle air pollutants and GHG emissions, and are starting to focus on SLCPs. As of 2022, 47 national and 36 sub-national governments had adopted or were analyzing the adoption of taxes, emissions trading systems, or a combination of both to promote the transition to a decarbonized economy.[1] Norway has imposed a tax on methane emissions from oil and natural gas operators and the US Inflation Reduction Act contemplates the establishment of a methane fee. Shipping will be included in the European Union's Emissions Trading System. This will only cover CO_2 during 2024 and 2025, but emissions of NOx, soot, and methane will be included from 2026. An analysis by Parry et al. (2022) finds that establishing a methane fee of around $70/t$CO_2$e among large economies would align 2030 emissions with the goal of limiting global warming to 2°C above preindustrial levels. Based on their analysis, most costs would be in extractive industries and abatement costs would be equivalent to just 0.1% of GDP (Parry et al. 2022).

Successful projects have been implemented in LMICs to mitigate SLCP emissions. Investments and policy reforms, underpinned by rigorous analytical work, have been instrumental to mitigate methane, black carbon and HFCs. As illustrated by the China Hebei Air Pollution Prevention and Control Project, achieving large scale reductions in air pollutants and climate warmers calls for multisectoral interventions; holistic measures that combine investments, policy reforms, strategic planning, and monitoring and evaluation; and a rigorous, forward looking evidence base.

The tradeoffs between air quality and climate mitigation goals need to be assessed carefully. Promoting electrification of the transport, industrial, and residential sectors, and advancing the use of hydrogen could reduce tail-pipe emissions of air pollutants; however, the effects of these measures on upstream emissions of air pollutants and GHGs will depend on the fuels used to produce electricity and hydrogen. Using conventional coal and gas sources could increase both types of emissions.

Tradeoffs arise can when an air pollutant that is hazardous for human health has a cooling effect on the planet. Examples include SO_2, NO_X, ammonia, organic carbon, and second inorganic aerosols. Other tradeoffs can become evident when designing policies that incentivize the use of one fuel source versus its alternatives. Interventions to reduce household air pollution generally consist of the substitution of biomass for cooking and heating with bottled liquefied petroleum gas, natural gas, or electricity and district heating fired by fossil fuels. While this substitution results in immediate reductions of $PM_{2.5}$ (and black carbon) emissions, with significant health benefits, it also leads to increased GHG emissions.

[1] Data from the Carbon Pricing Dashboard: https://carbonpricingdashboard.worldbank.org/map_data

Requiring the use of scrubbers and other air pollution control technologies may reduce $PM_{2.5}$ emissions, but also increase the use of energy that is frequently generated from GHG-emitting fossil fuels.

Decarbonization strategies that mitigate methane and black carbon emissions lead to near-term benefits in terms of improved air quality for human health, labor productivity, and agriculture and food security. These linkages provide a strong rationale for advancing strategies that integrate air pollution and climate mitigation as the fastest path to clean air and a safer climate future. The design and implementation of such strategies are key to achieve countries' NDCs and can also deliver immediate and direct health and economic benefits. In short, mitigating SLCP plays an essential role in climate stabilization and is indispensable to meet the goals of the Paris Agreement.

1. Introduction

Abstract

Air pollution and climate change are humanity's biggest environmental challenges, both current and in the future. Mitigating emissions of short-lived climate pollutants (SLCP) offers opportunities to build synergies between air pollution and climate mitigation solutions. SLCP are climate warmers with much shorter atmospheric lifetime than long-lived greenhouse gases; consequently, the climate benefits of mitigating SLCP can be observed in much shorter timeframes. Methane and Black Carbon (BC) are SLCPs with strong linkages with air quality. BC is a component of fine particulate matter ($PM_{2.5}$), the pollutant responsible for most air pollution-related deaths and illnesses worldwide. Methane is one of the main precursors to surface ozone, a pollutant toxic to people and plants. Reducing SLCP emissions results in improved air quality and health benefits that can be observed "here and now." These benefits can increase support for climate action in Low- and Middle-Income Countries that perceive climate change as a problem that they neither created nor can solve without much larger efforts by high-emitting countries.

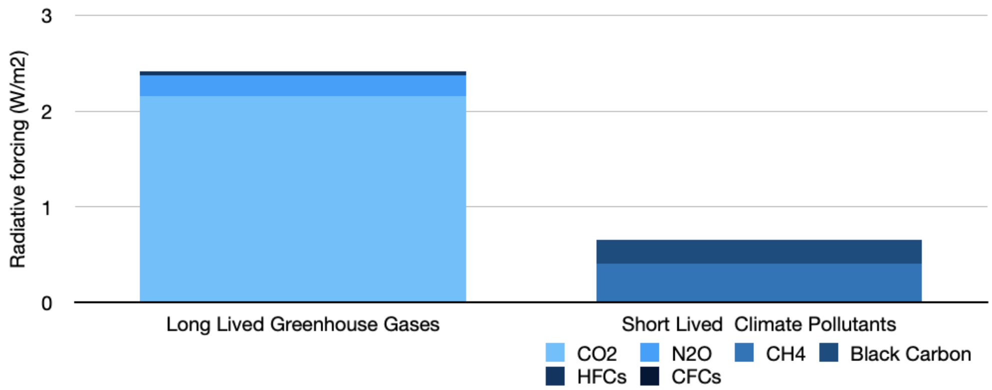
Air pollution and climate change are humanity's biggest environmental challenges, both current and in the future. Air pollution is the biggest environmental threat mankind faces today. Air pollution, including exposure to particulate matter in indoor and outdoor environments and ozone pollution, kills almost 7 million people a year, nearly as much as tobacco smoking, and more than road accidents, drug use, malnutrition, AIDS, malaria, and tuberculosis combined. It contributes to nearly one fifth of all cardiovascular disease, 40% of all lung cancer, and half of all chronic obstructive pulmonary disease. Its estimated health costs amount to 8.1 trillion dollars per year, equivalent to 6.1% of global GDP (World Bank, 2021a). Climate change has already become painfully evident, with climate-related natural disasters accounting for 2.56 trillion dollars in damages in the last two decades (Germanwatch, 2021). The impacts of climate change are projected to reach almost 25% of global GDP loss by the end of the century, making it the biggest environmental threat towards the planet's future. Tackling air pollution and climate change at once is crucial for humanity's short-, medium-, and long-term wellbeing.

Mitigating emissions of short-lived climate pollutants (SLCP) offers a concrete approach to integrate the climate and air pollution agendas, while also delivering quick climate and air quality wins. SLCPs are drivers of warming that have a relatively short residence time in the atmosphere, ranging from a few hours to less than 15 years. The primary SLCPs are methane (CH4), black carbon (BC), and many hydrofluorocarbons (HFCs). In addition to their potent warming effects, many times higher than that of carbon dioxide (CO_2), methane and BC have strong linkages with air quality. BC is both an SLCP and a component of fine particulate matter ($PM_{2.5}$), the pollutant responsible for most air pollution-related deaths and illnesses worldwide. Methane is one of the main precursors to surface ozone, a pollutant toxic to both people and plants. Reducing SLCP emissions can therefore have beneficial effects on development via improvements in human health, labor productivity, and agricultural productivity resulting from cleaner air and from the benefits that occur via reduced climate change.

Scientific evidence has increasingly emphasized the importance of mitigating SLCPs to reduce global warming. Long-lived greenhouse gases (LLGHGs), particularly CO_2, contribute most of the radiative forcing warming the planet; however, the relative contributions of SLCPs to radiative forcing are also significant, as shown by Figure 1. Because SLCPs do not accumulate quasi-permanently in the atmosphere, achieving net zero emissions of these pollutants is not required for climate stabilization.

However, achieving the Paris Agreement's goal of limiting global warming to well below 2°C above pre-industrial levels requires a rapid realization of net zero LLGHGs along with large reductions in SLCP emissions (Rogelj et al., 2018; Naik et al., 2021).

Figure 1. Estimated radiative forcing (1750-2019) of selected long lived and short lived climate pollutants



Source: IPCC AR6 report.

Reducing SLCPs is a fast-response, near-term measure to curb climate change and is complementary to the reduction of LLGHGs required for mitigating long-term climate warming. The climate response to decarbonization will be very weak in the next few decades because of the slow response of LLGHGs to emissions changes and the presence of cooling aerosols co-emitted alongside several large CO_2 emission sources (e.g., coal). In contrast, SLCP reductions can result in observable climate benefits in much shorter timeframes and are therefore the strongest lever available to slow the rate of warming and the mounting toll of extreme weather events in the first half of this century (Shindell & Smith, 2019; UNEP & CCAC, 2021).

Integrating the air quality and climate change mitigation agendas also offers opportunities to build wider support for action, particularly in Low- and Middle-Income Countries (LMICs). 90% of deaths due to air pollution occur LMICs, where citizens support action to clean air, as they see a link towards better health outcomes (Liao et al., 2015). Most LMICs also see climate change as something caused by a few, mostly high-income countries. GHG emissions from the US, EU, China, Russia, Japan, and India account for 74% of cumulative CO_2 emissions, while the rest of the world has contributed 26% (Nature, 2019). LMICs question the rationale for investing their scarce resources in climate mitigation efforts that will not move the needle if bigger emitters are not aligned with the Paris Agreement. However, if climate mitigation is linked to air pollution, and vice versa, LMICs that mitigate will experience local and immediate health benefits from reduced pollution, without depending on external efforts. Air pollution and its link to health is a way that can gain public and political support for climate action (Pillay et al., 2016; Workman et al., 2019).

Assessments of the linkages between air quality and climate change mitigation are relatively recent. In an article published in 2009, Bollen et al. noted how surprising it was that very limited analysis had been conducted of both issues in combination, given the many dimensions that they have in common. However, the number of publications considering the integration of these issues has expanded since then and considered the following issues:

- **Climate change and air quality should not be considered separate issues.** Both issues have common emission sources. Combustion is the source of most air pollutant and GHG emissions; therefore, promoting the use of energy sources that minimize or eliminate combustion can reduce emissions of both air pollutants and GHGs (Nature Communications 2021).

- **Climate change contributes to worse air pollution.** There are several pathways through which climate change can affect air quality. These include changes in the ventilation and dilution of air pollutants, photochemical reaction rates, removal processes, stratosphere–troposphere exchange of ozone, wildfires, and natural biogenic and lightning emissions. Changes in these processes are expected to result in increased ozone levels in polluted regions during the warm season, especially in urban areas and during pollution episodes. Remote regions are expected to experience decreased ozone pollution, but ozone pollution is overall expected to increase globally because of climate change (Silva et al., 2017). In addition, vulnerable populations, but even healthy individuals are susceptible to the combined effects of extreme heat and air pollution, which interact chemically and within the human body (Nature Communications 2021).

- **Climate change is expected to result in increased air pollution-related premature mortality.** Using an ensemble of global climate-chemistry models, Silva et al. (2017) estimate that climate change would result in significant increases in air pollution-related premature deaths. Annual ozone-related deaths would increase by 3,340 (−30,300 to 47,100) in 2030, relative to 2000 climate, and 43,600 (−195,000 to 237,000) in 2100. Annual $PM_{2.5}$-related deaths would increase by an estimated 55,600 (−34,300 to 164,000) deaths in 2030 and 215,000 (−76,100 to 595,000) in 2100. India and East Asia are projected to experience the highest increases in premature mortality attributable to climate change.

- **Some measures may contribute to address one issue, but not both.** Requiring end-of-pipe emission controls on coal fired power plants can reduce their air pollution emissions but dot mitigate GHG emissions (Nature Communications 2021). For instance, Zhang et al (2022) assessed city-level trends in $PM_{2.5}$, ozone, and CO_2 during 2015-2019 in 335 cities in China. They found significant reductions in $PM_{2.5}$ concentrations in cities with mandatory city-level reduction targets, especially in the Beijing-Tianjin-Hebe region. However, concentrations of ozone and CO_2 emissions increased in 91% and 69% of Chinese cities, respectively. To address both challenges holistically, the authors suggest complementing existing air quality measures with mandatory city-level CO_2 emission reduction targets and reinforcing clean energy and energy efficiency measures.

- **Increasing access to clean cooking fuels is an essential component of integrated air pollution and climate mitigation strategies.** Using an integrated modeling framework that estimated the spatial distribution of outdoor air pollution exposures and access to clean household energy sources, Rao et al (2013) found that a combination of stringent policies on outdoor air pollution, climate change and access to clean cooking fuels would result in a significant decline in the global burden of disease from both outdoor and household air pollution.

- **Achievement of recent climate-related targets would result in air quality improvements and consequently, in health benefits.** China's commitment to achieve carbon peaking in 2030 and carbon neutrality in 2060 will require significant reductions in coal consumption, leading to lower $PM_{2.5}$ emissions and, by 2060, concentrations levels that are in line with those recommended by World Health Organization (Jia et al. 2023). Similarly, Dimitrova et al. (2021) find that pursuit of aspirational climate change mitigation targets by India can avert up to 8 million premature deaths and add up to 0.7 years to life expectancy at birth due to cleaner air by 2050, compared to a business-as-usual scenario. Life expectancy could grow by 1.6 by combining aggressive climate change mitigation efforts with maximum feasible air quality control.

- **The tradeoffs between air quality and climate mitigation goals need to be assessed carefully.** Promoting electrification of the transport, industrial, and residential sectors, and advancing the use of hydrogen could help to reduce tail-pipe emissions of air pollutants; however, the effects of these measures on upstream emissions of air pollutants and GHGs will depend on the fuels used to produce electricity and hydrogen. Using conventional coal and gas sources could increase both types of emissions (Nature Communications 2021).

- **Generally speaking, tradeoffs arise can when an air pollutant that is hazardous for human health has a cooling effect on the planet.** Examples include SO2, NOX, ammonia, organic carbon, and second inorganic aerosols. Other tradeoffs can become evident when designing policies that incentivize the use of one fuel source versus its alternatives. Interventions to reduce household air pollution generally consist of the substitution of biomass for cooking and heating with bottled liquefied petroleum gas, natural gas, or electricity and district heating fired by fossil fuels. While this substitution results in immediate reductions of $PM_{2.5}$ (and black carbon) emissions, with significant health benefits, it also leads to increased GHG emissions. Taxing GHGs or increasing energy costs can work in the opposite direction, incentivizing the reduction of GHG emissions but forcing low-income households to revert to the use of "dirtier" biomass (Pezsko et al., 2022).

There are relatively few studies on the linkages between air quality management and climate mitigation that specifically focus on short-lived climate pollutants. Studies conducted to date find that measures to control black carbon and methane emissions would yield significant health, labor productivity, and agricultural productivity in the near-term, while significantly contributing to mitigate climate change. Relevant studies include:

- Shindell et al (2012) assessed the climate change, human health, and food security effects of around 400 measures to control methane and black carbon. Among all considered measures, they identified 14 that would reduce projected global mean warming by around 0.5°C by 2050, avert between 0.7 and 4.7 million annual air pollution-related deaths, and increase annual crop yields by 30 to 135 million metric tons in 2030 and beyond. The most significant health benefits would be observed in LMICs, such as Bangladesh, China, India, Pakistan, and Nigeria, among many others. The authors estimated benefits of $700 to $5,000 per metric ton of reduced methane emissions, a significantly higher value than the typical marginal abatement cost of less than $250. The analysis concluded that the selected measures would influence climate on shorter time scales than those of CO_2–reduction measures. Comparing various scenarios, the authors find that limiting increases in global average temperatures below 2°C is only feasible through the combination of all selected measures targeting methane and BC coupled with ambitious measures to mitigate CO_2.

- In another analysis focusing on the air quality and health co-benefits of mitigating methane and black carbon emissions, Anenberg et al. (2012) assessed the effects of 14 measures that could be implemented in increasingly stringent policy scenarios by 2030. They estimate that full implementation of these measures would reduce global population-weighted average surface concentrations of PM2.5 by 23–34%, leading to 0.6–4.4 million avoided annual premature deaths globally in 2030. Ozone concentrations would fall by 7–17%, averting 0.04–0.52 million premature deaths. More than 80% of the health benefits from these measures would occur in Asia.

- Shindell et al. (2021) assessed the co-benefits of climate change mitigation in the US. They find that decarbonization strategies lead to near-term benefits in terms of improved air quality for human health, labor productivity and agriculture; climate-related benefits from these strategies are realized mostly after 2050. Benefits would have a value in the tens of trillions of dollars for avoided deaths and tens of billions for labor productivity, crop yield increases, and reduced hospital expenditures. The authors incorporated the most recent scientific understanding about the human health impacts of exposure to air pollution and heat, resulting in benefit-cost ratios of decarbonization strategies that are significantly higher than those estimated by previous studies. The authors highlight how emphasizing local, near term air-quality benefits can help to reduce the mismatch between the perception of climate as a risk distant in time and space, and the need for rapid action to mitigate long-term climate change, which can ultimately increase support for mitigation policies.

This report aims to seize on the opportunity to promote climate action from the point of view of development priorities in LMICs. To that end, the report provides an overview of the most recent scientific information on SLCPs using a language that is accessible by a broad audience. It also aims to facilitate a better understanding about how to integrate air quality and climate agendas and references tools that can be used to achieve this goal by targeting SLCPs. These linkages provide a strong rationale for advancing strategies that integrate air pollution and climate mitigation as the fastest path to clean air and a safer climate future. The report also provides tools to strengthen the design of interventions that LMICs can use to achieve the goals of such strategies on their own, as well as with support from the World Bank and other development partners. The design and implementation of such strategies are key to achieve countries' Nationally Determined Contributions (NDCs) and can also deliver immediate and direct health and economic benefits.

The rest of the report is structured as follows: Chapter 2 provides an overview of black carbon emissions globally, regionally, and at the country level; it also describes the main sectoral sources of emission and key interventions that could be implemented to mitigate them. Chapters 3 and 4 have a similar structure, but focus on methane and HCFs, respectively. Chapter 5 discusses opportunities to design interventions that will mitigate SLCP emission and that will also contribute to improve air quality, therefore contributing to deliver health and other co-benefits. Chapter 6 provides examples of World Bank operations and analytical work that have been developed to tackle SLCP emissions, and which could be replicated based on client countries' demand for this type of World Bank support. Chapter 7 concludes.

2. Black Carbon Emissions, Climate Change Mitigation, and Air Quality Management

Abstract

Black carbon is both a Short-Lived Climate Pollutant and a component of fine particulate matter (also known as $PM_{2.5}$), the air pollutant that causes between 6.4 and 8.9 million premature deaths globally every year. Black carbon emission account for about 8% of the net warming impact of all human activities. Opportunities to build synergies between black carbon mitigation and air quality improvement include: substituting solid fuels with cleaner fuels for cooking and heating; controlling emissions from diesel engines and promoting their substitution with cleaner alternatives; controlling and banning agricultural burning; implementing emissions controls and providing incentives for fuel changes in industrial production; reducing waste burning by improving waste management and incentivizing waste reduction; and eliminating gas flaring inf oil and gas production.

2.1. Black Carbon's Contributions to Climate Change and Air Quality

While climate change manifests in the long term, air pollution, which has common emission sources, has shorter term health effects that can manifest from acute and chronic exposure to pollutants.[2] Particulate matter is a mixture of solid particles and liquid droplets found in the air, including both highly reflective aerosols that cause cooling (e.g., sulfates and nitrates) and highly absorbing aerosols that cause warming (e.g., black carbon). Inhalable particles are defined by size and represent those that have aerodynamic diameters of less than 10µm (i.e., PM_{10}). $PM_{2.5}$ are fine inhalable particles with a diameter of 2.5 µm and less. $PM_{2.5}$ can be emitted directly from sources such as the tailpipes of vehicles, or they can form in the atmosphere through the reaction of other pollutants, such as nitrogen oxide, sulfur dioxide, volatile organic compounds, and ammonia.

Particulate matter is the air pollutant that has the most significant association to increased health effects. $PM_{2.5}$ are tiny, about 20-30 times smaller than the diameter of a human hair and can therefore penetrate deeper into the lungs and have systemic impacts on our bodies. Exposure to PM2.5 can result in multiple health effects, including mortality and many morbidity impacts, such as respiratory and cardiovascular disease, hospitalizations, lost workdays, missed school days, preterm births, diabetes, and increased dementia and Parkinson's and Alzheimer's disease. The World Health Organization (WHO) has developed Air Quality Guidelines that indicate the levels at which air pollution concentrations, including for PM_{10} and $PM_{2.5}$, should be limited to reduce significant health risks (WHO 2021c). The WHO estimates that nine out of 10 people globally live in areas where air pollution exceeds its guideline limits.

An estimated 6.4 – 8.9 million people die every year because of exposure to $PM_{2.5}$. The impacts of $PM_{2.5}$ exposure on premature death were evaluated based upon the results of a meta-analysis including 41 cohort studies from around the world (Burnett et al., 2018). That study reported 8.9 million deaths attributable to $PM_{2.5}$ exposure annually worldwide, a level of impacts ~120% larger than previously estimated. Using a different methodology, the Global Burden of Disease 2019 Report estimated that particulate-matter pollution caused 6.4 million deaths in 2019 (GBD 2019 Risk Factors Collaborators).

[2] Air pollution can come in gaseous or particulate form. Tropospheric ozone, nitrogen oxide, carbon monoxide, and sulfur dioxide (SO_2) are gaseous species that lead to harmful health effects, resulting in increased morbidity and mortality.

Young children and the elderly are most affected the most by air pollution, which contributes to the premature mortality of most age groups, with special prevalence in children from 0-4 years old, and adults from 65 years old and above (Landrigan et al., 2017).

In addition to being a SLCP, black carbon is a component of harmful particulate matter. Its diameter can be smaller than $PM_{2.5}$, with particle sizes typically smaller than 1µm. Its chemical composition consists of recalcitrant organic compounds that result from incomplete combustion of fuels, which have a distinct toxicological impact and cause inflammation in the respiratory tract and in the cardiovascular system. These result in health effects that lead to increased respiratory and cardiovascular disease and lung cancer, which can ultimately lead to premature deaths (EPA, 2012).

Most countries have adopted air quality standards to reduce the concentrations of air pollutants that people breathe, including PM_{10} and $PM_{2.5}$. When they are exceeded, attainment plans are designed to reduce emissions of the pollutants and their precursors, with the objective to meet the standard. Because these plans focus on controlling emissions from sources that also emit GHG, they have large coincidences with decarbonization strategies that are often overlooked. Moreover, air pollution management has stronger regulatory frameworks that were adopted in most countries before climate action frameworks. Indeed, air pollution can be an excellent entry point to promote climate mitigation, and vice versa. The WHO recently published a report with specific recommendations on how to improve health through climate action including interventions with clear air quality benefits, such as phasing out fossil fuels, adopting WHO air quality guidelines, and investing in clean household energy (WHO, 2021a)

In its Sixth Assessment Report (AR6), the Intergovernmental Panel on Climate Change (IPCC) discussed extensively the role of BC in climate change. It is deemed a short-lived climate forcer, as its atmospheric lifetime ranges from days to weeks, whereas CO_2 has an atmospheric lifetime between hundreds and thousands of years. BC is a very potent warmer, with a global warming potential per unit of mass that is 460 to 1500 times that of CO_2. However, BC is very seldom emitted alone, and so the net impact of any interventions to reduce BC will depend upon the co-emitted pollutants, especially organic carbon (OC) and carbon monoxide (CO) as well as the BC itself. For this reason, prior suggestions to reduce BC for the sake of climate have emphasized control of "BC-rich" sources rather than BC in general.

BC emissions through 2019 account for about 8% of the net warming impact of all anthropogenic activities (IPCC, 2021). Though not all emissions of CO and OC are associated with BC emissions, a rough idea of the importance of these three compounds in total is 14% of net warming (CO (70% of CO+NMVOC based on AR5) about 12% of net warming and OC about -6%). By absorbing sunlight, BC causes heating of the atmosphere. These changes can induce shifts in monsoonal circulations and rainfall, and BC induces much larger shifts relative to its effect on global mean temperature than other climate change drivers (e.g., Tang et al., 2018; Liu et al., 2018). Black carbon contributes to global dimming and lower irradiation that reduces crop yields, which is more apparent in Brazil, China, India, and Pakistan (Shindell, 2012).

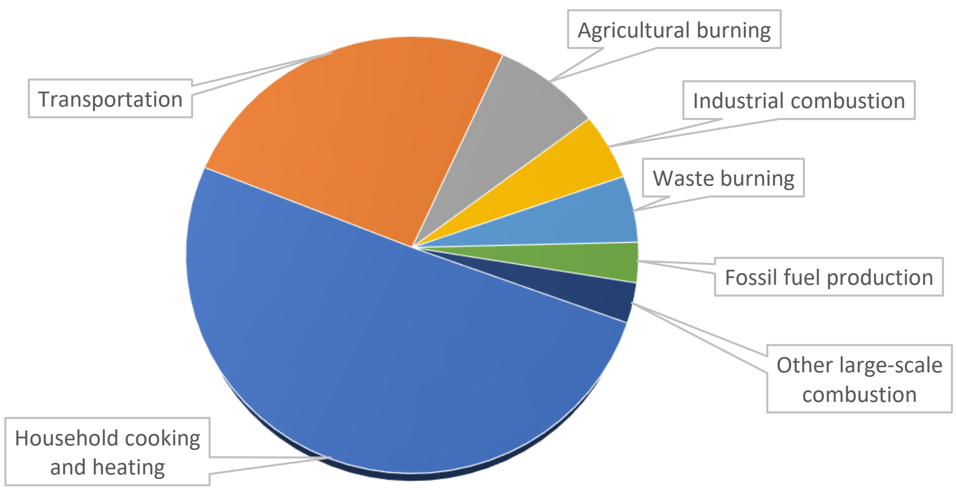
Air pollution is also entwined with climate change because the emissions driving both development problems come largely from the same sources (e.g., fossil fuel or biofuel burning). Furthermore, as there are also air pollutants that lead to cooling such as sulfates and nitrates, policies that do not optimize simultaneously climate change mitigation and air quality run the risk of causing unanticipated tradeoffs or 'win-lose' outcomes. Similarly, solutions that only focus on CO_2 emissions can sometimes promote technologies that deteriorate air quality. Such is the case of promoting diesel cars because of lower CO_2 emissions, which lead to higher NOx and black carbon emissions in the transport sector

(Brand, 2016), or promoting wood burning heaters as carbon neutral, even though they are significant source of black carbon emissions (Holder, et al., 2019). As these examples illustrate, explicitly targeting mitigation of SLCPs while including air pollution considerations more broadly in climate change and development efforts is therefore a logical step to address these inextricably linked issues.

2.2. Black Carbon Emissions at Global Level.

Multiple sources emit black carbon. Worldwide emissions of BC are estimated to be about 4800 Gg yr^{-1} from energy-related burning and about 2800 Gg yr^{-1} from open biomass burning. These are higher than preindustrial emissions by about 4400 Gg yr^{-1} and 1700 Gg yr^{-1}, respectively. Black carbon emission sources typically increase along with energy consumption but decrease as cleaner technology and fuels are adopted. Figure 1Figure 2 shows the main sources of BC globally.

Figure 2. Sources of Global Black Carbon Emissions



Source: www.ccacoalition.org/black-carbon

The primary sources of BC from energy-related combustion vary across the globe. Factors associated with emissions include access to clean cooking and heating fuels, which tend to be much higher in high-income countries and in urban areas. Residential biomass fuels and coal are dominant in Asia and Africa (60 - 80%) whereas on-road and non-road diesel engines are the main sources (about 70%) in Europe, North America, and Latin America. Residential coal contributes significantly to emissions in China, the former Soviet Union, and a few Eastern European countries. Coal combustion in power plants is a very minimal source of BC due to the extremely high temperatures achieved in such settings and the existence of emissions controls. Large forest fires can also substantially increase BC emissions.

Sources whose emissions are rich in BC can be grouped into a small number of categories. In order of highest to lowest BC to OC ratios, these are: diesel vehicles, residential burning of coal, small industrial kilns and boilers, burning of wood and other biomass for cooking and heating, and all open burning of biomass. A few of these sources also emit significant quantities of SO_2.

2.3. Black Carbon Emissions at a National Level.

Local emissions inventories for BC and OC seldom exist, but they can be derived from air pollution inventories through emission fraction conversions. Bottom-up inventories can be estimated using emission factors that are constructed on few data points for key sources, such as brick kilns or small industries; emission factors for open burning are highly dependent upon the conditions of the fire (e.g., dampness of the wood, fuel content, etc.). However, in advanced countries, super-emitters (e.g., diesel vehicles with atypically large emissions) are also difficult to capture in 'bottom-up' inventories constructed using average emission factors.

2.4. Bottom-up National Emission Inventories

Bottom-up national emissions inventories can be estimated using emission factors and activity information at different tiers of data requirements (EMEP-EEA, 2019). These can be summarized as Tier 1, Tier 2, and Tier 3.

- **Tier 1:** Linear factors that relate activity and emission factors, based on easily accessible data (e.g., fuel use, production output statistics, traffic counts, population density, etc.). Emission factors represent typical processes.
- **Tier 2:** Use activity data, but using country-specific emission factors, which need to be developed. They also consider abatement technologies and fuel quality (e.g., sulfur content, etc.). They may require more detailed activity data to represent sub-categories of activities.
- **Tier 3:** These may include facility-level information and specialized models. COPERT, for example, is one of such models for transport emissions. It is the EU standard vehicle emissions calculator and it can be used to estimate emissions and energy consumption at the country or regional level using data such as population, mileage, speed and ambient temperature.[3]

Biomass heaters and diesel passenger vehicles contribute to the largest quantities of black carbon per unit of energy. Table 1 shows some typical emission factors for heaters and light-duty vehicles, based on different type of fuels, and the mass fraction of BC in comparison to particulate matter.

Table 1. Emission factors for black carbon for selected sectors and fuels

Pollutant	Coal heater	Gaseous heater	Liquid fuel heater	Biomass heater	Gasoline passenger car	Diesel passenger car
$PM_{2.5}$ (g/GJ)	398	1.2	1.9	740	0.66	24.4
% of BC	6.4	5.4	8.5	10	12	57
BC (g/GJ)	25.47	0.06	0.16	74.00	0.08	13.9

Source: Tier 1 emission factors from EMEP-EEA (2019) for household and passenger vehicle emissions.

Models are available to integrate air pollution and climate mitigation assessments. For example, the Greenhouse Gas-Air Pollution Interactions and Synergies (GAINS) model was developed for integrating air pollution and climate mitigation assessments in over 165 regions in the world. Klimont, et al. (2017) used it for a global estimation of particulate matter emissions, and OC and BC fractions. They estimated that, on average, BC contributes to 15% of $PM_{2.5}$ emissions; however, it can reach 50% in the transport sector. This model considers detailed emission factors for residential combustion, including cooking,

[3] For more details, see https://www.emisia.com/utilities/copert/

heating, and lighting, considering a wide array of solid fuels from LMICs, such as dung cake, agricultural residue, fuelwood, coal, charcoal, liquid, and gaseous fuels. The model also considers detailed mitigation measures, including interventions to reduce emissions associated with heating, cooking, and lighting. These features allow policy makers to evaluate and prioritize actions to mitigate both LLGHGs and SCLPs.

The Climate and Clean Air Coalition (CCAC) has been providing technical support to estimate black carbon emission emissions, through its Supporting National Action and Planning (SNAP) project. CCAC has supported Argentina, Bangladesh, Chad, Chile, Colombia, Costa Rica, Côte d'Ivoire, El Salvador, Ghana, Kenya, Maldives, Mali, Mexico, Morocco, Philippines, Togo, Uganda, and Uruguay to carry out national planning. As an example, CCAC recently supported Argentina to carry out their first ever integrated GHG, SLCP and air pollutant emissions inventory, with recommendation on integrating climate and air pollution mitigation. CCAC assisted Colombia in developing methodologies to estimate the health benefits (reduced mortality and morbidity) of integrated air pollution and climate policies.

2.5. Potential Interventions for Black Carbon Mitigation

There are opportunities to build synergies between BC mitigation and air quality improvement across multiple sectors. The CCAC's guide on integrating SLCP into climate policy recommends including measures that reduce BC emissions, but also to include the air pollution reduction associated with decreases of CO_2 emissions. Mitigation options allow addressing issues on energy poverty and access to cleaner fuels. These are some typical mitigation options that have been used in many LMICs, including with World Bank support, and that can be easily replicated.

2.5.1. Household Energy

Solid fuels that are used for domestic purposes contribute to more than 50% of global black carbon emissions (Klimont et al., 2017). Support the use of cleaner fuels and cleaner cooking and heating technologies can help to reduce these emissions and can contribute to Sustainable Development Goals 5 (Gender equality), 7 (Affordable and Clean Energy), and 15 (Life on Land). Access to cleaner fuels contributes to lowering the time dedicated to collection of cooking and heating fuels in LMICs, which is largely carried out by women, who are also exposed to higher household air pollution. This collection is associated with deforestation (Miah et al., 2008), land degradation (Casse et al., 2004), and biodiversity loss (Xu et al., 2004).

Dirty fuels account for some of the highest BC emissions per unit of energy. Policies that reduce particulate and BC emissions from dirty cooking and heating are among the most cost-effective ways to reduce health impacts and address structural developmental challenges. Home insulation retrofit projects can also contribute to labor intensive investment opportunities that reduce energy demand and improve quality of life. Measures that can help reduce emissions stemming from household energy are:

- **Educational campaigns** that promote correct cookstove and heater use to reduce emissions through behavioral change.
- **Replacement of dirty cookstoves and heaters** through more efficient stoves that reduce biofuel consumption.

- **Replacement of dirty cookstoves and heaters with new artifacts** that use different fuels, such as pellets, LPG, natural gas, electricity, or briquettes.[4] Recent developments in highly efficient split inverter air conditioning systems have proved to be competitive ways to replace dirty wood burning heaters in colder regions.
- **Promotion of wood dryers and dry wood certification** has been an effective way to reduce emissions in existing wood burning heaters and cookstoves. Regulations on solid fuel origin, heat content and humidity levels can contribute to reduce unsustainable practices associated to land degradation and deforestation.
- **Home energy efficiency standards and home insulation retrofit programs** are a key contributor to reducing energy demand, and thus fuel use and emissions. These programs increase access to cleaner, more expensive fuels.

2.5.2. Transport

Diesel emissions account for the majority of the 26% contribution of the transport sector to global BC emissions (Klimont et al., 2017). Potential interventions to abate emissions include the adoption of vehicle emission standards for diesel vehicles requiring best available control technology and eliminating high emitting diesel vehicles, designing incentives to reduce high emitting vehicles with subsidies, or establishing targeted driving bans based on less stringent emission standards. More specific examples of these interventions include:

- **Adopt stringent standards** on new vehicles, such as Euro 6 or EPA2010, which include emission reductions through diesel particulate filters.
- Establish new **emission standards requiring low sulfur content.** Euro 6 emission standards require sulfur content of 10 parts per million (ppm) or less.
- **Establish existing vehicle management programs.** A low number of gross polluting vehicles, for example, can contribute to large fractions of emissions. Annual emissions testing programs can prevent them from circulating. Also, on-road enforcement of visible smoke, or through remote sensing can be effective ways to target them. Finally, low-emission zones, or driving bans based on emission standards can provide incentives to reduce emissions and to renew vehicular fleets.
- **Tax emissions from vehicle use.** Governments may tax new car purchases, vehicular registration, or annual car use, or they may place excise taxes on fuels. The Organization for Economic Cooperation and Development (OECD) has compiled different ways on how these taxes are applied, and what incentives are included to promote cleaner, more efficient vehicles. However, the lack of integration of local pollutants in these policies has yielded increased emissions of PM and NOx, as taxes imposed only on CO_2 rewarded dirtier diesel vehicles. Also, excise taxes are seldom proportional to typical emissions by fuel type, with most OECD countries having fuel taxes that are lower for diesel, despite its much higher emissions. Chile and Israel have established new car sale taxes that have contributed to cleaner new fleets. In Israel, the tax led to a large increase in cars meeting a better environmental grade. In Chile, the tax

[4] The World Bank has supported projects with relevant these types of interventions in China, Chile, Mongolia, Rwanda, among other countries.

accelerated the de facto adoption of Euro 6 by 2016 despite it only becoming mandatory by 2022.

- **Introduce no idling regulations,** which are low-cost measures to reduce fuel use and unnecessary exposure (Ryan et al., 2013).

2.5.3. Agriculture

Agricultural burning emits 8% of global BC emissions (Klimont et al. 2017). Open burning of such waste generates significant emissions that contribute to some of the highest concentrations of particulate matter globally. It also degrades soil quality, with burned lands having lower fertility and higher erosion rates. Such lands require more fertilizer use and reduce water retention in 25 to 30% (UNEP, 2021). Measures that can contribute to reduce agricultural emissions include:

- **Promote no-burn and lower tilling practices in agriculture** by redirecting harmful agricultural subsidies towards land conservation programs.
- **Use agricultural waste to manufacture cleaner biofuels such as pellets and briquettes** by creating incentives for installing pellet and briquette manufacturing, through subsidies or tax exemptions, or through clear regulatory signals on banning dirtier fuel use.
- **Use biomass for bedding and fodder in livestock production**, which can be incentivized by incremental bans in agricultural burning.
- Use biomass for anaerobic digestion to create methane or second-generation biofuels to generate **added value to the waste.**
- **Gradually ban agricultural burning.** Start by limiting agricultural burning to moments of higher ventilation, later include seasonal bans, and eventually ban them completely.

2.5.4. Industrial Production

Industrial combustion emits 5% of global BC emissions (Klimont et al. 2017). Industrial emissions can be curtailed by a mix of incentives, taxes, and emission standards**.** Best available control technologies allow implementing emissions controls that can reduce particulate emissions, while taxes on local emissions can also create incentives for fuel changes. Operational bans of higher emitting sources in poor air quality days promotes the installation of emission controls or fuel change. Interventions that can reduce industrial emissions of black carbon include:

- **Establish emission standards** for power plants, boilers, and other industrial sources, which can install electrostatic precipitators or baghouse filters to reduce particulate and black carbon emissions in over 99%.
- **Establish emissions-based green taxes on PM, NOx and SO2 emissions**. These create incentives to reduce emissions beyond emissions standards, based on estimations of externalities. Such taxes can be effective in contributing to emissions reductions and act as de-facto emission standards (Atria and Otero, 2021). Also, fuel excise taxes based on emissions of fuels can contribute to emission reductions.
- **Replace traditional brick kilns with more efficient brick production techniques.** This allows improved brick quality and labor productivity and contributes to reducing biofuel collection with

known impacts on land degradation and deforestation. In mountainous regions, brick kilns contribute substantially to deposition of BC into snow and glaciers, accelerating melting and reducing water availability (Mani, 2021). Brick kilns emission standards and technology bans contribute to emission reductions. Access to capital for technology overhaul both through economic development banks or subsidies can modernize obsolete production techniques and improve quality control.

2.5.5. Waste

Black carbon emissions from open burning of waste contribute to 2-10% of global CO_2 equivalent emissions (Reyna-Bensusan et al.,2019). Emission factors are usually uncertain and depend on waste composition. Emissions inventories usually do not account for emissions from trash burning, but when included, these particulate matter emissions are comparable to those stemming from fossil fuel use in cities (Hodzic et al., 2012; Wiedinmyer at al., 2014). Measures that contribute to reducing waste burning include:

- **Establish a waste collection system** so it is landfilled, recycled, or managed through other adequate practices. Only 39-51% of waste is collected in low and lower-middle income countries; out of the managed waste, 33% ends up in open dumps that are prone to burning (Kaza et al., 2019).
- **Shut down open dumps and replace them with landfills and other waste management systems.** Open dumps are prone to open burning due to methane mismanagement or action by waste pickers. Covered landfills allow methane to be recovered and prevent open burning.
- **Support extended producer responsibility or recycling laws.** These can reduce the amount of waste that needs to be disposed. It places the burden of establishing collection and recycling systems on the producer and fosters the design of products that require less recycling and collection.

2.5.6. Fossil Fuel Operations

Oil and gas flaring contribute to 3% of global BC emissions. It also contributes to large CO_2 emissions (400 million tons per year). 42% of BC surface concentrations in the Arctic come from gas flaring operations (Stohl et al., 2013).

Eliminate gas flaring in oil and gas production. Gas flaring is a routine operation in oil and gas production. It can be prevented by capturing the gas and utilizing it in the productive process. Emission standards can be established but require enforcement. The World Bank has established a Zero Routine Flaring by 2030 Initiative that promotes capturing, storing, transporting, and distributing gas instead of flaring. The initiative has been endorsed by 34 national and sub-national governments from countries of all income levels, 49 oil companies, and 15 development institutions. Capital is required for small, modular electricity generation plans, truck mounted liquification or compression. The World Bank works with Ecuador, Egypt, Gabon, Indonesia, Iraq, Kazakhstan, Mexico, Nigeria, and Russia in reducing gas flaring. In addition, the IFC has provided loans to limit flaring of natural gas, including to Iraq's Basrah Gas Co.

3. Methane Emissions, Climate Change Mitigation, and Air Quality Management

Abstract

Methane is the second largest contributor to global warming after carbon dioxide (CO_2). It is responsible for 45% of the net warming impact of all anthropogenic activities to date. Since methane is both a powerful SLCP and a major precursor to surface ozone, emissions reductions are beneficial for both climate change mitigation and air quality. The main anthropogenic sources of methane are agriculture (enteric fermentation and manure management from livestock and rice cultivation), coal mining, oil and gas production and distribution, waste (organic municipal waste and wastewater treatment), and biofuel and biomass burning. Interventions are available to mitigate methane emissions from all sectors. Low-cost controls, defined as costing less than $600 per ton of methane (~$20/tCO₂e), have the potential to abate at least half of the abatement potential estimated for each sector. Several interventions in agriculture, oil and gas, and municipal waste could result in net savings. Those in agriculture and municipal waste contemplate using methane to generate energy.

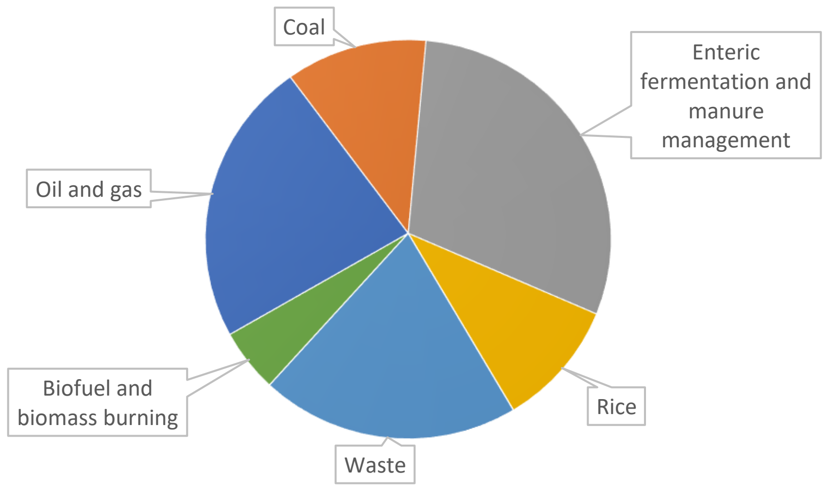
Methane is the second largest contributor to global warming to date after carbon dioxide (IPCC 2021). Methane emissions through 2019 account for about one-third of the warming impact of all well-mixed GHG and 45% of the net warming impact of all anthropogenic activities (IPCC, 2021). Hence methane control plays a key role in meeting long-term climate goals, but a distinct one from control of CO_2 emissions. At the time of reaching net zero emissions for the long-lived GHGs, the level of emissions of methane (and other short-lived substances) will play an important role in determining the level at which temperatures stabilize.

Methane stabilization at a level greater than the pre-industrial level will mean a long-term commitment to warming relative to the pre-industrial level. Any continued changes in methane emissions will contribute further to future temperature changes. As a GHG that does not accumulate quasi-permanently in the atmosphere, achieving net zero methane emissions is not required for climate stabilization nor is it expected; in contrast, net zero emissions in the sum of CO_2 and N_2O are required for climate stabilization (Rogelj et al., 2018). As a short-lived gas, methane controls also greatly affect near-term climate change, and in fact methane abatement is likely humanity's greatest leverage over climate change during the next 20-30 years (UNEP & CCAC, 2021).

3.1. Methane Emission Sources and Trends

Methane (CH4) has both natural and anthropogenic sources that are geographically dispersed and cover a broad range of magnitudes, including some that are small individually. The major sources are well known, but their relative contributions to atmospheric methane levels remain uncertain due to the difficulty in measuring emissions from such a broad set of sources. At the global scale, anthropogenic emissions account for approximately 60% of the total flux to the atmosphere and amount to about 365±30 Mt CH_4 yr^{-1}. Figure 3 shows the main contributions of the main sources of anthropogenic global methane emissions (Saunois et al., 2020). Methane emissions are also generated by several natural sources, including wetlands, geological releases, wild animals, termites, and permafrost. Sectoral partitioning of methane emissions varies greatly among countries and regions and large uncertainties remain in both anthropogenic and natural emissions.

Figure 3. Sources of Global Methane Emissions



Source: Saunois et al., 2020

Bottom-up and top-down estimates of methane emissions. Bottom-up approaches for methane emissions reporting traditionally use some type of activity data representative of the sector multiplied by an appropriate emission factor. Conversely, Top-down approaches use atmospheric observations and inverse models to indirectly estimate emissions. The bottom-up approach has the advantage of being able to cover all potential sources, even small, dispersed ones based on the availability of source-specific emission factors that are combined with statistical activity data (e.g., livestock numbers or amount of oil and gas extracted). However, bottom-up approaches have uncertainties that can be large at the national/sectoral scale. Even in countries like Germany or the UK with well-established emission reporting systems, methane emissions inventories have been revised by up to 60% between subsequent national reports (Bergamaschi et al., 2010). Uncertainties tend to be even larger for LMICs (Solazzo et al.,2021).

Top-down approaches are based on atmospheric observations at the surface, airborne or from satellite. Top-down approaches are therefore potentially highly accurate but subject to the limits of the available data and inverse models. Measurement-based verification is critical because of the complexity and large number of methane sources, as noted above. In contrast to anthropogenic CO_2, for which both activity data and emission factors are very well established, bottom-up methane emissions estimates have large uncertainties. Top-down approaches have proved effective in correcting emission factors used for coal in China (e.g., Saunois et al. 2017), in revising oil and gas sector methane emissions upward substantially in multiple geographies (e.g., Alvarez et al., 2018; Zavala-Araiza et al., 2021), and even identifying specific sources and mitigation opportunities (Lyon et al., 2016; Johnson et al., 2017). These examples show that top-down approaches can support the reporting process by providing additional constraints. Updated IPCC reporting guidelines recommend application of top-down methods as an additional quality control element (IPCC, 2019). However, through mid-2021, only the UK and Switzerland included top-down estimates of methane emissions in an Annex to their national inventory reports (Manning et al., 2011; Henne et al., 2016).

Top-down methods are challenged by the difficulty in disentangling different sources and separating natural from anthropogenic emissions. The latter is particularly critical for the many countries with large natural emissions. Besides uncertainties in the underlying transport models, these methods are highly dependent on the density of observations. While observations from satellites can overcome the scarcity of in-situ network coverage, they remain less sensitive to methane sources than high-frequency in-situ surface measurements and can only capture the largest emission sources. They are also limited by cloud coverage, especially in the tropics, and are less reliable at high latitudes.

Several research projects have compared estimates of anthropogenic methane emissions from bottom-up inventories and top-down approaches at different geographical scales (Bergamaschi et al. 2018; Petrescu et al., 2021; Deng et al. 2021). These suggest that there may be substantial underreporting of emissions from several large countries. Most of the studies are based on global inverse models at rather coarse resolution, preventing confident estimates at national scale, especially for "small" countries. Regional or national systems at finer resolution like those used in Henne et al. (2016) or Petrescu et al. (2021) can overcome this issue. However, they are sensitive to the methane levels prescribed at the model domain boundaries, which determine the large-scale background concentrations, and which are usually taken from a global reanalysis model.

The opportunities, challenges, and future developments of both bottom-up and top-down approaches have been investigated in detail (Ganesan et al. 2019; Saunois et al. 2020). Given that large uncertainties remain in national level methane emissions by source, there is no single dataset that can be recommended for all purposes. The Emissions Database for Global Atmospheric Research produced by the Joint Research Centre of the European Commission provides a valuable sector and country specific emissions dataset for many gases and particulates.[5] National emissions inventories are clearly critical first steps to assessing mitigation opportunities.

The primary drivers of methane emissions are highly sector dependent. Within the fossil fuel sector, demand obviously plays an overarching role; however, unlike CO_2, methane is not produced by fossil fuel usage and therefore use is not the dominant driver. Instead, practices and methods used to minimize unintended release of methane during extraction, processing, transmission, and storage play a major role in this sector.

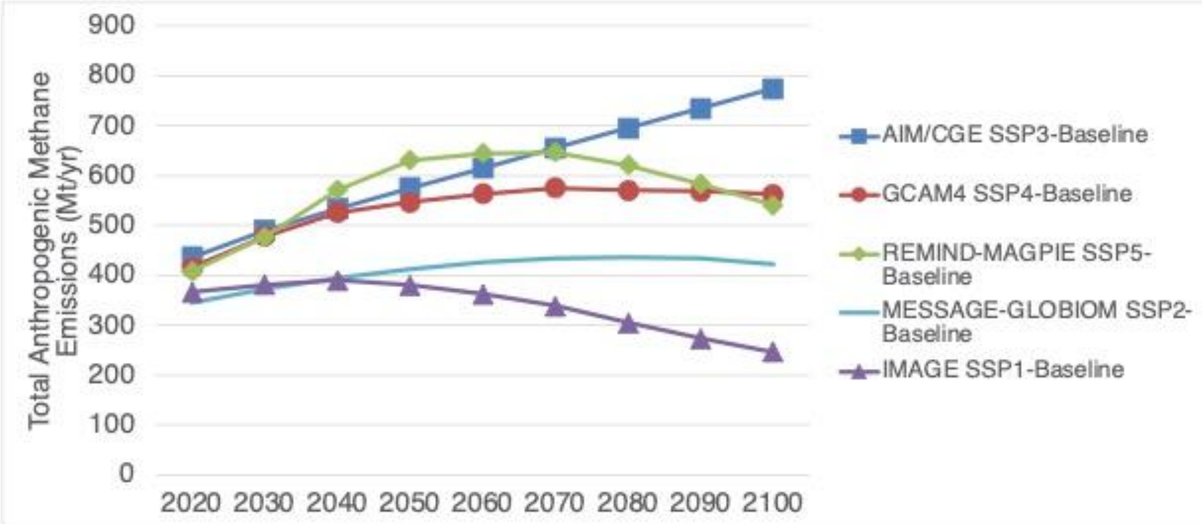
Within the agricultural sector, the main driver is the demand for cattle-based foods (beef and dairy), as emissions from enteric fermentation by ruminant animals is the main source of emissions. Sectoral emissions are affected to a lesser extent by the overall demand for animal products that influences manure, by manure management practices, and by the area under cultivation for rice.

Within the waste sector, the primary driver is total consumption (which is highly correlated with total population), and secondarily with waste management practices.

In the absence of additional future policies focused specifically on methane emissions mitigation or climate change mitigation, anthropogenic methane emissions are projected to increase under most socio-economic pathways (Figure 4). High population growth tends to drive additional consumption overall and hence additional waste, as well as consumption of cattle-based foods. Under scenarios with high population growth, methane emissions increase by 50-100% over the 21st century. Under the SSP2 'middle-of-the-road' scenario, methane emissions increase only modestly (~10-15%) whereas under the 'sustainability' SSP1 scenario they remain fairly level through 2060 after which they decrease by around 40%.

[5] These are available at: https://zenodo.org/record/5548333#.YVwqu6CxVpQ. See also Minx et al., 2021 and https://edgar.jrc.ec.europa.eu/dataset_ghg60)

Figure 4. Estimated global total anthropogenic methane emissions under the five shared socioeconomic pathway baseline scenarios as projected by the indicated Integrated Assessment Models, 2020–2100, million metric tonstonnes per year.



Source: Data from IIASA SSP database version 2.0.

3.2. Impacts of Methane Emissions and their Valuation

Since methane is both a powerful SLCP and a major precursor to surface ozone, emissions reductions are beneficial for both climate change mitigation and air quality. UNEP & CCAC (2021a) conducted a multi-model analysis and found that each megaton of methane emissions reductions leads to:

- Approximately 1,400 avoided premature deaths due to ozone exposure per year globally. Those are roughly evenly divided between avoided premature deaths due to respiratory diseases and those due to cardiovascular diseases.
- About 4,000 fewer asthma-related emergency room visits and 90 asthma-related hospitalizations per year due to reduced ozone exposure.
- Annual avoided losses of 145,000 metric tons of wheat, rice, soy and maize attributable to both decreased ozone exposure and averted climate changes. These impacts alone lead to damages of ~$38 (2018 US$) per metric ton of methane.
- Avoided losses of ~400 million hours of work per year due to reduced heat exposure. These apply to heavy labor categories, including agriculture and construction, and have a current valuation of ~$60 per metric ton of methane.

The total social cost of methane is estimated at $4,300-$7,900 per metric ton of methane from biogenic sources. The lower bound is estimated using a cross-nation income elasticity of 1.0 and the upper bound one of 0.4, with both of them using a constant discount rate of 3% (UNEP & CCAC, 2021). These values are ~$150 per metric ton larger for fossil methane sources that cause net additions of CO_2 to the atmosphere. Valuation is dominated by the health impacts of ozone, which occur immediately and hence, the total value is only weakly sensitive to the discount rate. The benefits per metric ton would be ~US$ 700 less using a discount rate of 5% and ~US$ 700 greater using a 1.4 % discount rate.

These numbers are comparable to those reported previously using a social cost framework that incorporated both climate and air pollution related impacts (Shindell *et al*. 2017). They are slightly larger because of the updated epidemiology underlying the estimates of ozone-attributable premature deaths. However, they are much larger than social costs estimates that only account for climate-related damages and neglect air quality-related damages, such as those used by the United States government.

The impacts of methane emissions occur via two pathways: effects on surface ozone and effects on climate. The ozone effects are essentially instantaneous, and modeling shows they are nearly linear so that per metric ton impact estimates can be made with high confidence. The climate effects take roughly 1-2 decades before they are mostly manifested and continue to grow slowly thereafter. Such effects are less linear and therefore, estimates of per metric ton impacts are only approximates.

3.3. Methane Mitigation Potential

Several sources have assessed potential methane emissions mitigation measures. Studies conducted to date have most focused on the abatement potentials and costs of scaling up of existing technical controls targeted specifically at methane. The analyses are similar in their aims but differ in coverage and methodology**.** As described in the Global Methane Assessment (UNEP & CCAC, 2021), such studies have been conducted by several teams, including:

- The International Energy Agency (IEA) This analysis includes only the oil and gas subsector and analyzes present-day abatement potentials associated with targeted control measures. It uses a 10% discount rate (IEA 2020).
- The analysis by the International Institute for Applied Systems Analysis (IIASA) covers all sectors and includes time-dependent estimates of both changes in baseline emissions and mitigation. The latter include sector-specific assumptions about technology turnover times, based on the literature, improvements in technology over time, and the achievable pace of regulations. The IIASA analysis includes discount rates of 4 and 10% in their cost evaluation and extends to 2050 (Höglund-Isaksson 2020).
- The US EPA produced analyses in 2019 that similarly include projected changes in baseline emissions, extend to 2050, and use a discount rate of 10% in cost estimates (US EPA 2019).
- They analysis by Harmsen et al., (2019) covers all sectors and includes estimates of technology development, the removal of implementation barriers through 2050 (as implemented in the Integrated Model to Assess the Global Environment (IMAGE) IAM following the SSP2 scenario), and uses a discount rate of 5%. This analysis is not entirely independent of the others as it relies upon IIASA data for the fossil fuel sector and earlier US EPA data (US EPA 2013) for the waste sector; however, it implements different projections of future development and obtains different results in those sectors, as well as in the agricultural sector for which it provides an independent analysis.

Many measures that do not have methane emissions abatement as their primary aim can substantially affect methane. They include fuel switching and increased efficiency as part of decarbonization plans. They also comprise demand management, which may be especially relevant in the agricultural sector in which targeted mitigation options leave a large share of methane emissions unabated. Analyses of methane abatement potentials in response to such interventions is carried out with Integrated Assessment Models and by sector-specific studies (e.g., examining food waste and loss reductions or dietary changes). In contrast to technical controls, many behavioral measures do not have clear cost estimates. Methane abatement mitigation measures vary greatly across the many sources, and hence specific measures are discussed by source category below. Note that abatement potentials and costs also vary substantially across regions. Only global average values are discussed here; examining locally appropriate values is indispensable to design data-based interventions at the country level.

3.3.1. Agriculture, Including Rice Cultivation and Ruminant Livestock

Methane abatement measures in the agricultural sector include those targeting emissions from livestock and rice and comprise both technical and behavioral measures. Primary technical measures for livestock include feed changes and supplements, as well as breeding to improve productivity and animal health/fertility for ruminant animals (primarily cattle, but also sheep, goats, and others). The remaining technical abatement potential comes from improved manure management for ruminants and pigs, which might include manure treatment in biogas digesters, decreased manure storage time, improved manure storage covering, improved housing systems and bedding, and manure acidification.

Livestock-related measures have an estimated potential to abate, on average, ~19 Mt/yr of methane emissions by 2030, roughly 1/8th of agriculture sector emissions. Within livestock, the analysis separating manure management and feed/breeding measures estimated the former to be a smaller portion of the potential abatement (~4 Mt/yr). The average cost per metric ton of methane is estimated at about $850/tCH4 (~$30/tCO2e using GWP100 as a rough 'equivalence' with a value of 29 based on IPCC AR6). Estimates for abatement potentials in the livestock sector are highly sensitive to assumptions about the willingness of ranchers to adopt high-productivity breeds from other parts of the world, resulting in significantly different values across analyses. Specifically, abatement potentials range from 4 to 42 Mt/yr across the three estimates studied, with average costs from $400-1,000/tCH4.

The average cost of livestock-related measures includes some very expensive controls. It is also useful to examine the portion of the controls available at 'low' costs, defined as <$600/tCH4 (~$20/tCO2e using GWP100). Of the 19 Mt/yr average total abatement potential across the analyses, roughly 14 Mt/yr are available at low cost, with an average cost for those 14 Mt/yr of $-360/tCH4. These negative net costs are due to factors such as energy recovery from biodigesters and improved herd health.

Several measures are available to mitigate methane emissions from rice cultivation. These include improved water management or alternate wetting and drying, direct wet seeding, phosphogypsum and sulphate addition to inhibit methanogenesis, composting rice straw, and use of alternative hybrid cultivars. Across the available analyses, these rice-related measures have an estimated potential to abate, on average, ~8 Mt/yr of methane emissions by 2030, roughly 5% of agriculture sector emissions. The average cost per metric ton of methane is estimated at about $1,700/tCH4 (~$60/tCO2e using GWP100). The three available estimates are extremely similar in terms of abatement potentials, with values ranging from 6-9 Mt/yr, but differ greatly in costs with averages ranging from $150/tCH4 to $3100/tCH4. As with livestock, a large portion of the abatement is available at low costs. The low-cost potential is 4.5 Mt/yr at an average cost of $23/tCH4 (<$1/tCO2e).

Redirecting agricultural subsidies could play a double role in climate mitigation. Current national agricultural funding is predominantly used to subsidize production rather than reduce emissions. Consequently, agricultural subsidies encourage increased GHG emissions. Redirecting agricultural subsidies could be used to both support the mitigation measures discussed here and to encourage more efficient agricultural production that would be associated with lower GHG emissions.

Banning and enforcement of existing bans on agricultural waste burning is another agricultural sector control measure. It is estimated to have the potential to reduce methane emissions by ~2 Mt/yr at zero cost. It would also contribute greatly to improved air quality and, depending on how the waste was used, could also contribute to soil health.

Reducing food waste and loss is a control measure that spans both agriculture and waste and requires behavioral change. Estimates of mitigation potential for methane emissions vary widely depending upon the assumed waste and loss reduction, as well as potential rebound effects associated with price declines as wastage is reduced. Global food waste and loss reduction could potentially result in methane emissions abatement in the range of 6-20 Mt/yr (UNEP & CCAC, 2021).

Minimal data is available on costs associated with food waste and loss reduction programs or successful examples of deployment at large scales. Many small-scale interventions, on both the production and consumption sides, have promise, however. These include changing food date labelling practices and in-store promotions; improving the cold-storage food chain; establishing online marketplaces to facilitate sale or donation of perishable products; facilitating increased donation of unsold foods from cafeterias and restaurants; providing training for restaurant, cafeteria, and supermarket management to forecast customer demand and reflect demand in food purchasing to avoid bulk purchases; educating consumers to correctly interpret label dates; and increasing the involvement of women in food safe campaigns, among others. Targeting women in behavioral change programs is particularly important for the consumption stage since they are the ones that generally purchase and prepare food. Improvements in the cold food chain – storage and transport –not only influence methane emissions but include opportunities to replace hydrofluorocarbons with more climate friendly substances (see section 4).

Dietary change to healthier consumption levels for cattle-based foods is another behavioral change that could lead to substantial abatement of methane emissions. In many parts of the world, consumption of cattle-based foods, particularly beef, greatly exceeds healthy guidelines. Switching to healthier diets needs to recognize that health and sustainability are not necessarily always aligned. Several studies provide estimates of the change in consumption of cattle-based foods, for which the impact on methane emissions can readily be quantified. Evaluating these, the Global Methane Assessment (UNEP & CCAC, 2021) estimated that methane emissions abatement of 15-30 Mt/yr could be achieved were healthy and sustainable diets to be fairly widely adopted globally by 2030. Costs are likely to be minimal for implementation of such measures, but achievement will depend on social acceptance and consumer education. Reduced demand for beef and dairy can also be important for achieving net zero CO_2 emissions, as many scenarios reach net zero by expanding areas used for afforestation and/or biofuels on areas formerly used for cattle pastures or feed (Rogelj et al., 2018).

3.3.2. Coal Mining

In the coal mining sector, abatement measures consist of pre-mining degasification, air methane oxidation with improved ventilation, and flooding of abandoned mines. Across the available analyses, these coal-related measures have an average estimated abatement potential of ~17 Mt/yr of methane emissions by 2030, roughly 13% of fossil sector emissions. The average cost per metric ton of methane is estimated at about $340/tCH4 (~$12/tCO2e using GWP100). The three available estimates vary substantially in terms of abatement potentials, with two having values of 12-14 Mt/yr but the value being 25 Mt/yr in the third. Costs also differ substantially, ranging from \$160/tCH4 to \$700/tCH4. A large portion of the abatement is available at low costs: 14 Mt/yr at an average cost of \$116/tCH4 (\$4/tCO2e). Roughly 2/3rds of the entire world's abatement potential of coal-mine methane emissions is estimated to be in China. Currently, about 15% of the abatement potential is estimated to be related to abandoned mines, but that proportion is expected to grow as the coal market diminishes in the future.

3.3.3. Oil and Gas Production and Distribution

Extensive work has been done to study methane abatement potentials and costs within the oil and gas sector. Control measures that have been evaluated include upstream and downstream leak detection and repair (LDAR), blowdown capture during well completion and equipment maintenance, recovery and utilization of vented gas with vapor recovery units and well plungers, and installation of flares. Measures for existing devices include replacing pressurized gas pumps and controllers with electric or air systems, replacing gas-powered pneumatic devices and gasoline or diesel engines with electric motors, early replacement of devices with lower-release versions, replacing compressor seals or rods, and capping unused wells.

Across the full oil and gas sector, these measures have an average estimated abatement potential of ~40 Mt/yr of methane emissions by 2030, roughly 30% of fossil sector emissions, based on the average across the available analyses. The average cost per metric ton of methane is estimated at about \$520/tCH4 (~\$18/tCO_2e using GWP100). The four available estimates vary substantially in terms of abatement potentials, with values ranging from 25 to 57 Mt/yr. Costs diverge even more sharply, ranging from a high of \$2300/tCH4 to a low with a net savings of \$660/tCH4. More than half of the abatement is available at low costs: 23 Mt/yr at an average cost of -\$370/tCH4 (-\$13/tCO2e). Within this sector, the largest abatement potential lies within oil production, followed by natural gas production and lastly downstream natural gas (UNEP & CCAC, 2021). According to IEA (2020), the control measure with the largest abatement potential is upstream leak detection and repair, which is also the cheapest. That analysis also finds that most negative cost options occur in four source categories, onshore conventional oil and gas and offshore oil and gas; abatement within the unconventional oil and gas and downstream categories typically have positive costs.

Private companies are rapidly deploying new technologies to detect and measure methane emissions in the oil and gas sector. Their services range from providing methane detection capabilities using satellites, aircrafts and unmanned aerial vehicles, using Artificial Intelligence to develop incident prevention platforms (including identification of corroded and leaky gas pipes), and the development of robust compressed air pneumatic systems and control valves (Oil and Gas Climate Initiative 2021).

Subsidies for oil and gas need to be reformed or eliminated to align national policies with the goals of the Paris Agreement. As with agriculture, current national fiscal policies often provide subsidies or tax breaks to encourage production, thereby increasing emissions of both methane and carbon dioxide.

3.3.4. Biomass Burning

Recent estimates of methane emissions from biomass burning range from 11 to 24 Mt/yr (Saunois et al., 2020). Reducing or halting intentional deforestation would therefore yield methane mitigation. In practice, this may be extremely difficult to achieve at the global scale as climate change continues to exacerbate wildfires. However, programs to prevent deforestation could easily include methane credits alongside CO_2 reduction credits.

3.3.5. Municipal Waste Landfilling and Wastewater Treatment

Extensive work has also been done to study methane abatement potentials and costs within the waste sector. Within that sector, municipal solid waste offers the greatest abatement potential. Control measures that have been evaluated include source separation with recycling and/or reuse, preventing landfill of organic waste, treatment with energy recovery, anaerobic digestion, composting and collection and flaring of landfill gas. Within the related industrial solid waste sectors, similar controls include recycling or treatment with energy recovery and preventing landfill of organic waste.

The other component of the waste sector is wastewater. For residential wastewater, mitigation measures include upgrading of primary treatment to secondary/tertiary anaerobic treatment with biogas recovery and utilization, and substituting latrines and disposal with wastewater treatment plants. Within industrial wastewater, controls include upgrade of treatment to two-stage treatment (i.e., anaerobic treatment with biogas recovery followed by aerobic treatment). Given that the primary goal of wastewater treatment is to improve water quality rather than air quality, the high per metric ton costs of methane mitigation only reflect a minor part of the benefits of wastewater treatment.

Across the waste sector, these measures have an average estimated abatement potential of ~30 Mt/yr of methane emissions by 2030. These represent roughly 40% of waste sector emissions, based on the average across the available analyses. The estimated average cost per metric ton of methane is about -\$230/tCH4 (-\$8/tCO2e using GWP100). The three available estimates are consistent in terms of abatement potentials, with values ranging from 29 to 32 Mt/yr. Costs, however, diverge greatly, ranging from a high of \$3,900/tCH4 to a low value with a net savings of \$5,800/tCH4. This reflects different boundaries included in the waste sector analyses, different prices for recycled goods (especially paper), and different discount rates that affect the value of both gas from energy recovery and recycled goods. The highest cost estimate is from older US EPA data used in the Harmsen et al., study, which has since been updated to much lower costs in the newer US EPA analysis. Roughly half the abatement is available at low costs on average: 16 Mt/yr at an average cost of -\$4300/tCH4 (-\$150/tCO2e). Additionally, the average cost across all measures that capture methane and utilize it for electricity generation (~8 Mt/yr) is net negative (-\$1800/tCH4).

Despite the net negative costs over time, lack of up-front capital can be a barrier to implementing waste sector methane mitigation, especially in low-income countries. Lack of municipal capacity is another frequently encountered barrier, with many locations in low-income countries having minimal waste management infrastructure at all, let alone source separation or methane capture at landfills. In such situations, both financing and capacity building are typically needed. The IFC has a strong track record supporting the development of Public-Private Partnerships to improve landfill management, including projects to generate and sell electricity using biogas that was previously flared to improve the landfill's financial and environmental performance (IFC 2014).

4. HFCs: Emissions and Climate Change Mitigation

Abstract

Hydrofluorocarbons (HFCs) were created as replacements for fluorinated gases that destroy ozone. The 2016 Kigali Amendment to the Montreal Protocol included regulations of HFCs due to their impacts on climate change. Full compliance with the Kigali Amendment would achieve an estimated 61% decrease in HFC emissions between 2018 and 2050, and 0.07°C of avoided global mean warming by 2050, compared to a reference scenario. The maximum technical abatement potential for HFCs, relying on existing technologies, is 85% below the reference scenario emission levels between 2018 and 2050. Transitioning to available low-Global Warming Potential (GWP) alternatives faster and more deeply than contemplated by the Kigali Amendment offers significant opportunities to further reduce HFC emissions.

Though originally designed solely to protect the stratospheric ozone layer, the Montreal Protocol was amended in 2016 to include regulation of hydrofluorocarbons (HFCs) due to their impacts on climate change. This amendment is generally known as the Kigali Amendment. Although HFCs do not deplete ozone, they were created as replacements for fluorinated gases that do destroy ozone and were phased out under the Montreal Protocol, providing a logical link for their inclusion under that agreement. Analyses of the impacts of HFC reductions are highly sensitive to the reference scenario against which they are compared as current emissions are very small (unlike other GHGs). Höglund-Isaksson et al., (2017) estimate that full compliance with the Kigali Amendment could reduce global HFCs emissions by 0.7 Gt CO_2e per year in 2030, and up to 2.7 Gt CO_2e per year in 2050 (based on GWP100). The cumulative emissions avoided between 2018 and 2050 would be 39 GtCO_2e.

Expected improvements in the energy efficiency of refrigeration and air conditioning appliances and equipment during the changeover from HFCs to newer alternatives are also expected to result in indirect CO_2e mitigation. This abatement would be additional to the direct reductions of HFCs emissions under the Kigali Amendment. Past phase-outs under the Montreal Protocol have catalyzed improvements in the energy efficiency of appliances of up to 30% in some subsectors (US EPA, 2002). The adoption of more energy efficient technologies that would take place with full compliance with the Kigali Amendment have been estimated to potentially reduce global electricity consumption by between 0.2 and 0.7 percent during 2018 – 2050 (Höglund-Isaksson et al. 2017). This would result in a cumulative reduction of about 5.5 Gt CO_2e using country-specific emission factors that consider transformation and distribution losses. Another study found that in the room air conditioning sector alone, improving energy efficiency of equipment by 30% while simultaneously transitioning to low-GWP alternatives could save an amount of electricity equivalent to up to 2,500 medium-sized power plants globally by 2050, while providing total (HFC and CO_2) climate mitigation of nearly 100 GtCO_2e by 2050 from this sector (Shah et al., 2015).

4.1. Emissions at the National Level

National HFC emissions inventories have been assembled in several countries. These include the inventories developed by IIASA (Höglund-Isaksson et al., 2017) and by the Joint Research Centre of the European Commission within their Emissions Database for Global Atmospheric Research product (through 2019, not yet available in the 2020 product). They are also reported by Annex I countries to the UNFCCC. Emissions from China and developing countries rose substantially during the 2000s and 2010s while growing more modestly in Annex I countries (Yao et al., 2019). For any country that has ratified the Kigali Agreement, tracking national emissions is an important part of putting that Agreement into place.

4.2. Potential HFCs Mitigation Measures

In countries with high ambient air temperatures, almost 70% of sectors currently using HFCs can leapfrog past high-global warming potential hydrofluorocarbon refrigerants, directly to low-global warming potential alternatives with equal or better energy efficiency (Zeiger et al., 2014). Full compliance with the Kigali Amendment would achieve a 61% decrease in HFC emissions in the period between 2018 and 2050, compared to the emission levels in a reference scenario (Höglund-Isaksson et al., 2017). That same study reports that the maximum technical abatement potential, relying on existing technologies, is 85% below the reference scenario emission levels (in the period between 2018 and 2050). This indicates that there is a significant opportunity to further reduce HFC emissions by transitioning to available low-GWP alternatives faster and more deeply than contemplated by the Kigali Amendment. In addition, strengthened phase-down efforts would also avoid additional future emissions by precluding a build-up of storage HFC banks (Velders et al., 2014). The World Bank is the implementing agency of the Global Environment Facility for the Kigali Amendment.

Full implementation of the Kigali Amendment would be expected to lead to about 0.07°C of avoided global mean warming by 2050 relative to a reference scenario without the Kigali Amendment. Following a maximum feasible reduction pathway would lead to about 0.10°C of avoided 2050 warming (UNEP, 2017). Full implementation of the Kigali Amendment is by no means assured, with illegal production during the end of the last decade having caused levels of some HFCs to increase to record high levels despite the worldwide phaseout (Stanley et al., 2020).

5. Designing Interventions to Mitigate SLCPs and their Linkages with Air Quality Management

Abstract

Most countries do not have specific commitments on mitigation of SCLPs. Methane and HFCs are covered under the UNFCCC; however, most countries have not set specific targets for methane and less than half of the countries mentioned HFCs in their first NDC. Black carbon is not part of the GHGs covered by the UNFCCC. As of April 2022, less than 10 countries explicitly mentioned black carbon in their NDC. Cost-benefit analysis of combined local air pollution and global climate change mitigation shows a net welfare gain in comparison to each policy being carried out alone. The total benefits of climate change mitigation outweigh costs in the near-term when air pollution is included, even in high-income countries with relatively clean air. Accounting for air pollution-related impacts enables developing countries to develop "no-regrets" strategies that will yield societal gains regardless of whether the rest of the world takes action to mitigate climate change or not. Different policy instruments are available to mitigate SLCP emissions, which have been tested in low-, middle- and high-income countries.

5.1. Building the case for integrating air quality and climate change mitigation policies

Most countries do not have specific commitments on mitigation of SCLPs. Methane is one of the GHGs considered under the UNFCCC, but it is also an SLCP because of its relatively shorter atmospheric lifetime and because of its role as a precursor of tropospheric ozone. Therefore, methane is typically part of national GHG reduction targets, but countries have not historically set specific targets for methane. HFCs are similarly covered under the UNFCCC and were also included under the Montreal Protocol after the passage of the Kigali Amendment to the Protocol. When Nationally Determined Contributions (NDCs) were first submitted in 2015, less than half of the 192 submitted NDCs mentioned HFC emissions reductions. As of October 2021, 120 parties had submitted updated NDCs to the UNFCCC, half of which included HFC emission mitigation measures.[6] Black carbon is, however, not part of the GHGs covered by the UNFCCC. Out of the 119 countries that had endorsed the pledge by October 2022, 96 included methane as part of their overall GHG reduction target, but only 15 had set specific methane mitigation targets (Fransen et al, 2022).

In the absence of explicit methane mitigation goals, a large international research project has developed a range of plausible implementation pathways to achieve the NDCs that countries have submitted to the UNFCCC. Based on this research, it is estimated that some countries' pledges would result in significant decreases in their methane emissions by 2030, and even greater reductions by 2050 (**Error! Reference source not found.**). A group of major emitting countries, including Canada, European Union nations, Japan, and the United States, have NDCs that will likely result in reductions of ~80–88% of those seen in 2°C least-cost pathways by 2030 compared with 2015, and ~69–77% by 2050. However, for most countries, NDCs are expected to deliver only about a third of 2030 methane reductions expected under 2°C scenarios. China, the Russian Federation, India, and Australia show the greatest emission gaps.

[6] https://accelerate24.news/regions/global/more-countries-include-hfc-emissions-reduction-in-climate-accounting/2021/

Table 2. Projected changes in methane emissions relative to 2015 under nationally determined contributions and under a 2°C scenario

	2030	2030	2030		2050	2050	2050
Country	% decrease in NDC	% decrease in 2°C	NDC/2°C fraction	Country	% decrease in NDC	% decrease in 2°C	NDC/2°C fraction
Republic of Korea	26	29	89	USA	44	57	77
USA	30	34	88	EU	37	50	74
Canada	44	51	87	Japan	39	55	71
Japan	46	54	86	Canada	50	72	69
EU	22	28	80	Indonesia	40	65	61
Indonesia	23	40	59	Brazil	21	38	56
Turkey	22	38	58	Republic of Korea	31	64	49
Brazil	11	23	48	Turkey	26	59	44
Global	11	34	34	Global	23	55	41
Rest of world	10	34	30	Rest of world	22	57	39
Australia	2	9	18	China	18	59	30
Russian Federation	5	35	16	Russian Federation	19	63	30
China	6	40	15	India	8	46	17
India	1	26	3	Australia	5	43	12

Note: Projections for both the NDCs and the 2°C scenario are based on Roelfsema *et al.* (2020) and PBL Netherlands Environmental Assessment Agency (undated). Although ranges across the models were not specified for methane alone, the tenth to ninetieth percentile range of the emissions gap between the NDCs and 2°C scenario for all GHGs was ~36 per cent at the global level and 30–55 per cent at the national level, indicating that a similar uncertainty range is appropriate for methane estimates. The assumptions and underlying data are described in Roelfsema *et al.* (2020).

Source: UNEP 2021b.

In November 2021, 104 nations signed on to the Global Methane Pledge that includes a global effort to reduce 2030 emissions by at least 30% relative to 2020. This Pledge is separate from, but complementary to, NDCs. CCAC has also developed a guidance document to introduce air pollution directly into NDCs.[7] It is also useful to review the alignment between NDCs and the Paris Climate Agreement, or more often the lack thereof, as annually documented in reports such as the UN Environment Programme's Emissions Gap Reports.

[7] https://www.ccacoalition.org/en/resources/opportunities-increasing-ambition-nationally-determined-contributions-through-integrated

5.1.1. Economic analysis of the integration of air pollution and climate policies

Most climate strategies do not fully account for the air quality improvements and health co-benefits that would be associated with their implementation. When these co-benefits are included in the cost-benefit analysis of mitigation measures, the net present value of such measures increases substantially. On a global scale, meeting the Paris Agreement targets will bring huge health benefits in terms of avoided air pollution, creating up to US$28.3 trillion in net benefits between 2020 and 2050, while preventing over 42 million deaths. The ratio of health benefits to mitigation costs ranges from 1.4 to 2.45 and reaching the 1.5°C target can yield net benefits from US$3.28-8.4 trillion in India and US$0.27-2.31 trillion in China (Markandaya et al., 2019).

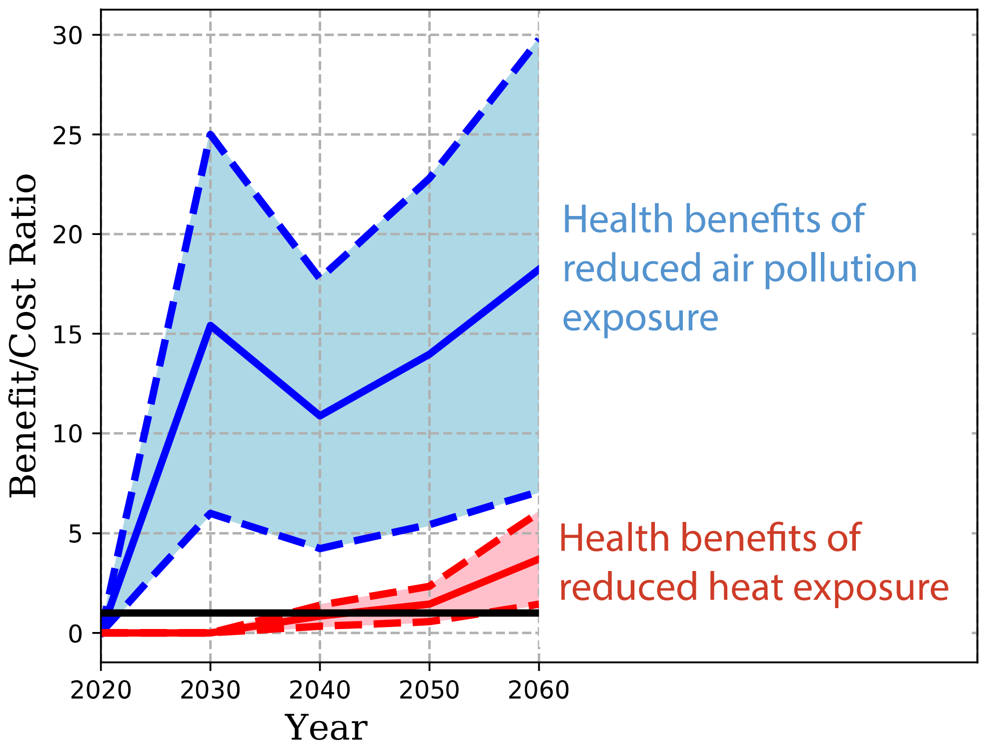
Cost-benefit analysis of combined local air pollution and global climate change mitigation shows a net welfare gain in comparison to each policy being carried out alone (Bollen et al., 2009). Mexico and Chile, the two countries that submitted black carbon mitigation targets in their NDCs, have a history on integrating air quality and climate change policies. In the case of Chile, integrating air pollution and climate policies has been shown to amplify marginal abatement benefits of decarbonization by a factor of 5. Chile's net zero emissions strategy would increase the country's economic annual growth rate by 0.4 percent, at a marginal savings of US$23/metric ton of CO_2 reduced (World Bank, 2020; E2Biz, 2020). When health benefits are included, these amount to 2.5% of GDP and increase net savings to US$119/metric ton of CO_2. Colombia included into its updated NDC a 40% reduction in black carbon emissions by 2030 because of the health benefits that are unlocked through this approach (Breathe Life, 2021).

Economic instruments can be adjusted to promote emission mitigations. Between 2008 and 2018, Mexico reduced fossil fuel subsidies and introduced a carbon tax that raised revenue (1.6% of GDP), and contributed to reduced emissions of both local and global pollutants, preventing between 0.8 and US$3.3 billion in health impacts per year (World Bank, 2021b). Integrated approaches unlock and accelerate opportunities for sustainable development.

5.1.2. Building local support by emphasizing that air quality benefits are "here and now"

It is well-established that that long-term damages from unmitigated climate change are greater than the mitigation costs worldwide (e.g. Stern, 2006). However, costs greatly exceed climate benefits in the near-term. New research shows that even in high-income countries with relatively clean air, the total benefits outweigh costs even in the near-term when including air pollution (Shindell et al., 2021; see **Error! Reference source not found.**). Further, those near-term benefits stem primarily from national actions, whereas long-term climate-related benefits require global cooperation. Near-term air quality would be substantially greater in most developing countries with higher levels of present-day ambient air pollution. Hence accounting for both air quality and climate change improves decision-making about the effects of mitigation actions on overall societal welfare. Accounting for air pollution-related impacts enables developing countries to develop "no-regrets" strategies that will yield societal gains regardless of whether the rest of the world takes action to mitigate climate change or not.

Figure 5. Benefit/cost ratios for the US for a 2°C (SSP1_26) scenario relative to a high emission (SSP5_85) reference case over the next several decades.



Source: Adapted from Shindell et al. (2021).
Note: Blue lines show mean and range for the health benefits of reduced air pollution vs mitigation cost

Building local support for air quality interventions requires public understanding of both the levels of air pollution and their health effects. Support for local air quality monitoring networks and data provision to the public is therefore another key area for mobilizing action. Networks of low-cost sensors are becoming much more widely deployed but are of varying quality and should ideally be tied to at least a modest number of high-quality stations, such as those deployed on US Embassies around the world.

5.1.3. Instruments for climate and pollution management policies[8]

Many net-zero emission targes do not have mandatory legal frameworks that go beyond the international commitments in the context of the UNFCCC. WRI (2021) shows that net zero emission commitments mostly lack specificity, do not cover all greenhouse gases, do not have gross emission reductions, or are misaligned to NDCs for 2030. As these frameworks are developed, it is important to use pre-existing legal frameworks that can be used to promote mitigation of emissions. For instance, countries and cities that have seen air quality improvements have adopted air quality goals in the form of legal standards, but also complementary tools that lead to implementation of concrete actions, including air pollution attainment programs, emission standards, vehicle inspection programs, and other command and control instruments. Unfortunately, many countries do not have air quality standards, and when they do exist, they are misaligned with WHO guidelines. The WHO's 2021 updated guidelines

[8] This section draws largely from Sánchez-Triana, Enriquez and Siegmann (2020).

provide interim targets that can gradually lead to achievement of air pollution levels that do not represent an environmental health risk. The Air Quality Guidelines updated by the WHO in 2021 should lead to updates in air quality standards in practically all countries in the world. Supporting the development of these standards is an effective entry point for mitigation of emissions, which can contribute to GHG emission reductions.

Development of complementary regulations can catalyze the adoption of clean technologies. These can be the "straw that breaks the camel's back", as they make the leap to clean technologies smaller. The coal phase out agreement in Chile resulted from a combination of factors, including carbon pricing, stringent emission standards, and unbundling renewable energy auctions from baseload energy (Plutschack et al., 2021). Electric buses were economically feasible earlier than in the rest of Latin America because a stringent emission standard (Euro 6) was adopted as a baseline (World Bank, 2020). Mexico has long had an integrated approach between AQ and CC. Since its inception, the air quality management program for the Mexico City Metropolitan Area, Proaire 2002-2010, explored synergies that resulted in Latin America's first climate change action plans, and specific investments in a bus rapid transit system that contributed to cleaner air and lower greenhouse gas emissions, as well as to other co-benefits, such as reduced congestion.

Different policy instruments are available to mitigate SLCP emissions, which have been tested in low-, middle- and high-income countries. From an economic standpoint, many environmental problems (including climate change and air pollution) are caused by externalities, which arise when the agent making the production or consumption decision does not bear all the costs or benefits of this decision (OECD, 2001). Externalities mean that market prices fail to reflect the environmental damage and natural resource depletion caused by production and consumption of goods and services.

Several policy instruments are available to correct negative externalities and promote positive ones, with the aim of mitigating SLCPs. At one extreme, such instruments include fines or sanctions that are linked to traditional command-and-control (CAC) regulations.[9] At the other extreme, they include laissez-faire approaches that require consumer advocacy or private litigation to act as incentives for improving environmental management. In between are the more familiar tax-and-subsidy approaches, as well as the less familiar mechanisms relying on traded property rights (Sánchez-Triana, Enriquez, & Siegmann, 2020).

There is no single standardized definition of an incentive-based or market-based instrument (MBI). The commonly held understanding and the definition employed here is that an MBI must, foremost, attempt to align private costs with social costs to reduce externalities (Panayotou, Economic Instruments for Environmental Management and Sustainable Development, 1994). Within this definition, the strength of an MBI then depends on the degree of *flexibility* that a polluter or resource user has in achieving a pollution mitigation target. A very weak MBI essentially dictates through regulation the type of technologies that firms must use, or the targets they must meet. This is the inflexible CAC approach – which also entails an economic incentive to the extent that failure to comply can result in monetary sanctions. A very strong MBI allows market signals rather than explicit directives determine the best way to meet a given standard or goal.

[9] According to Giner (2012), command and control regulations focus on preventing environmental problems by mandating standards and technologies to control pollution. This approach generally relies on emissions standards, ambient standards, and technology-based and performance-based standards in conjunction with enforcement programs.

Flexibility is operationalized by equating it to the level of decentralization that occurs in transferring social (or state) decisions to the private (individual) level. A strong MBI decentralizes decision making to a degree that the polluter or resource user has a maximum amount of flexibility to select the production or consumption option that minimizes the social cost of achieving a particular level of environmental quality. When the polluter or resource user is driven by profit- or utility-maximizing behavior, a strong MBI also generates a lowest social cost outcome for the achievement of a given policy objective.

Error! Reference source not found. **illustrates the broad spectrum of instruments that might be available, all of which implicitly or explicitly have some incentive effect.** They fall across a continuum ranging from very strict CAC approaches to decentralized approaches that rely more on market or legal mechanisms.

Table 3. Policy Instruments to Mitigate SLCP Emissions

Minimum Flexibility — *Greater Government Involvement* ⟷ **Maximum Flexibility** — *Greater Private Initiative*

Control Oriented	***Market-Oriented***			***Litigation-Oriented***
Regulations and Sanctions	***Charges, Taxes, Fees, and Performance-Based Payments***	***Market Creation***	***Final Demand Intervention***	***Liability Legislation***
General Examples				
Standards Government restricts nature and amount of emissions for individual polluters or mandates the use of specific technologies. Compliance is monitored and sanctions imposed (fines, closure, and jail terms) for noncompliance.	**Emission Charges**: Government charges fees to individual polluters based on the emitted amount of pollution. Fee is high enough to create incentive to reduce impacts. **Subsidies:** Government subsidizes cleaner technologies to reduce their costs and accelerate their adoption, helping manufacturers to reach economies of scale and become competitive with conventional technologies. **Climate Auctions:** auctions provide project developers and commercial entities a guaranteed price for emission reductions or carbon credits generated from clean technologies	**Tradable Permits**: Government establishes a system of tradable permits for pollution or resource use, auctions or distributes permits, and monitors compliance. Polluters trade permits at unregulated market prices.	**Performance Rating**: Government supports labeling/performance rating program that requires disclosure of environmental information on the final end-use product. Performance based on adoption of ISO 14000 voluntary guidelines: zero pollution discharge, mitigation plans submitted; pollution prevention technology adopted, reuse policies and waste recycling.	**Strict Liability Legislation**: The polluter or resource user is required by law to pay any damages to those affected. Damaged parties collect settlements through litigation and the court system.
Specific Examples				
• Emission standards for power plants, boilers, other industrial sources, and vehicles • Emission and technology standards for brick kilns • Mandatory methane leaks inspection and repair programs in the oil and gas sector • Banning agricultural waste burning • Bans applied to certain HFCs previously used for refrigeration	• Pollution charges on primary ($PM_{2.5}$) and secondary (NO_x and SO_2) air pollutants. • Methane taxes • Subsidies to substitute the use of solid fuels for cooking with LPG, pellets, briquettes, or electric stoves. • Subsidies for anaerobic digesters and improved agricultural practices. • Tipping fees on solid wastes. • Wastewater treatment fees. • Removal of agricultural and fossil fuel subsidies. • Methane reduction auctions.	• Tradable permits for air pollution emissions and GHGs. • Tradeable quotas for HFCs and other chemicals. • Establishment of biogas markets. • Creating markets for fertilizers or bioenergy from biosolids found in wastewater and from organic waste.	• Consumer product labeling (eco-labels) relating to production practices, energy efficiency, and so forth. • Supply chain intervention where intermediate buyers insist on installation of Effluent Treatment Plants for upstream product production processes. • Education regarding recycling and reuse. • Use of lifecycle analysis and carbon footprints	• Lawsuits to governmental authorities for not enforcing clean energy regulations • Climate change lawsuits against vehicle manufacturers to phase out combustion engines.

Source: adapted from Sánchez-Triana, Ruitenbeek, Enríquez, and Siegmann (2020).

There is a broad range of MBIs available to address externalities and mitigate SLCPs (Error! Reference source not found.**)**. A key consideration in selecting the most appropriate instrument is *cost-effectiveness.* For example, the asymmetry of information often implies that individual agents, private firms, or community associations are more likely than governments to identify the most cost-effective means for achieving a given environmental goal, such as reduced methane or black carbon emissions. This forms the basis for the common theoretical result that—if one focuses entirely on private costs—strong forms of MBIs are more cost effective than their weaker counterparts or than CAC approaches (Tietenberg 1990; Hahn and Stavins 1992).

Another advantage of stronger MBIs is that, to the extent that they provide economic agents flexibility to choose how they achieve a given environmental objective, they provide incentives for *innovation*, such as the development and adoption of better abatement technologies (Stavins and Whitehead, 1992). In a seminal article, Porter and van der Linde (1995) argued that more stringent but well-designed environmental regulations (particularly strong MBIs) trigger innovation to such an extent that it can increase the competitiveness of the regulated firms. This argument, known as the Porter Hypothesis, suggests that pollution is often a waste of resources and that innovation aiming to increase efficiency in their use may lead to an improvement in the productivity with which resources are used.

Multiple empirical studies have been developed to test the Porter Hypothesis. Some of these studies find that environmental regulation is associated with increased Research and Development by firms, particularly when regulation is stable and flexible (Ambec, Cohen, Elgie, & Lanoie, 2011). They also find that environmental regulation can increase productivity, as in the case of refineries located in Los Angeles, California, which achieved significantly higher productivity than other U.S. refineries despite their need to comply with a more stringent air pollution regulation than those located in a different geographic area (Berman & Bui, 2001). In a different study, stricter regulations led to modest long-term gains in productivity in a sample of 17 manufacturing sectors in Quebec. Importantly, productivity slightly fell after the first year of the regulation's adoption, but then rose in subsequent years, leading to productivity gains that more than off-set the first year's decline. This finding is consistent with the Porter Hypothesis assumption that innovation may take time and underscores the need to ensure the stability of regulations (Lanoie, Patry , & Lajeunesse, 2008).

In addition to addressing externalities and ensuring cost-effectiveness, policymakers often have a third goal when designing an appropriate economic incentive system: *revenue generation*. Stronger MBIs have the advantage over conventional CAC regulations of delivering a double dividend, meaning that, in addition to advancing environmental goals, they also generate government revenues. This is particularly the case of charges, taxes, and fees, and potentially of tradeable permits in which the initial allocation of permits is auctioned. The government may use revenues collected through these instruments to increase its expenditure and investment in socially desirable areas, such as further environmental protection (Hahn & Stavins, 1992). The revenues collected by taxing "bads" such as pollution can be used to lower existing distortionary taxes on desirable activities such as labor. Analysis in the European Union found that using revenues from environmental taxes to repay government debt negatively affected GDP, employment, and real household incomes. However, when revenues were used to reduce income tax, GDP, employment, and real household incomes across the income distribution rose (Mottershead et al. 2021).

There are, however, practical tradeoffs to consider between revenue generation and incentive effects. For example, it would be possible to levy a very high charge that effectively discourages all polluting activity. Abatement levels would be very high in such a case, but no revenue would be generated. Similarly, very low charges would generate little revenue and generate little abatement because there is no incentive for firms to reduce pollution. Typically, revenue is maximized at some intermediate level of abatement. A policy decision must be made relating to how much additional revenue (beyond the maximum) a government is willing to give up generating higher levels of abatement. The answer to this policy question should be related to the marginal benefits of pollution abatement. However, it is typically more a function of government budgetary realities that regard such taxes as a convenient means for underwriting environmental management efforts.

The following subsections provide more details and examples of the available MBIs.

Command and control regulations, fines, and penalties

Centralized control-oriented approaches relying extensively on regulatory guidelines, permits, or licenses have traditionally been the preferred mechanisms for controlling environmental impacts in urban areas. For instance, Thailand banned in 2019 the burning of agricultural waste, including from sugarcane, rice, and maize corn, to combat air pollution. Bans have also been used in the context of the Montreal Protocol to phase out the use of ozone-depleting substances and countries are advancing regulations to ban high Global Warming Potential HFCs. For instance, the US Environmental Protection Agency announced in December 2022 a proposed rule to ban high GWP HFC refrigerants from 2025.

Command and control regulations can be separated in two types: technology-based and performance-based (Stavins and Whitehead, 1992). Technology based regulations specify the methods and equipment that firms must use to meet pre-established target. Conversely, performance standards set an overall target for each firm, or plant, and let firms decide how to meet the standard but hold them to a uniform level across the industry.

A relevant example of a command-and-control instrument is the amendment in 2019 of Bangladesh's Brick Manufacturing and Kiln Installation Act. The amendment includes phased targets to reduce the use of "dirtier" clay-fired bricks between 2019 to 2025, except for the construction of base/sub-base of the high-ways. The amendment establishes fines, or even imprisonment, for using excessive polluting materials (e.g., sulfur, ash, mercury), or for exceeding established limits of gaseous emissions and liquid discharges.

Although it is technically simple to impose regulations with specific fines for noncompliance, the problems associated with implementing them and achieving compliance are insurmountable for many developing countries. First, regulatory drag can occur when the regulatory approval system, because it is overburdened, unnecessarily holds up critically important investments, and in so doing acts as a drag on economic development prospects. Second, the capacity to implement regulations is often limited because of inadequate human resources, or inadequate supportive infrastructure such as environmental information or monitoring networks. Third, local financing constraints arise because authority for environmental regulations is often delegated to lower (local) levels of government without adequate sources of financing for implementing and monitoring the regulations. Fourth, conflicting standards often prevail where individual ministries or departments have been responsible for setting environmental regulations within their own departments; lack of coordination often leads to conflicting or overlapping regulations. Finally, conflict of interest within government programs exists where government agencies are themselves the implementing or investing authority (e.g., stage-owned oil and gas companies); self-regulation becomes problematic under such circumstances and seldom are there built-in incentives to ensure compliance. This is especially a problem with common infrastructure facilities that typically are a government mandate.

In addition, command and control regulations give the manufacturer little incentive to improve efficiency and environmental performance. While these regulations were successful in securing the first tranche of emissions reductions from previously unregulated industries, they are now viewed as increasingly burdensome (Austin, 1999).

Phasing out Subsidies[10]

Subsidies are deliberate policy actions that maintain consumer prices artificially low leading to higher consumption of subsidized goods. Subsidies therefore result in higher natural resources extraction, consumption, pollution, and GHG emissions (Enriquez, Larsen, & Sanchez-Triana, 2018).

Subsidies for goods and services can result in severe environmental degradation (Sterner, 2003). As mentioned in the previous sections, subsidies to fossil fuels and agriculture increase methane emissions. By not pricing the waste management system and bearing the costs it generates, governments implicitly subsidize organic waste generation, which also releases methane and has other negative environmental effects. Subsidies may also lead companies to under-invest in more efficient and environmentally friendly technologies, discouraging innovation and making methane emission abatement interventions less attractive (Enriquez, Larsen, & Sanchez-Triana, 2018; Coady, Parry, Sears, & Shang, 2016)

Restructuring environmentally harmful subsidies represents a "win-win" opportunity for the economy and the environment (OECD, 2005). For instance, removing fossil fuel subsidies would reduce greenhouse gas, methane, and black carbon emissions and would increase government revenues. Fossil fuel subsidies were estimated at $2.9 trillion or 6.8% of global GDP in 2020 and are expected to rise to 7.4% of GDP IN 2025. Efficient fuel pricing in 2025 would reduce global CO_2emissions 36% below baseline levels, which is in line with keeping global warming to 1.5°C, while raising revenues worth 3.8% of global GDP and preventing 0.9 million local air pollution deaths per year (Parry, Black, and Vernon 2021).

Even though energy subsidies are often well intentioned, they usually do not benefit the poor or even the lower middle class. Wealthier people have bigger homes to heat, own more and bigger cars and use more energy. Therefore, resources that were meant to protect the poor are ultimately transferred to the wealthier part of society. Even though subsidy reforms are politically sensitive and opposed on the grounds that they would hurt low-income households, the regressive effects of energy subsidies has been established in many countries, including Mexico (Plante & Jordan, 2013) and Indonesia, among many others (Inchauste & Victor, 2017).

In addition, when governments provide subsidies, they spend scarce resources that could have been invested in projects, as education or infrastructure, which could genuinely benefit those who are most in need (Rzeczpospolita, 2014). A comparison of 109 Low-and-Middle-Income-Countries found that an increase in the amount spent of energy subsidies equivalent to 1% of GDP was associated with public expenditures in education and health that were on average lower by 0.6% of GDP (Ebeke & Lonkeng Ngouana, 2015).

Subsidies have clear and well-documented negative economic, environmental, and social impacts. Yet, they are difficult to reform because they are extremely popular politically and attract groups willing to mobilize politically to resist their restructuring (Inchauste & Victor, 2017). Political risks that are possible to occur because of subsidies reforms can be reduced through a combination of communication and compensation strategies. Communication with stakeholders on the costs and opportunities of a reform

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[10] This section draws largely from Enriquez, Larsen, & Sanchez-Triana (2018).

can determine whether it turns out to be successful or not. Communication can build support and acceptance, trust, and understanding of the political decisions that underpin the reform. Disseminating information on the negative effects of subsidies and how those resources will be spent in the future is key to gaining social support for subsidy reform (Worley, Pasquier and Canpolat 2018). A compensation strategy should ensure that the poorest do not end up suffering the most from the subsidy removal/reduction by for example, implementing a better-targeted social protection system (Yemtov and Moubarak 2018).

Subsidy reforms are not a single event but a process that takes times and effort to implement. Creating social assistance programs to compensate the poor may take years and often includes administrative and technological innovations. Ideally, social assistance should be implemented in the form of direct transfers of cash that vulnerable groups can then decide how best to allocate (Inchauste & Victor, 2017). Lessons from energy reforms undertaken by countries around the world suggest that reforms are more likely to be successful if they are part of a comprehensive long-term strategy for the energy sector, developed in consultation with stakeholders. In addition, the reduction of subsidies should be based on automatic and transparent pricing mechanisms with the aim of depoliticizing the issue (IMF, 2013).

Pollution Charges and Taxes

As other economic instruments, pollution charges seek to influence a producer or consumer behavior through a monetary incentive. They can be applied in different ways: i) charges to emissions; ii) charges to users; and iii) charges to products.

Pollution charges are applied to emissions that are released into the air and are most suited for large stationary sources. They can be levied on emissions that are directly metered, on a proxy source, a presumptive pollution level or in the form of a flat rate (World Bank Group; United Nations Environment Programme; United Nations Industrial Development Organization, 1999). When a presumptive pollution level is considered, a firm is compelled to pay the charge with no specific monitoring conducted. If the firm wishes to reduce its tax burden, it must conduct monitoring at its own expense (but still subject to regulatory audit) to demonstrate that its actual pollution loads are less than the presumed loads. Emissions charges can be used to address local challenges: for example, taxes for airborne pollutants such as Nitrogen Oxides (NOx) and Sulphur emissions provide a continuous incentive to implement pollution-abatement options and encourage innovation. For instance, Sweden has accomplished reductions in NOx emissions through emissions charges. In 1990 the Swedish Parliament passed a legislation introducing NOX charges emitted from energy generation at combustion plants. The charge is applied to measured emissions, or to presumptive emissions levels and plant operators may choose to pay the charge on the basis of presumptive emissions levels or by installing measuring equipment. By 2004, Sweden achieved a 65 percent reduction on NOx emissions compared to 1990 (Swedish Environmental Protection Agency, 2006).

More recently, in 2014, Chile adopted a tax on particulate matter, NOx, SO_2, and CO_2 emitted by companies with fixed emission sources, comprising of boilers or turbines with a power equal to, or higher than, 50MWt. The same reform established a tax on the first sale of new vehicles, based on their fuel efficiency and NO_x emissions. In 2019, these taxes generated government revenues of more than $186 million and contributed to the reduction of 22% of particulate matter emissions, 5% of SO_2 emissions, and 6% of NO_x emissions.

The Government of Norway has imposed a tax on methane emissions from oil and natural gas operators on the Norwegian Continental Shelf, at a rate of about \$50/tCO_2e. The US Inflation Reduction Act similarly contemplates the establishment of a methane fee rising to \$50/tCO_2e in 2026. An analysis by Parry et al. (2022) finds that establishing a methane fee of around \$70/tCO_2e among large economies would align 2030 emissions with the goal of limiting global warming to 2°C above preindustrial levels. Based on their analysis, most costs would be in extractive industries and abatement costs would be equivalent to just 0.1% of GDP (Parry et al. 2022).

Most countries tax fossil fuels in one way or another. However, as explained in the section on subsidies, most countries also subsidize fossil fuels. The net result in practically all countries is that retail prices for fuels such as coal, natural gas, gasoline and diesel is significantly lower than what should be charged if the prices reflected externalities, including local air pollution, climate change, and congestion. According to Parry, Black and Vernon (2021), only 8% of the global subsidies for fossil fuels in 2020 reflected undercharging for supply costs (explicit subsidies), while undercharging for environmental costs and foregone consumption taxes (implicit subsidies) accounted for the remaining 92%.

While price mechanisms could be used to encourage the use of cleaner fuels, this is seldom the case. OECD countries tax coal and heavy fuel oil at the lowest rate, even though they are the most carbon-intensive and polluting fuels. Energy taxes on diesel, a key source of BC emissions, are lower than those on gasoline in all countries studied by OECD (2019) except Mexico, Turkey, and the United States (Mottershead 2021).

User charges are payments for specific environmental services, such as collective or public treatment of wastewaters or household waste disposal. These payments are intended to reflect the costs of providing the service. Taxes on waste, based on weight or quantity, can promote waste minimization and composting practices while diverting waste from landfills (European Environment Agency, 2000).

Before fixing the tax rate, governments need to carefully analyze the country's economic, social, and political context. If not correctly designed and implemented, pollution taxes may sometimes cause undesired effects or disproportionately affect low-income groups. To prevent these cases from happening, models can be useful in predicting potential leakage or distributional impacts and mitigation measures (Partnership for Market Readiness, 2017).

Market Creation: Tradable Permits

At a more complex level, market-oriented approaches can include some form of market creation. The most complex system involves tradable permits where regulators establish an allowable level of pollution which is distributed among firms in the form of permits. Polluters that need important amounts of money to reduce their emissions can buy emissions allowances from polluters that have cheaper abatement costs (World Bank, 2014) and companies that manage to keep their emissions below their allocated level can sell their surplus allotment to other firms or use them to cover excess emissions in other parts of their facilities (Stavins R. N., 2003). Emission trading systems enable emission reductions where it is cheapest to achieve them (OECD , 2019).

One of the most well-known cases of tradable permits is the European Union Emission Trading System (EU ETS). It was set up in 2005 as the world's first international ETS and is the major carbon market worldwide. The EU ETS works on the 'cap and trade' principle where a cap is set on the total amount of greenhouse gases that can be emitted by installations covered by the system. In this context, companies receive or buy emission allowances that can be traded among the different actors. Each year a firm must prove that has enough allowances to cover all its emissions in order to not to get fined. If a company reduces its emissions, it can keep the spare allowances to cover its future needs or else sell them to another company that is short of allowances. The cap reduces with time to achieve a reduction of emissions (European Commission, 2019). Emissions from stationary installations have declined by around 29 percent between 2005 and 2018 (Healy, et al., 2019). In November 2022, EU institutions reached a preliminary agreement to extend the ETS to cover the shipping sector. The ETS for shipping will only cover CO_2 during 2024 and 2025, but emissions of NOx, soot, and methane will be included from 2026.

Instruments to set a price on carbon have gained prominence in the fight against global change. As of 2022, 47 national and 36 sub-national governments had adopted or were analyzing the adoption of taxes, emissions trading systems, or a combination of both to promote the transition to a decarbonized economy.[11] It is estimated that these initiatives cover 11.86 $GtCO_2e$, representing 23.2% of global GHG emissions.[12]

Another example of the application of tradable permits is the Regional Clean Air Markets (RECLAIM) program in California. RECLAIM was established in 1994 to reduce nitrogen oxide and sulfur dioxide emissions in the Los Angeles area and is the world's first comprehensive market program for reducing air pollution. The program sets a factory-wide pollution limit for each business and let them decide the most cost-effective best way to meet their emission limits. As in the case the case of the EU ETS, allowable emission limits decline a specific amount each year and companies that can reduce emissions more than required can then sell excess emission reductions to other firms. Each firm participating in the program receives trading credits equal to its annual emissions limit that are based on past peak production and the requirements of existing rules and control measures. By 2018, RECLAIM achieved a 73 percent reduction for NOx emissions and a 70 percent reduction for SOx emissions compared to 1994 levels (Illes, Sanford, Hynes, Burleigh Sanchez, & Maxwell, 2020).

One potential advantage of tradable permit systems is that they may reduce bureaucracy and government participation in the process. Such decentralization of decision making is particularly important in high growth economies where regulatory drag might otherwise be a problem.

Market Creation: Payment for Ecosystem Services

The Payments for Ecosystem Services (PES) entails the creation of arrangements where individuals or communities are paid to undertake actions that increase or maintain the levels of ecosystem services. In contrast to the "polluter pays principle", PES follows the "beneficiary pays principle" in which individuals or communities whose land use (or other decisions) influence the provision of ecosystem services are compensated. The Clean Development Mechanism is perhaps the most well-known such arrangement that facilitates the payment by the global community for carbon emission reductions, to those providing the emission-reduction ecosystem service.

Liability Legislation

Liability for environmental harm is designed to compensate affected individuals or groups, with a particular focus on restoring or replacing damaged resources and/or compensating lost value (Jones, Pendergrass, Broderick, & Phelps, 2015). Litigation-oriented approaches to environmental management require only that legislation be in place that confers relatively straightforward rights and obligations to

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[11] Data from the Carbon Pricing Dashboard: https://carbonpricingdashboard.worldbank.org/map_data

[12] https://carbonpricingdashboard.worldbank.org/map_data

resource users. These approaches form a legal umbrella for court cases, which then consider the nature and extent of environmental damages on a case-by-case basis. Advocates of liability legislation argue that it is a highly efficient instrument to address externalities because it only requires monitoring of specific incidents, rather than a need to monitor behavior, as is required by regulation (Shavell, 2013). Most of these approaches are relatively new and until recently, had seen very limited application in developing countries (quite often because legal systems are themselves weak in such countries).

Citizens and NGOs have sued their government for their failure to ensure people's right to a clean environment, including clean air. Supreme Courts in countries such as Bangladesh and India have ordered national governments to take urgent measures to improve air quality. In 2019, the Indian Supreme Court declared that state governments will need to compensate their citizens if they fail to provide clean air and water.

Climate litigation has proliferated in recent years. As of May 2022, there were more than 2,000 ongoing or concluded cases of climate change litigation from around the world. The vast majority (1,426) were filed before courts in the United States and 576 were before courts in 43 other countries and 15 international or regional courts and tribunals. At least 88 cases had been filed in courts in LMICs, including 47 in Latin America and the Caribbean, 28 in Asia Pacific, and 13 cases in Africa (Setzer and Higham 2022).

Most cases have been brought against national and subnational governments or companies with the aim of enforcing climate standards. These cases generally aim to integrate climate standards, questions, or principles into governments' decision-making to stop specific harmful policies and projects, as well as to mainstream climate concerns among policymakers. Other type of litigation concerns "framework cases", in which national and subnational governments, and increasingly corporations, are sued with the aim of legally forcing them to enhance the ambition of their climate change-related targets and plans. Cases have also been filed to challenge the flow of public money to projects that are not aligned with climate action (e.g., coal-fueled power plants), with the expectation that litigation will increase the cost of capital for high emitting activities and make them economically unviable even if they remain legally permissible. Compensation cases have also grown, with defendants seeking compensation for alleged contributions to climate change harms (Setzer and Higham 2022).

Litigation specifically linked to SLCPs is expected to grow. A case against the government of the Indian state of Himachal Pradesh was filed in 2014 by an individual seeking legal action to avoid the effects of black carbon emissions on the melting of glaciers in the Himalayan region. However, as SLCPs gain prominence through the actions such as the signing of the Methane Pledge and their relationship to climate change is better understood, the number of filed cases specifically focusing on SLCP emissions is likely to increase (Setzer and Higham 2022).

Common challenges faced in developing countries include difficulties in estimating damages and the required compensation and limited accountability for ensuring that recoveries intended for restoration are actually spent to that end (Jones, Pendergrass, Broderick, & Phelps, 2015). Even in industrial countries, the use of liability legislation is hampered by the analytical difficulties of establishing cause and effect, or of ascribing blame or negligence. One of the factors that has helped to overcome this challenge in climate litigation has been the growth of climate attribution science. For example, a database[13] maintained by the Columbia University's Sabin Center for Climate Change Law included by early 2023 more than 540 scientific resources focusing on:

[13] See https://climateattribution.org/

- Climate change attribution (i.e., assessing the effects of rising concentrations of heat-trapping gases in the atmosphere on other aspects of the global climate system, including global mean temperature, sea level, and sea ice),
- Extreme event attribution (e.g., assessing the effects of a changing climate system on the probability and characteristics of extreme events),
- Impact attribution (e.g., analyzing how changes in the global climate system affect humans and ecosystems), and
- Source attribution (e.g., establishing the relative contributions of different sectors, activities, and entities to climate change).

One significant objection to using litigation-oriented mechanisms is neither environmental nor economic: it is social. Because such systems assume that all have equal access to the courts, the mechanisms often discriminate against the poor and others with limited access to legal recourse.

6. Recommendations to Integrate Air Quality and Climate Change Interventions.

Abstract

A major obstacle to build synergies between climate change mitigation and air quality management is limited awareness on the opportunities for such synergies. A good starting point is to assess whether air quality standards exist, and what air quality management strategies can be derived from their exceedance. Focusing on energy poverty is an excellent entry point to include the air pollution - black carbon agenda. There are relevant examples of projects from countries across different income levels that have contributed to integrate air quality and climate change interventions. These include investments, policy reforms, and analytical work to underpin SLCP mitigation actions.

This report aims at helping to build synergies between climate change mitigation and air quality management. A major obstacle to overcome is limited awareness on the opportunities for such synergies, which is in turn linked to the lack of robust air quality monitoring networks that can help to evidence the significance of air pollution in client countries.

A good starting point to identify potential synergies is to assess whether air quality standards exist, and what air quality management strategies can be derived from their exceedance. The WHO database on these standards is a valuable reference (WHO, 2021). Country participation in regional agreements that aim to address air pollution, such as the Convention on Long-Range Transboundary Air Pollution, the Malé Declaration (South Asia) or the ASEAN Haze Agreement are also worth noting or encouraging if they are lacking.

Focusing on energy poverty is an excellent entry point to include the air pollution - black carbon agenda. As a first approach, using World Bank (2021c) data on energy and environment can help to identify energy poverty challenges. Data and indicators can be obtained from sectors that emit black carbon emissions, such as the burning of dirty household and transportation fuels, and from agricultural burning. For instance, indicators such as access to electricity, access to clean fuels and technologies for cooking, and mean annual $PM_{2.5}$ concentrations provide excellent context on the opportunities of integrating air pollution and climate action.

Air pollution observations for both $PM_{2.5}$ and ozone, and air quality attainment status also provide local information that is very valuable to provide context on the country's air quality and capacity. These data are not always available and the reliability of those that are might be questionable. Metrics such as total air pollution monitors per million inhabitants should provide a good indicator on the measurement gap.

There are relevant examples of projects from countries across different income levels that have contributed to integrate air quality and climate change interventions. These include investments and interventions financed by the World Bank to heldp client countries mitigate SLCPs emissions from the sectors that are responsible for the largest emissions of black carbon, methane, and HFCs. The rest of this section provides a brief overview of relevant examples, as well as of their analytical underpinnings. These operations and analytical work could be replicated across LMICs interested in mitigating SLCP emissions and in building synergies between climate change mitigation and air quality management.

6.1. Investment Project Financing (IPFs)

Through **Investment Project Financing (IPF),** the World Bank provides financing to governments for activities that create physical and/or social infrastructure necessary to reduce poverty and create sustainable development. IPF also serves as a vehicle for sustained, global knowledge transfer and technical assistance.

6.1.1. Operations to Mitigate Black Carbon Emissions

Mongolia: Ulaanbaatar Clean Air Project

Ulaanbaatar, the capital of Mongolia, is among the most polluted cities in the world and air pollution levels remain high in winter, particularly in ger neighborhoods.[14] Of the 1.4 million population residing in Ulaanbaatar, more than half (about 200,000 households) live in the ger areas (slums) without access to district heating and mainly rely on stoves and small boilers burning coal and wood to meet their heating needs. It is estimated that their use of high heat emitting heating appliances has contributed to more than 60 percent of the ground level $PM_{2.5}$ concentration in Ulaanbaatar. The ground-level air pollution is also a major cause of severe respiratory diseases, putting vulnerable groups at high risk. Without ger households switching to cleaner alternatives, air quality is unlikely to significantly improve especially considering the increasing ger population (World Bank 2019a).

The Ulaanbaatar Clean Air Project (UBCAP), initially approved in 2012 and which received additional finance in 2019, was developed to enable consumers in ger areas to access heating appliances producing less particulate matter emissions and to further develop selected medium-term particulate matter abatement measures in Ulaanbaatar. The project has a strong linkage to mitigation of BC emissions because of its central focus on reducing $PM_{2.5}$ emission from coal and wood burning, which are a well-known source of BC emissions.

The project includes the following four components, three of them included in the project's original design and the last one added as part of revisions made to request additional finance (World Bank 2012; 2019a):

1. **Ger Area Particulate Matter Mitigation.** Activities under this component enabled switching households away from using polluting stoves, strengthening regulatory framework for heating appliances, and building capacity on stove producers and users. Specific activities included a stove replacement program, standards development, insulation improvement of selected residential and public houses/buildings, and technical support for stove producers and users. More than 40,000 clean stoves were distributed by the project between 2013 and 2015, exceeding the end target of 80 percent of targeted ger households.

2. **Particulate Matter Mitigation in Central Ulaanbaatar.** This component supported the completion of four studies on city greening, district heating, affordable housing, and ash pond and power plant emission monitoring. The studies were completed to help the government accelerate approval of action plans for large-scale, medium-term pollution reduction measures in key sectors. The project completed all studies, which were endorsed by the municipal government and key institutional recommendations developed under this component were adopted.

[14] Districts in which people live in gers or round removable wooden homes traditionally used by Mongolian and other Central Asian nomads.

3. **Public Awareness Raising, Program Coordination and Project Management.** The main activities implemented under this component included air quality monitoring and analysis, provision of air quality monitoring equipment, implementation of detailed public awareness program, and project management and monitoring and evaluation (M&E).

4. **Electricity for Heating in Targeted Ger Areas.** This component was included in 2019 to enable ger households in the targeted area to access modern heating appliances, such as electric thermal storage heaters. The target households are mainly those small and medium sized households that are still using traditional coal-burning stoves. The component mainly finances: (i) provision and installation of clean heating appliances at selected houses, along with needed distribution network upgrades, such as installation of two-tariff electric meters, power cable connection and wire upgrade for the last mile distribution lines from meters to selected houses; and (ii) technical assistance and capacity building on advanced heating technologies and associated program design.

The implementation of the different measures to improve air quality—among which replacing stoves with cleaner, more efficient models was the most important—has resulted in the reduction of more than 60% of $PM_{2.5}$ concentrations in Ulaanbaatar.

6.1.2. Operations to Mitigate Methane Emissions

Indonesia - Improvement of Solid Waste Management to Support Regional and Metropolitan Cities Project

Roughly 40 % of existing urban households in Indonesia do not have access to solid waste collection. The country faces the challenge of addressing this gap while also expanding its capacity to manage an annual increase of about 4,000 tons of solid waste, driven by population and waste growth. The Citarum River Watershed evidences the urgent need to improve solid waste management. According to the government's *Adipura* (2017) data, the cities and districts in the upper portion of Citarum Watershed have around 8 million residents and unacceptably low collection rates, with around 2,000 tons of waste unaccounted for every day (World Bank 2019b).

The Indonesia Improvement of Solid Waste Management to Support Regional and Metropolitan Cities Project aims to improve solid waste management services for urban populations in selected cities across Indonesia. The project comprises the following four components (World Bank 2019b):

1. **Institutional and policy development** will support institutional strengthening and capacity building of central government agencies responsible for various technical and administrative aspects of solid waste management services.

2. **Integrated planning support and capacity building for local government and communities** will finance the costs of experts and community facilitators throughout the program cycle to support capacity building (including longer-term management support, training, workshops, and knowledge exchange events between cities as well as urban sub-districts) of local governments and communities to design and manage solid waste service improvements.

3. **Solid waste infrastructure in selected cities** will support integrated solid waste management systems for Citarum watershed cities and other selected cities.

4. **Implementation support and technical assistance** will finance program management during implementation, construction supervision consultants, monitoring and evaluation, and specific technical assistance for cities and district governments receiving the investment component.

The project will directly contribute to mitigate methane emission by introducing large scale sanitary landfilling and thus collection of landfill gas. The gas generated from decomposing organic waste will be captured and, depending on scale, used for power generation or to be flared rather than released into the air as occurs with dumping. The project assumes that sanitary landfills have a 50% methane capture rate and that 75% of the methane will be used for electricity generation and the remaining 25% will be flared. Other project contributions to mitigate methane emissions include introducing composting in Indonesian cities (World Bank, 2019b).

6.1.3. Operations to Mitigate HFCs

The Bank has launched efforts specifically designed to help client countries mitigate HFC emissions, including the Efficient, Clean Cooling Initiative. Established in 2019, the initiative aims to maximize climate and development benefits from a combined strategy that links the phase-down of HFCs mandated by the Kigali Amendment with improved cooling efficiency. The initiative aims to raise awareness on the benefits of efficient cooling at senior and political levels and identify additional resources to implement actions that will lead to the phase out of HFCs.

Over the course of 2020 and 2021, the Efficient Cooling Initiative is organizing a series of virtual technical workshops and high-level roundtable events focused on identifying financial frameworks to support improvements in energy efficiency in the cooling sector together with those covered by the Multilateral Fund for the implementation of the Montreal Protocol, and increase awareness of the available energy efficient alternative refrigerants and not-in-kind solutions.

While efforts to implement the Kigali Amendment are relatively recent, the Bank has a strong track record helping client countries achieve its commitments under the Montreal Protocol. Since 1991, the Bank has supported the implementation of 700-plus investment and technical assistance phase-out activities in client countries. This has generated a phase-out of more than 500,000 tons of production and use of ozone depleting substances, which in turn has avoided emissions of more than 1.2 billion tons of CO_2 equivalent.

Since 1991, The World Bank–China Montreal Protocol partnership alone has phased-out the consumption and production of more than 219,000 tons of ozone-depleting substances from sectors as diverse as refrigeration, air-conditioning, foam manufacturing, aerosol production and fire extinguishing. The CO_2 equivalent avoided by these achievements equals 885 million tons, the same as taking 184 million-some cars off the roads.

Thailand: HCFC Phaseout Project

The objective of the Hydrochlorofluorocarbons (HCFC) Phase-out Project for Thailand is to reduce HCFC consumption in the air-conditioning and foam sectors, in line with Thailand's efforts to meet its obligations under the Montreal Protocol. The project provided sub-grants to: (i) enterprises in the foam sector to carry out HCFC consumption reduction subprojects; (ii) carry out demonstration subprojects to perform in-house testing of new non-HCFC- foam systems; (iii) 12 enterprises in the air-conditioning sector to implement HCFC consumption reduction subprojects; and (iv) enterprises for the development of non-ozone depleting substances compressors for refrigeration and air-conditioning equipment. (World Bank 2014).

The project also provided technical assistance to support phase-out of HCFCs in the air-conditioning sector through activities such as technical workshops on climate friendly refrigerants for large and small AC systems, the development and provision of train-the-trainer programs on good servicing practice for air-conditioning units using newer technologies, and inclusion of such programs in the curricula of training institutes.

6.2. Development Policy Finance

Development Policy Financing provides rapidly disbursing budget support to governments for policy and institutional actions to help achieve sustainable, shared growth and poverty reduction. Disbursements of development policy operations require that counterparts meet prior actions, which are identified during project preparation and are deemed critical to achieving the objectives of a program supported by a DPF operation.

Mexico Environmental Sustainability and Urban Resilience DPF

This DPF was proposed to as part of the World Bank support to help the Government of Mexico address the health, social and economic shocks induced by the COVID-19 pandemic. The government implemented a series of measures to face the COVID-19 crisis. The DPF was designed to complement such measures by supporting policy reforms that would enhance resilience to the shocks arising from climate change while still contributing to a more robust and sustainable medium-term recovery. The operations included eight Prior Actions (PA), with two of them being particularly relevant for this report.

One PA supported the launch and piloting of the Emissions Trading System (ETS) test program. Through its updated NDC, Mexico committed to reduce by 35% its GHG emissions by 2030, relative to a projected baseline scenario. The ETS was established to mitigate GHG emissions in a way that would stimulate innovation and economic efficiency. The ETS pilot program included all the energy (oil and gas) and industrial facilities that emitted more than 100,000 tons of CO_2 per year in 2014, 2015 and 2016. The system-wide emissions cap established for the ETS was designed to enable the Mexican government to ensure that the main GHG emitters stay under an acceptable emissions limit that is aligned with the country's NDC goals under the Paris Agreement. The design of Mexico's ETS was deemed to be reliable (with robust monitoring, reporting, and verification systems) and flexible (allowing companies to develop their own strategies to meet compliance in cost-effective ways).

The Mexican ETS Pilot Program started operating on January 1, 2020. Mexico's Secretary of Environment and Natural Resources (SEMARNAT) issued the core system's design elements and operational rules for the ETS Pilot Program, which were supported by the DFP operation. The pilot phase was designed to run for two years (2020–2021) plus a year of transition (2022) that will lead to a fully operational ETS in 2023. The Mexican ETS design and initial phase also aimed at enhancing the quality of facility-level emissions data and build capacity in emissions trading for covered entities.

During the pilot phase of Mexico's ETS program, emissions allowances were distributed at no cost by SEMARNAT to emitters in the energy and industrial sectors that met appropriate criteria. Starting in the full operational phase, the ETS will generate carbon revenue to support the country's climate policies. At the time when the DPF operation was approved, this initiative was among the most advanced and comprehensive mechanisms in Latin America and across emerging economies. Mexico was the first country in Latin America to establish a national ETS and globally, among emerging economies, only Kazakhstan and China had piloted a similar system though different in scope. Also, globally, Mexico was the only emerging economy to complement an established carbon tax with an ETS, leading to a more robust carbon pricing system.

By the project's closing date, an estimated 37% of Mexico's GHG emissions were covered by the ETS, contributing to consolidate a market-based instrument to mitigate climate change and attain the NDC.

Another PA focused on expanding Mexico's policy toolkit to address ambient air pollution, which was estimated to cause 40,000 premature deaths and 1.4 billion days of illness nationally in 2018, resulting in costs that were equivalent to 3.7% of Mexico's GDP.

The DPF supported a new norm (NOM-172-SEMARNAT-2019) to harmonize how authorities communicate information about air pollution and the associated health risks. The norm requires that state and municipal governments disseminate a color-coded index combining information on air quality and health risks. The index considers six criteria air pollutants: ozone, NO_2, SO_2, CO, PM_{10}, and $PM_{2.5}$. For each of these pollutants, the norm describes the concentration levels that are associated with five different air quality levels and health risks, as well as the associated color code (e.g., red for very bad air quality and very high health risks).

Authorities are required to update the index on an hourly basis. The norm mandates state and local authorities to disseminate messages with the activities that are advisable given different levels of air quality. The messages must include recommendations for the general population, as well as for groups that may have higher sensitivity to air pollution, including children, the elderly, and people with pulmonary or cardiovascular diseases.

The policy reform was designed to have positive environmental and social effects. The poor and other vulnerable groups are particularly at risk from AAP and COVID-19. Ambient air pollution is particularly severe in low-income neighborhoods because they are located close to pollution sources, such as factories, agriculture, or warehouses. In addition, the urban poor have less resources or access to health services to receive treatment. As a result, their immune systems tend to be less prepared to resist infections caused by viruses such as COVID-19. The NOM was designed to increase the visibility of air quality monitoring efforts and to contribute to strengthen the demand side of environmental management, thereby contributing to improve environmental conditions that benefit the poor and other vulnerable groups.

Previous actions adopted by the Government of Mexico to address atmospheric pollution have included command and control regulations, economic instruments. and administrative procedures. The policy supported by the DPF complemented these instruments by adopting procedures to provide citizens with more timely information about air pollution and measures they can take to reduce exposure in the short term, while more comprehensive action is taken to reduce air pollution levels.

By the time the DPF operation closed, information was being disseminated in compliance with the norm in six cities that have a population of more than 2 million and at least three smaller cities. According to the most recent demographic census (2020), the total population of these metropolitan areas together surpasses 43 million people, which benefitted from the reform.

6.3. Program for Results (PforR)

Program-for-Results (PforR) finance links disbursement of funds directly to the delivery of defined results, helping countries improve the design and implementation of their own development programs and achieve lasting results by strengthening institutions and building capacity.

Hebei Air Pollution Prevention and Control Program

China's JingJinJi Region, comprising Beijing, Tianjin, Hebei, and neighboring provinces, was among the highest polluted urban areas in the world. In 2012, the annual average ambient $PM_{2.5}$ concentration in Hebei was 112.9 microgram per cubic meter ($\mu g/m^3$), 12.7 $\mu g/m^3$ in Tianjin and 88 $\mu g/m^3$ in Beijing. Hebei was responsible for about 70% of the $PM_{2.5}$ emissions in the regional JingJingJi "airshed."

Hebei was the largest iron and steel producer in China, had an installed capacity for cement production that was nearly 10 times the combined production capacity of Beijing and Tianjin, and produced about 17% of national flat glass in China. These industries were the source of 54% of primary $PM_{2.5}$ emissions and the main contributor of secondary $PM_{2.5}$ emissions (43% of NO_x emissions and 63% of SO_2 emissions). Other major emissions sources included residential emissions from stalk burning and the burning of coal, mainly to fuel domestic stoves (33% of $PM_{2.5}$ emissions); the power sector, which was almost entirely fueled by coal (27% of NO_x and 20% SO_2 emissions), and transport (26% of NO_x emissions).

Hebei was also the largest agricultural producer in the region, producing more than 11% of China's wheat. With a nitrogen fertilizer application rate 5.6% above China's average and about 30% higher than the global average, agriculture emitted significant ammonia (NH_3) emissions, an important precursor of secondary $PM_{2.5}$ through its reaction with SO_2 and NO_x.

As mandated by the national government's actions to control air pollution, Hebei prepared in 2013 the Hebei Pollution Prevention and Control Implementation Action Plan (HAP) 2013–2017, with a goal of reducing $PM_{2.5}$ concentrations by 25% by 2017 compared to 2012. The World Bank financed, PforR "Hebei Air Pollution Prevention and Control Program" supported HAP implementation. The program established ambitious emissions reductions targets covering all main pollution sources, which were significantly exceeded during program implementation (**Error! Reference source not found.**).

Table 4. Indicators, Original Targets and Actual Achievements of the Hebei Air Pollution Prevention and Control Program

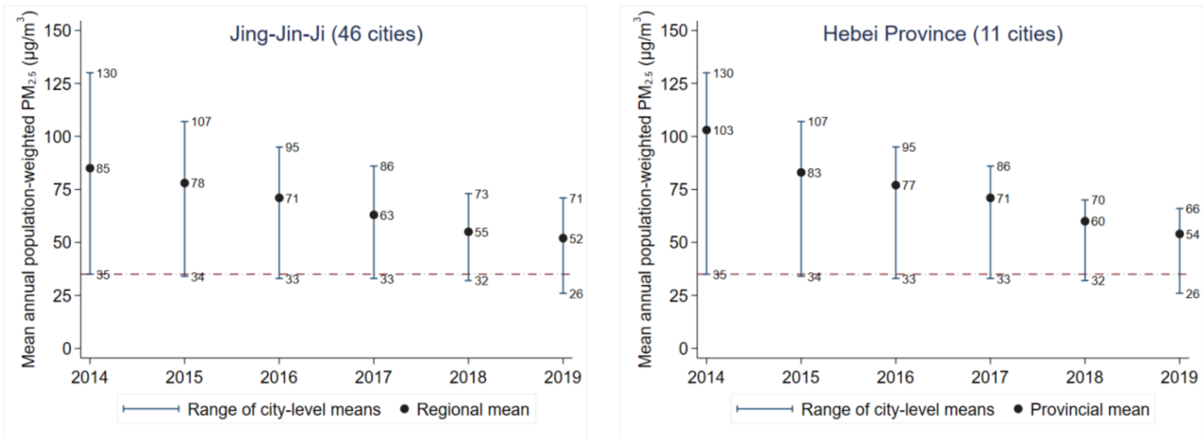
Results Areas supported	PDO indicator	Program target	Actual achievement
Results Area 1: Comprehensive control of industrial enterprises and reduced emission of multi-pollutants emissions (SO2, NOx, and primary PM2.5) from key industrial sectors	**PDO1** - Reduction of SO_2 emissions from enterprises included in the CEM (tons)	150,000	**454,000**
	PDO2 - Reduction of NOx emissions from enterprises included in the CEM (tons)	160,000	**331,100**
Results Area 2: Area pollution control and dust control	**PDO3** - Reduction of PM2.5 emissions from the 800,000 clean stoves deployed (tons)	1,300	**3,269**
Results Area 3: Prevention and control of emissions from mobile sources	**PDO4** - Reduction of NOx emissions from the transport sector (tons)	40,000	**51,272**

Source: World Bank (2020c).

The program significantly contributed to reduce $PM_{2.5}$ concentrations and the associated health risks. The mean annual population-weighted $PM_{2.5}$ in the larger JingJinJi region fell by about 33%, from 78 $\mu g/m^3$ in 2015 to 52 $\mu g/m^3$ in 2019, and about 53%, from 83 $\mu g/m^3$ in 2015 to 54 $\mu g/m^3$ in 2019 in Hebei province (**Error! Reference source not found.**). These results also managed to significantly reduce the share of population exposed to poor air quality (**Error! Reference source not found.**). The PforR directly contributed to these achievements through the reduction in primary $PM_{2.5}$ emissions, mainly though the replacement of domestic stoves, and through the mitigation of emissions of precursor gases (SO_2 and NO_x) from enterprises, agriculture, and transport.

Figure 6. Mean Annual Population-Weigthed $PM_{2.5}$ in JingJinJi and Hebei Province, 2014-19

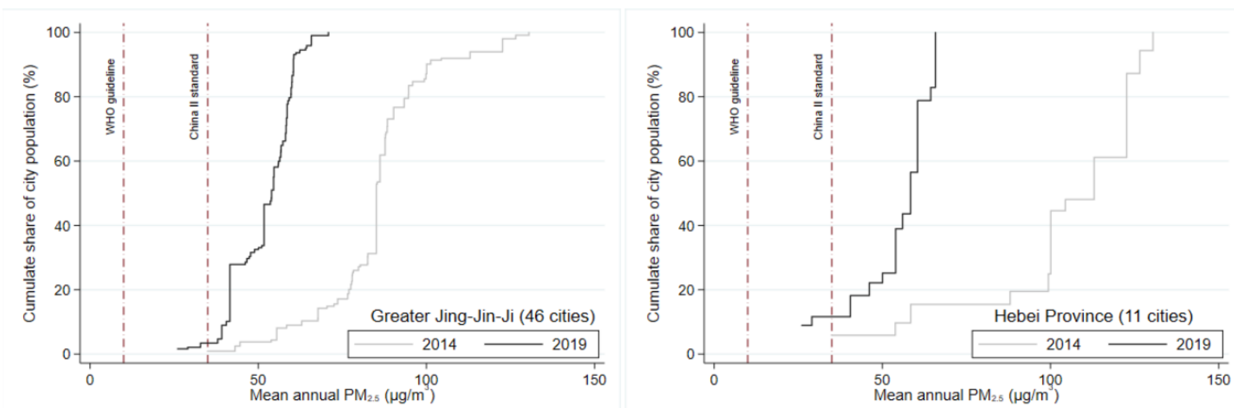
Panel A Panel B



Source: World Bank (2020c).

Figure 7. Share of Population in JingJinJi and Hebei Province Exposed to Varying Levels of Mean Annual $PM_{2.5}$ in 2014 and 2019 (%)

Panel A Panel B



Source: World Bank (2020c).

The program also achieved significant climate change co-benefits. The implementation of Hebei's air quality management measures avoided 7% of the province's overall CO_2 emissions by 2020, compared with a baseline in which no air quality action plan was implemented. This accounts to 64 million tCO_2e avoided cumulatively from 2018 to 2020. Even though the program's focus was to reduce air pollutants, it delivered about 5 million tCO_2e emissions reductions per year. By installing 1,221,500 new, clean stoves in two municipalities, the program generated over 4.4 million tCO_2e emissions reductions per year, which is equivalent to taking more than 860,000 passenger cars off the road each year. The cumulative CO_2 emissions reductions achieved through the addition of a new energy bus fleet from 2016 to 2019 is estimated at around 3 million tCO_2e.

The Program's Implementation Completion and Results Report credited the following factors as contributing to the program's significant air pollution emissions reductions:

- Interventions were multisectoral, engaging the industrial, domestic heating, agriculture, and transport sectors, which did not frequently collaborate and are managed by different agencies. This multi-sectorality was also reflected in the PforR implementation arrangements, which contemplated the establishment of a High-Level Provincial Working Group to oversee program implementation and included high-level representatives from those sectors.
- Supported measures were holistic, combining investments, policy reforms, strategic planning, and overarching monitoring and evaluation.
- Implemented measures were evidence-based and forward looking. A specific source apportionment study underpinned the inclusion of industries, the power sector, transport, and heating in the program to reduce air pollution. Agriculture was not included in the source apportionment and had not been traditionally involved in air pollution reduction in Hebei. However, research showed its ammonia emission potential and informed the decision to include the sector in the program.
- The verification protocols were carefully designed to expand the limits of national-level knowledge. They facilitated the inclusion of international good practices and standards in the selection of methodologies and quality control. For instance, the International Institute for Applied Systems Analysis was included in the data analysis and process of developing a cost-effective action plan, which helped drive innovation, efficiency, and impact.

6.4. Analytical Underpinnings

Analytical work is key to identify opportunities for building synergies between the air quality and climate agendas. It is also essential to underpin the design of specific investments and interventions. The types of analytical work described below have been instrumental in the development of relevant World Bank operations.

6.4.1. CCDRs

The World Bank Group's Climate Change Action Plan (CCAP) 2021-25 aims to advance the climate change aspects of the WBG's Green, Resilient, and Inclusive Development (GRID) approach, which pursues poverty eradication and shared prosperity with a sustainability lens. To implement CCAP, the Bank will build a strong analytical base at the global and country level, including by introducing Country Climate and Development Reports (CCDRs) that address the interplay between climate and development. CCDRs have been developed in all the World Bank regions and are being used to inform, prioritize, and sequence climate action through the country engagement process and thus implement CCAP.

These CCDRs investigate how climate change and decarbonization may impact a country's development path and priorities, and identify potential mitigation, adaptation, and resilience-building actions to improve development outcomes. They therefore support the preparation and implementation of Nationally Determined Contributions (NDCs) and Long-Term Strategies (LTSs) and feed into the WBG's

Systematic Country Diagnostics, Country Private Sector Diagnostics, and Country Partnership Frameworks.

These diagnostics also underpin country-level dialogue on policy directions and institutional strengthening. They support a "whole of economy" approach that focuses on policies and plans to create the right enabling environment for climate action and deliver transformative change, including private sector-led growth. Beyond greening projects, the aim of CCDRs is to help the World Bank on the greening of entire economies, while supporting a just transition. Explicitly incorporating SLCPs in CCDRs and linking them to air quality and other development priorities like agricultural and labor productivity provides an opportunity to target SLCPs at a strategic level. Annex 1 provides examples of CCDRs that have included linkages with air pollution and SLCP mitigation.

6.4.2. Priority Setting

Several analytical methods are available to help client countries identify the environmental challenges that are most closely associated with poverty reduction and shared prosperity. These include:

Estimating the Cost of Environmental Degradation (COED). The Bank has used this approach to estimate the economic and social effects of different types of environmental degradation. It has been useful to raise awareness of the significance of environmental challenges among policymakers, including officials from the Ministries of Finance or other sectors that are not generally involved in environmental policymaking, but who have a key role in terms of allocating resources and defining government priorities. Also, by presenting the effects of different categories of environmental degradation using a common metric (e.g., total cost, % of GDP, etc.), COED studies help to rank environmental priorities. For example, this approach was instrumental in including air pollution as a key development challenge in countries such as Lao PDR, where air pollution has a cost equivalent to more than 9% of GDP and which had received limited attention from policymakers (Sánchez-Triana et al., 2021). This approach has also been used in reports such as "Sustainability and Poverty Alleviation: Confronting Environmental Threats in Sindh, Pakistan" (Sanchez-Triana et al., 2015) and "Opportunities for Environmentally Healthy, Inclusive and Resilient Growth in Mexico's Yucatan Peninsula" (Sanchez-Triana et al., 2020).

As an initial step, stakeholders in LMICs might consider simple estimations of the health effects of air pollution and the associated costs. Simple estimations can be estimated using global databases such as the Global Burden of Disease (GBD, 2021), which can later be refined with more robust methodologies and the needs of specific cities or regions (e.g., exposure in heavily polluted locations with strong thermal inversions). Sanchez-Triana et al. (2021) describe a methodology to estimate population exposure to air pollution and the associated health effects and costs.

Distributional impacts of environmental degradation. In addition to estimating the total costs of environmental degradation, analytical work can analyze which social groups are more severely affected. Distributional analyses have been conducted as part of several environmental ASAs (World Bank 2007) that found that the impacts of environmental health damages on the poor were significantly higher than for the non-poor. The use of geographic information systems for environmental degradation data with household poverty location could be very useful to establish the distributional impacts for each type of degradation. This type of analysis can help to strengthen the rationale for building synergies between climate change mitigation and air quality management as part of client countries' efforts to fight poverty and promote shared prosperity.

Eliciting perceptions on environmental degradation. This approach focuses on conducting surveys among multiple stakeholder groups that will help to elicit their perceptions on the severity of environmental challenges, which of such challenges requires more urgent attention, and how they affect their wellbeing. Such information can be used to identify priority problems using a rigorous methodology that complements the economic analysis suggested above. This method was used by the World Bank in Colombia and the results showed that each stakeholder group had different perceptions about what constituted the most urgent environmental problem faced by the country (Sanchez-Triana, Ahmed and Awe, 2007). As an example, policymakers' perception differed markedly from those of the poor and other vulnerable groups that were particularly affected by environmental degradation.

6.4.3. Technical and Scientific Studies

This group of studies refers to analytical work that increases understanding about SLCPs' baseline emissions and their sources, informs the design of interventions to mitigate them, and generates information that can help to monitor and evaluate the results of such interventions. The Bank's Pollution Management and Environmental Health (PMEH) program supported authorities and other stakeholders in seven countries (China, Egypt, Ghana, India, Nigeria, South Africa, and Vietnam) to conduct this type of analysis and use it to design programs that address air quality management and SLCP mitigation.

- **Air quality monitoring**. This type of analytical work focuses on measuring concentrations of air pollutants in a geographic area. Ideally, this analytical work would be based on data collected through a network of ground-level air quality monitoring stations, supported by well-established quality control and quality assurance procedures. Caution should be exercised in the use of satellite-based data in areas without ground-level monitoring stations. Recent research published in peer reviewed journals, including by Alvarado et al (2019), has shown that the uncertainty in satellite-based estimates of air pollution can be very large. Adding satellite data to ground-level monitoring data may reduce the number of ground level monitoring sites needed to characterize pollution, but this needs to be determined on a case-by-case basis given that the reliability of satellite-based data is influenced by factors such as the city's location, weather, and altitude. In general, satellite-based data tends to be less reliable in coastal cities, either due to persistent clouds or the mixture of land and water surfaces.

- **Emission inventory and dispersion modeling studies** help identify the sources of pollution contributing to serious air pollution levels in the major cities and are essential for understanding the causes of air pollution. These studies generally start with an emission inventory that identifies all sources of air pollution and their contribution to the problem. Then, the emission inventory can be used in air quality (i.e., dispersion) models to assess the effects of different emission control strategies on local air quality.

- **Receptor modeling or source apportionment studies** can be used to assess strategies that will focus on the sources with the greatest contributions to the problem, and they can be prioritized in terms of cost-effectiveness.

- **Integrated climate and air quality modeling,** using models such as the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS).[15] Using the GAINS model and local data for air

[15] The GAINS model, originally developed and applied by the International Institute for Applied System Analyses (IIASA) in Austria, provides a coherent framework, calculation routines and data for systematic analysis of cost-effectiveness and cost benefits of reducing air pollution and greenhouse gases. It has served many implemented policy and investment applications in the countries of the European Union, countries covered under the Long-Range Transboundary Air Pollution Convention, and increasing number of Asian countries: e.g., China, India, Korea, Thailand, and Indonesia.

quality and emissions of GHG and SLCPs, most countries and cities supported by the PMEH were able to assess the climate co-benefits of reducing air pollutants. In cases, such as Cairo, Egypt and Hanoi, Vietnam, implementation of the NDCs at the national level would result in major improvements in air quality in the targeted urban areas.

Pezsko et al. (2022) propose an integrated air quality and climate change process that is underpinned by several of the studies described above. Such approach consists of: 1) establishing a ground-level air quality monitoring system to determine if pollution levels reach concentrations that pose health risks, 2) assessing exposure of people, ecosystems, and assets to high pollution levels and the consequent health impacts and other damages, 3) identify key emission sources based on source apportionment studies, inventories, and pollution dispersion modeling, 4) assess the costs of available technical, behavioral, and structural abatement measures, as well as the potential of these measures to reduce population's exposure to pollution, and 5) design, implement, and enforce the integrated package of regulations to incentivize firms and households to implement the prioritized abatement measures.

The impact of the most cost-effective measures to abate air pollution on climate forcing can be estimated while conducting step 4 above. Measures with high climate co-benefits can be prioritized if they do not significantly compromise air quality. Also, complementary climate mitigation measures can be assessed at this stage if the priority air pollution measures are expected to temporarily increase GHG emissions (e.g., by substituting biomass for cooking with liquified petroleum gas), of if they will reduce emissions of climate coolants (such as SO_2 and NO_x).

6.4.4. Benefit-cost analysis (BCA) of interventions to mitigate SLCP emissions.

Conducting BCAs can help to ensure that the social benefits exceed the costs of implementing interventions that mitigate SLCPS. The book "Cleaning Pakistan's Air: Policy Options to Address the Cost of Air Pollution" provides examples of CBAs for interventions to reduce air pollution (Sanchez-Triana et. al., 2014). Similarly, the book "Sustainability and Poverty Alleviation: Confronting Environmental Threats in Sindh, Pakistan" provides examples of CBAs for potential interventions to reduce both household and ambient air pollution. CBAs were also part of the analytical work that underpinned the Ulaanbaatar Clean Air Project mentioned above. This analytical work (The World Bank 2011) found that replacing existing stoves with "cleaner stoves" would yield important health benefits in the short term that significantly exceeded the costs of implementing a stove substitution program. While other alternatives, such as expanding district heating or expanding electricity-based heating might seem preferable, they were not technically or economically feasible at the time when the assessment was conducted.

6.4.5. Political economy analysis

A political economy analysis considers the formal and informal "rules of the game" and their enforcement mechanisms. The analysis generally also identifies key stakeholders and their incentives, in order to understand which groups would back the interventions supported by the project and which groups are likely to oppose them. The book "Greening Growth through Transport Sector Reforms: Strategic Environmental, Poverty and Social Assessment" includes a relevant political economy analysis for Pakistan's transport sector (Sanchez-Triana et al. 2013).

6.4.6. Institutional analysis.

This institutional analysis can help identify key gaps or constraints that might affect the implementation of the proposed interventions. They can assess the capacity of the organizations with the mandate to lead air quality and climate mitigation strategies in terms of their human resources, equipment, and capacity to monitor and follow up the project's progress towards achieving the expected outcomes. The Country Environmental Analyses for Bangladesh (World Bank 2018) and Lao PDR (Sanchez-Triana 2021) included an institutional analysis that recommended several reforms to strengthen the capacity of agencies for environmental planning, management, and monitoring and enforcement. Both analyses found that, even though ambient and household air pollution were the categories of environmental degradation that resulted in the most significant social and economic costs, they had not been identified as a priority in national plans. The institutional analyses recommended measures to improve air quality standards, laws, and regulations, as well as to strengthen the capacity of the organizational units responsible for air quality management.

6.5. Capacity Needs

LMICs frequently require technical assistance and institutional strengthening to implement air quality management and climate mitigation interventions. Support is generally needed to conduct three key functions:

1. **Coordination** among government agencies and other stakeholders that are responsible for implementing interventions across multiple sectors (e.g., energy, agriculture, fiscal policies, transportation, etc.). A common practice is to establish a multi-agency Steering Committee chaired by a high-level official. Some level of institutional strengthening is generally required, particularly when such agencies tend to work in silos. Agencies might need Bank support to develop the process to work together; identify areas of collaboration that are key to achieve the results; collect, synthesize, and manage information that is relevant for decision makers; and provide secretariat-level support to working groups to improve effectiveness and sharing of information.

2. **Implementation** of project activities. This might include responsibilities spanning project management, procurement, and financial management. While these functions are often conducted by project implementation units, it is key to use the Bank operations to build the capacity of country organizations to conduct them.

3. **Monitoring and evaluation.** Measuring progress in achieving improved outcomes requires qualified staff, infrastructure, and budgets. For instance, programs designed to mitigate BC emissions will require actual monitoring of BC, or at least $PM_{2.5}$ to: (1) determine the levels of air quality at the locations proposed for interventions in the project, including for establishing the baseline and to enable the measurement and monitoring of the outcomes of the interventions; (2) determining air quality trends that are affected by changes in the economy and changes in population, and the effect of the project and other relevant interventions. In addition, data collected as part of this M&E framework should undergo rigorous quality assurance and quality control, potentially including periodic audits of the air monitoring system (equipment, data transfer and staff) to ensure that the monitoring program is providing accurate data on an ongoing basis. Depending on the existing institutional capacity in place, organizations might need support in areas such as procuring appropriate hardware and software facilities,

conducting selected studies, training of personnel to oversee the different functions, improvements to the reporting and use of air quality information for planning, informing the public (via website and other media), and developing public alert systems.

7. Conclusions

Abstract

Scientific evidence shows that reducing SLCPs is needed to slow the rate of global warming in the first half of this century, as well as to stabilize the climate and achieve the goals of the Paris Agreement. Integrating the air quality and climate change mitigation agendas also offers opportunities to build wider support for climate action. By delivering clean air, health, and productivity benefits "here and now," strategies that focus on mitigating SLCPs can strengthen support for climate action. It is technically feasible to reduce SLCP emissions from all key sources, often through interventions that are low cost or that would result in net savings. Most countries do not have specific commitments on mitigation of SCLPs. In contrast, air pollution management has stronger regulatory frameworks that were adopted in most countries before climate action frameworks. The tradeoffs between air quality and climate mitigation goals need to be assessed carefully.

Air pollution and climate change are humanity's biggest environmental challenges, both current and in the future. Air pollution kills around 7 million people year and causes multiple illnesses with significant consequences, including reduced labor and agricultural productivity. The deaths and illnesses caused by air pollution have an estimated cost of 8.1 trillion dollars per year, equivalent to 6.1% of global GDP (World Bank, 2021a). The impacts of climate change are already evident and expected to rise, causing losses that could be equivalent to almost 25% of global GDP by the end of the century and confirming that it the biggest environmental threat towards the planet's future. Tackling air pollution and climate change at once is crucial.

Mitigating emissions of short-lived climate pollutants (SLCP) offers opportunities to build synergies between air pollution and climate mitigation solutions. Scientific evidence clearly shows that reducing SLCPs is needed to slow the rate of global warming in the first half of this century, as well as to stabilize the climate and achieve the goals of the Paris Agreement. In addition, integrating the air quality and climate change mitigation agendas also offers opportunities to build wider support for climate action. By delivering clean air, health, and productivity benefits "here and now," strategies that focus on mitigating SLCPs can strengthen support for climate action. In LMICs, where 90% of deaths due to air pollution occur, the prospects of saving lives and reducing illnesses in the short term can gain public and political support for climate action.

It is technically feasible to reduce SLCP emissions from all key sources, often through interventions that are low cost or that would result in net savings. Interventions that would reduce black carbon emissions such as substituting solid fuels with cleaner fuels for cooking and heating, improving solid waste management to reduce burning of waste, and introducing low-sulfur diesel frequently generate health and other benefits that significantly outweigh the cost of implementing them (Sanchez-Triana, 2021). In the case of methane, where more comprehensive assessments have been conducted to date, low-cost controls of less than $600 per ton of methane (~$20/t$CO_2$e) have the potential to abate at least half of the abatement potential estimated for each sector (**Error! Reference source not found.**).

Table 5. Abatement Costs of Methane Emissions in Key Sectors

Sector	Cost Category	Abatement cost per ton of methane	Estimated Abatement Potential (Mt per year of methane emissions by 2030)
Livestock	Average cost (tCH_4) Average cost (tCO_2e) Range of all abatement costs (tCH_4) Average abatement cost through low-cost controls (tCH_4)	\$850/tCH_4 ~\$30/tCO_2e \$400 to 1,000/tCH_4 \$-360/tCH_4	19 Mt/yr 14 Mt/yr
Rice cultivation	Average cost (tCH_4) Average cost (tCO_2e) Range of all abatement costs (tCH_4) Average abatement cost through low-cost controls (tCH_4)	\$1,700/tCH_4 ~\$60/tCO_2e \$150 to \$3100/tCH_4 \$23/tCH_4	8 Mt/yr 4.5 Mt/yr
Coal Mining	Average cost (tCH_4) Average cost (tCO_2e) Range of all abatement costs (tCH_4) Average abatement cost through low-cost controls (tCH_4)	\$340/tCH_4 ~\$12/tCO_2e \$160 to \$700/tCH_4 \$116/tCH_4	17 Mt/yr 14 Mt/yr
Oil and Gas	Average cost (tCH_4) Average cost (tCO_2e) Range of all abatement costs (tCH_4) Average abatement cost through low-cost controls (tCH_4)	\$520/tCH_4 ~\$18/tCO_2e -\$660 to \$2300 /tCH_4 -\$370/tCH_4	40 Mt/yr 23 Mt/yr
Biomass burning	N/A	N/A	11 to 24 Mt/yr
Waste	Average cost (tCH_4) Average cost (tCO_2e) Range of all abatement costs (tCH_4) Average abatement cost through low-cost controls (tCH_4) Average cost across all measures that capture methane and utilize it for electricity generation	-\$230/tCH_4 -\$8/tCO_2e -\$5,800 to \$3,900/tCH_4 -\$4300/tCH_4 -\$1800/tCH_4	30 Mt/yr 16 Mt/yr 8 Mt/yr

Source: Authors, based on sources discussed in Chapter 3. Note: Low-cost interventions abate emission at a cost of ≤\$600 per ton of methane (~\$20/tCO2e)

Most countries do not have specific commitments on mitigation of SCLPs. As of April 2022, less than 10 countries explicitly mentioned black carbon in their NDC. Out of the 119 countries that had endorsed the Methane Pledge by October 2022, 96 included methane as part of their overall GHG reduction target, but only 15 had set specific methane mitigation targets (Fransen et al, 2022).

In contrast, air pollution management has stronger regulatory frameworks that were adopted in most countries before climate action frameworks. These frameworks generally set limits on the concentrations of air pollutants (including $PM_{2.5}$, PM_{10}, and ozone). When they are exceeded, attainment plans are designed to reduce emissions of the pollutants and their precursors, with the objective to meet the standard. Because these plans focus on controlling emissions from sources that also emit SLCPs and GHG, they have large coincidences with decarbonization strategies and can be an excellent entry point to promote SLCP mitigation.

Different policy instruments are available to mitigate SLCP emissions, which have been tested in low-, middle- and high-income countries. These range from fines or sanctions that are linked to traditional command-and-control regulations to laissez-faire approaches that require consumer advocacy or private litigation to act as incentives for improving environmental outcomes.

Economic instruments have been used to tackle air pollutants and greenhouse gas emissions, and are starting to focus on SLCPs. As of 2022, 47 national and 36 sub-national governments had adopted or were analyzing the adoption of taxes, emissions trading systems, or a combination of both to promote the transition to a decarbonized economy.[16] Norway has imposed a tax on methane emissions from oil and natural gas operators and the US Inflation Reduction Act contemplates the establishment of a methane fee. Shipping will be included in the European Union's Emissions Trading System. This will only cover CO_2 during 2024 and 2025, but emissions of NOx, soot, and methane will be included from 2026. Reforming subsidies in agriculture and energy sectors could reduce methane and other GHG emissions, while also freeing resources that could be used to support climate action.

Climate litigation has proliferated in recent years and at least 88 cases have been filed in courts in Low- and Middle-Income Countries. Cases have different objectives, including suing governments and corporation for failing to enforce climate standard or with the aim of forcing them to enhance the ambition of their climate change-related targets and plans. Cases have also been filed to challenge the flow of public money to projects that are not aligned with climate action and from defendants seeking compensation for alleged contributions to climate change harms. Litigation specifically linked to SLCPs is expected to grow as SLCPs gain prominence and their relationship to climate change is better understood (Setzer and Higham 2022).

Successful projects have been implemented in LMICs to mitigate SLCP emissions. As discussed in Chapter 6, investments and policy reforms, underpinned by rigorous analytical work, have been instrumental to mitigate methane, black carbon and HFCs. As illustrated by the Hebei Air Pollution Prevention and Control Program, achieving large scale reductions in air pollutants and climate warmers calls for multisectoral interventions; holistic measures that combine investments, policy reforms, strategic planning, and monitoring and evaluation; and a rigorous, forward looking evidence base.

A major obstacle to overcome in trying to build synergies between air quality and climate mitigation goals is limited awareness on the opportunities for such synergies. This is generally linked to the lack of robust air quality monitoring networks that can help to evidence the significance of air pollution in client countries.

A good starting point to identify potential synergies is to assess whether air quality standards exist, and what air quality management strategies can be derived from their exceedance. The WHO database on these standards is a valuable reference (WHO, 2021). Country participation in regional agreements that aim to address air pollution, such as the Convention on Long-Range Transboundary Air

[16] Data from the Carbon Pricing Dashboard: https://carbonpricingdashboard.worldbank.org/map_data

Pollution, the Malé Declaration (South Asia) or the ASEAN Haze Agreement are also worth noting or encouraging if they are lacking.

Focusing on energy poverty is an excellent entry point to include the air pollution - black carbon agenda. As a first approach, using World Bank (2021c) data on energy and environment can help to identify energy poverty challenges. Data and indicators can be obtained from sectors that emit black carbon emissions, such as the burning of dirty household and transportation fuels, and from agricultural burning. For instance, indicators such as access to electricity, access to clean fuels and technologies for cooking, and mean annual $PM_{2.5}$ concentrations provide excellent context on the opportunities of integrating air pollution and climate action.

Air pollution observations for both $PM_{2.5}$ and ozone, and air quality attainment status also provide local information that is very valuable to provide context on the country's air quality and capacity. These data are not always available and the reliability of those that are might be questionable. Metrics such as total air pollution monitors per million inhabitants should provide a good indicator on the measurement gap.

The tradeoffs between air quality and climate mitigation goals need to be assessed carefully. Promoting electrification of the transport, industrial, and residential sectors, and advancing the use of hydrogen could help to reduce tail-pipe emissions of air pollutants; however, the effects of these measures on upstream emissions of air pollutants and GHGs will depend on the fuels used to produce electricity and hydrogen. Using conventional coal and gas sources could increase both types of emissions (Nature Communications 2021).

Generally speaking, tradeoffs arise can when an air pollutant that is hazardous for human health has a cooling effect on the planet. Examples include SO_2, NO_X, ammonia, organic carbon, and second inorganic aerosols. Other tradeoffs can become evident when designing policies that incentivize the use of one fuel source versus its alternatives. Interventions to reduce household air pollution generally consist of the substitution of biomass for cooking and heating with bottled liquefied petroleum gas, natural gas, or electricity and district heating fired by fossil fuels. While this substitution results in immediate reductions of $PM_{2.5}$ (and black carbon) emissions, with significant health benefits, it also leads to increased GHG emissions. Taxing GHGs or increasing energy costs can work in the opposite direction, incentivizing the reduction of GHG emissions but forcing low-income households to revert to the use of "dirtier" biomass (Pezsko et al., 2022).

Some measures may contribute to address one issue, but not both. Requiring end-of-pipe emission controls on coal fired power plants can reduce their air pollution emissions but dot mitigate GHG emissions (Nature Communications 2021). For instance, Zhang et al (2022) assessed city-level trends in $PM_{2.5}$, ozone, and CO_2 during 2015-2019 in 335 cities in China. They found significant reductions in $PM_{2.5}$ concentrations in cities with mandatory city-level reduction targets, especially in the Beijing-Tianjin-Hebe region. However, concentrations of ozone and CO_2 emissions increased in 91% and 69% of Chinese cities, respectively. To address both challenges holistically, the authors suggest complementing existing air quality measures with mandatory city-level CO_2 emission reduction targets and reinforcing clean energy and energy efficiency measures.

This report aims to seize on the opportunity to promote climate action from the point of view of development priorities in LMICs. To that end, the previous chapters provided an overview of the most recent scientific information on SLCPs using a language that is accessible by a broad audience. It also aims to facilitate a better understanding about how to integrate air quality and climate agendas and therefore references tools that can be used to achieve this goal by targeting SLCPs. These linkages provide a strong rationale for advancing strategies that integrate air pollution and climate mitigation as the fastest path to clean air and a safer climate future. Previous chapters also provided tools to strengthen the design of interventions that LMICs can use to achieve the goals of such strategies on their own, as well as with support from the World Bank and other development partners. The design and implementation of such strategies are key to achieve countries' Nationally Determined Contributions (NDCs) and can also deliver immediate and direct health and economic benefits.

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Annex 1. Incorporation of Short-Lived Climate Pollutants (SLCPs) in CCDRs

Several CCDRs have explicitly addressed the linkages between climate change and pollution management, including those of Argentina, Bangladesh, Brazil, Honduras, Kazakhstan, Pakistan, Rwande, Türkiye, Vietnam. Key linkages include:

- **Air pollutants and greenhouse gases (GHGs) are emitted by the same sources.** Fossil fuel combustion in vehicles, industry, and power plants, as well as biofuel burning for cooking and heating are examples of activities that contribute to both air pollution and climate change. Unlike GHGs, air pollutants have been regulated for years in most countries through air quality standards that are designed to reduce exposure (i.e., the pollution concentrations that people breathe). When they are exceeded, attainment plans are designed to reduce emissions of the pollutants and their precursors, with the objective to meet the standard. These plans have large coincidences with decarbonization strategies that the CCDRs acknowledge.
- **Discussing the role of short-lived climate pollutants (SLCPs) as climate warmers and health damaging air pollutants.** SLCPs include black carbon (BC) and methane. Both have a much higher global warming potential than carbon dioxide, but their atmospheric lifetime is much shorter, making them the strongest lever available to slow the rate of warming and the mounting toll of extreme weather events in the first half of this century. Several CCDRs recognize the importance of reducing methane as part of their commitments under the Global Methane Pledge and highlight the opportunity to integrate circular economy approaches in sectors such as solid and agricultural waste and wastewater treatment to mitigate methane emissions, reduce pollution, and generate energy, organic fertilizers, and other valuable resources.
- **Recognizing the significant health, economic, and social co-benefits of climate action.** BC is both an SLCP and a component of fine particulate matter ($PM_{2.5}$) and methane is one of the main precursors to surface ozone, a pollutant toxic to both people and plants. In addition to warming the planet, black carbon and methane (through ozone formation) contributed to hazardous air pollution levels that resulted in around 7 million premature deaths in 2019 and contributed to many additional morbidity impacts, including asthma cases, hospitalizations, lost workdays, missed school days, preterm births, diabetes, and cognitive decline. As such, CCDRs recognize that reductions in SLCP emissions can have beneficial effects on development via improvements in human health, labor productivity, and agricultural productivity resulting from cleaner air, as well as those benefits that occur via reduced climate change. Several CCDRs include economic analysis and note that, when co-benefits are considered, achievement of climate goals, including those that are part of NDCs, would yield net economic benefits. When these goals are achieved through the reduction of fossil fuels and other fiscal and economic instruments, climate action also contributes to improved fiscal sustainability and allows governments to reallocate spending towards other activities (e.g., public transportation, deployment of renewable energies and energy efficiency technologies, promotion of resilient farming practices, etc.) that would result in better development outcomes.
- **Recognizing that an integrated air-pollution and climate-mitigation strategy is the fastest path for achieving cleaner air and a safer climate.** The design and implementation of such strategy is key to achieve countries' NDCs and can also deliver immediate and direct health and economic benefits. Emphasizing the health benefits that air quality management can deliver "here and now" can be used to encourage climate action that will bring global and future benefits, since health is generally at the top of most national political agendas and has become an even more pressing issue because of the COVID-19 pandemic. Linking health to the air-pollution agenda, and ultimately to the climate agenda, allows better public and political support for mitigation efforts.

The following excerpts from several CCDRs further illustrate the issues above.

1. Emissions

"Although Vietnam only contributes about 0.8 percent of global GHG emissions, mitigation measures are in the national self-interest. Measures that reduce GHG emissions would also abate severe air pollution in the main urban centers, which the World Health Organization (WHO) estimates to cause about 60,000 deaths annually, imposing large economic costs through health and productivity losses. Moreover, multinational companies and consumers in Vietnam's main export markets are shifting toward a low-carbon economy. To remain competitive, Vietnam will need to decarbonize its energy sector and take actions in the agriculture, transport, and manufacturing sectors" – *Vietnam CCDR, pg. 2*

"The agriculture sector is the second-largest contributor of GHG emissions in Vietnam, at about 19 percent of total emissions in 2020. Rice production accounts for about 48 percent of those emissions, followed by enteric fermentation in livestock production (15.3 percent), synthetic fertilizer application (12.9 percent), and manure management (9.5 percent). A unique feature of the sector's GHG emissions is that more than 70 percent are methane and nitrous oxide, not carbon dioxide (CO2). Methane and nitrous oxide both have far shorter atmospheric lifetimes than CO2, but they are also many times more potent, so reducing them would have a rapid and powerful impact in reducing near-term warming." – *Vietnam CCDR, pg. 49*

"The [resilient and net zero pathway] RNZP illustrates the feasibility and overall benefits of aligning development with climate-related goals. As Türkiye imports 99 percent of its gas and 93 percent of its oil, energy efficiency and renewable energy could generate major benefits by reducing air pollution, energy imports and expenditure, and vulnerability to disruptions in global energy markets. When all costs and co-benefits are accounted for, the net economic impact of the RNZP is positive over 2022–30, and it increases when considering longer-term horizons: the RNZP leads to a net $15 billion gain over 2022–30 and a $146 billion gain over 2022–40, largely due to reduced fuel imports and health benefits from decreasing air pollution" – *Turkiye CCDR, pg. 9*

"The energy sector—which includes the power, transport, building, and industrial sectors—is the country's single largest contributor to greenhouse gas (GHG) emissions, accounting for threequarters of total emissions. Türkiye imports 99 percent of its gas and 93 percent of its oil, making it heavily exposed to supply disruptions and price volatility in global and regional energy markets, and to the consequences of global crises, such as the war in Ukraine. Boosting energy efficiency and renewable energy could generate major benefits by reducing energy imports, expenditures, and air pollution." – *Turkiye CCDR, pg. 22*

"Emissions from livestock dominate the emissions profile of Rwanda. Based on BUR1, the agriculture, forestry, and other land use (AFOLU) sector accounts for approximately 74%, or 6.26 MtCO2e, with emissions from livestock contributing the most. Energy accounts for 18%, or 1.54 MtCO2e, of the total, mainly from energy combustion in households, and gasoline and diesel use in road transport, with only a small contribution from the country's predominantly hydro-based power generation sector. Industrial processes and product use (IPPU) accounts for just 1% of the total, or 0.08 MtCO2e, mainly representing emissions due to calcination from domestic clinker production. The waste sector accounts for around 8% of the total (0.64 MtCO2e), mainly methane emissions from solid waste disposal sites at unmanaged dumpsites, and from waste-water treatment and discharge." – *Rwanda CCDR, pg. 22*

"According to the alternative GHG pathway, Rwanda's emissions from its waste and industrial processes sectors can be reduced by 48% compared to the NDC pathway + FOLU scenario by 2050. Under the NDC pathway + FOLU scenario, emissions from the waste and IPPU sectors are forecast to increase to approximately 2.6 MtCO2e by 2050. Under the alternative GHG scenario, emissions of 1.4 MtCO2e in 2050 is plausible. The emissions reduction of 0.1 MtCO2e is expected from achieving the additional substitution of clinker in cement production by 2050, with a very small emissions reduction potential from substituting ozone-depleting substances (ODS). In the waste sector, additional efforts in relation to sustainable waste practices—namely wastewater treatment, landfill gas utilization, composting and waste-to-energy (WtE) mitigation measures—are seen to be much more significant drivers of emission reduction outcomes; they also have important co-benefits—such as, improved sanitation, revenue generation and green employment potential." *– Rwanda CCDR, pg. 25*

"Brazil has one of the most decarbonized energy sectors in the world. Renewables account for roughly 48 percent of the Brazilian energy matrix and over 80 percent of its power matrix, compared to world averages of approximately 15 percent and 27 percent, respectively." – Brazil CCDR, pg. 9

"Emissions are reduced thanks to modal shifts towards rail and waterways from road transportation, and higher participation of public transport in urban areas. Ministry of Science and Technology (MCTI) assumptions (of reductions in emission by 2050 compared to 2020) were used for waste (16 percent), energy use in industry and agriculture (10 to 20 percent over the three decades), fuel production (23.5 percent by 2050), buildings (50 percent), fugitive emissions (90 percent), and constant emission for bunker fuels". *– Brazil CCDR, pg. 37*

"The dominant use of coal and other solid fuels contributes significantly to local air pollution. Kazakhstan's building stock is also relatively inefficient, requiring greater levels of energy to heat. Kazakhstan's residential buildings consume 270 kWh/m2 - which is more than double that in Europe (100-120 kWh/m2) and much higher than even neighboring Russia (210 kWh/m2). There is, therefore, huge potential to reduce emissions from the building stock through both supply and demand side measures." *– Kazakhstan CCDR, pg. 29*

"Pakistan is the world's fourth-most polluted country. WHO air quality limits are regularly exceeded in all parts of the country. In Pakistan, air pollution results primarily from the burning of fossil fuels and biomass, industrial processes, especially steel and cement, brick kilns, and road traffic. The most harmful emissions are fine particulate matter or PM2.5 and NOX that can be easily inhaled, and pose high health risks of respiratory infections, cardiovascular diseases, and lung cancer." *– Pakistan CCDR, pg. 23*

"Mitigation measures in urban transport can help reduce air pollution, improving liveability. The transport sector represents around 23 percent of the total GHG emissions of Pakistan, 57 percent of which is specifically urban. (…) It is estimated that inefficiencies in the urban transport sector cost Pakistan 4 to 6% of its GDP every year. Decarbonizing urban passenger transport in the country will require encouraging the use of: (i) sustainable mass transit public transport (including non-motorized transport); (ii) using travel demand management to appropriately price the negative externalities of vehicle use and nudge travel toward sustainable alternatives; (iii) facilitating the adoption of innovative technologies; and (iv) cleaner fuels. EVs can play a major role in the longer term yielding ~57% of emission reduction from the passenger sector by 2050 even though they are not having a significant impact through 2030." *– Pakistan CCDR, pg. 45*

2. **Short-lived climate pollutants (black carbon, ozone, methane)**

"Several options were analyzed for an economywide carbon tax. The most modest option would start at about $12 per tCO2e in 2022, which is the weighted average of the EPT rate on coal, diesel, and gasoline, and ramp up to $40 per tCO2e by 2040. The two other options are to ramp up to $90 or to $120 per tCO2e by 2040 (from the same starting point). The $90 option appears sufficient to generate the necessary changes in emitting activities. Combined with sectoral investments, the $90 tax would reduce emissions by 42.8 percent relative to the BAU scenario by 2030, and 73.6 percent by 2040. The reduction would mainly be driven by the gradual increase in the carbon tax, technology shifts in manufacturing/ trade, and the transition of the energy sector away from coal. The power sector would make the greatest contributions to GHG emission reductions, followed by manufacturing, transport, and agriculture." *Vietnam CCDR, pg. 35*

"The new strategies have yet to be translated into significant changes in Vietnam's fiscal policy. For example, some progress has been made toward the development of carbon pricing instruments, but such instruments are not yet implemented at scale. The existing carbon tax — the Environmental Protection Tax (EPT) — is around $0.50 per tCO2e on coal, $77.60 per tCO2e on gasoline, and $32.90 per tCO2e on diesel, lower than most countries and too low to incentivize large-scale decarbonization. However, the authorities have demonstrated a strong interest in using quantity-based caps in a trading system (under preparation with WBG support) and have started to shift subsidies from petroleum to renewable sources of energy, which contributed to a private investment boom in solar energy in 2020.19 On the expenditure front, a recent analysis of six key ministries found climate-related spending varied annually from 2016 to 2020, but held relatively steady, ranging from 26 to 38 percent of the ministries 'combined budgets.20 About 25 percent of public capital expenditures were fully or partially directed to adaptation, mainly in irrigation and transport projects" – *Vietnam CCDR, pg. 12*

"The agriculture and food sector is both part of the climate problem and an important contributor to its solution. It is relatively carbon intensive, compared with the rest of the economy, representing 13 percent of total 2019 GHG emissions, 62 percent of methane emissions, and 73 percent of all nitrous oxide emissions. Emissions from agriculture relate primarily to enteric fermentation (especially dairy and non-dairy cattle), agricultural soils (mainly fertilizer use), and manure management. Many solutions are available to reduce emissions from these activities, such as improved feed and forage/pasture management, proper treatment and storage of manure, nutrient management, and reduced food loss and waste. The sector also offers considerable potential for carbon sequestration via carbon farming and nature-based solutions applied to agriculture land. Through a proper mix of policy instruments and support, implementing such measures can, gradually, be achieved at scale." – *Turkiye CCDR, pg. 49*

"Methane emissions in 2018 accounted for 23 percent of GHGs, with 73 percent of these from the agriculture, livestock, forestry, and other land uses sector, 19 percent from waste, and 8 percent from energy production. In 2018, Argentina was in the top 12 methane-emitting countries. It is a signatory of the COP26 Global Methane Pledge, which aims to collectively reduce global anthropogenic methane emissions across all sectors by at least 30 percent of 2020 levels by 2030. The largest potential to reduce methane is in the livestock sector, which accounted for 69 percent of methane generated in Argentina in 2018, on solid waste methane emissions capture, and on oil and gas fugitive methane emission reductions." – *Argentina CCDR, pg. 7*

"Revenues generated through a carbon tax could make meaningfully contribute to climate financing. A US$ 10 carbon price is estimated to result in an additional annual revenue of 0.9 percent of GDP in 2030. Additional revenue from the carbon tax could potentially be earmarked for promoting domestic equity and transition to a greener economy. Government debt is not particularly high and available resources could be used to dampen the contractionary impact on real variables. In the illustrated simulation the government channels the generated resources to increase public investments, current spending, and household transfers. As shown in figure 19, that would offset negative effects of carbon tax and lead to neutral or positive GDP outcomes throughout the considered period. In addition, welfare benefits are expected to further offset the potential economic costs. These benefits consist of (i) air pollution co-benefits, including health; (ii) transport co-benefits (averted road accidents, reduced road damage and reduced congestion as fewer passenger vehicles are on the road); as well as (iii) global climate (contribution to the global warming reduction) benefits." *– Bangladesh CCDR, pg. 72*

"The government has achieved important progress regarding incorporating climate change actions into planning and budgeting instruments. The *Checklist for Environment and Climate Change Mainstreaming* helps sectors and districts integrate climate change actions established in the NST, NDC, and GGCRS in their action plans. The checklist extracts the programs, outputs, and indicators established in these three high-level documents and assigns them to the responsible agencies with targets and deliverables. This mainstreaming approach has achieved greater progress at the sectoral-ministries level (with over 60% of key environmental and climate change indicators integrated in sectoral action plans) than at the district level (with less than 30% of indicators integrated into district action plans*." – Rwanda CCDR, pg. 32*

"To illustrate the potential of a carbon tax to simplify and streamline Brazil's tax system, analysis shows the introduction of an economy-wide upstream carbon charge on fossil fuels starting at R$75 (~US$14) per tCO2 at the beginning of 2022, and rising to R$350 (~US$67) in real terms by 2030, can be a substantial source of revenues in the coming decade. The carbon charge would raise about R$150 billion (US$31 billion, or 1.3 percent of GDP) in additional revenues in 2030 from fossil fuels against a baseline of maintaining the existing excise regime." *– Brazil CCDR, pg. 27*

"Solid waste management represents an important component in reducing GHG (notably methane) emissions in Brazil's cities. For example, GHG emissions inventories for Rio de Janeiro, Salvador, Curitiba, and São Paulo show that 22 percent (0.5 tCO2e per capita), 16 percent (0.13 tCO2e per capita), 8.6 percent (0.2 tCO2e per capita), and 8.2 percent (0.11 tCO2e per capita) of the respective cities ' emissions are from the solid waste sector." *– Brazil CCDR, pg. 56*

"Kazakhstan has established a solid starting framework for tackling climate change but will need to substantially strengthen its policy ambition if it is to meet its climate goals. Since making its first international emissions reduction commitment in 2012, Kazakhstan has introduced an emissions trading scheme (ETS), renewable energy auctions, energy efficiency legislation, green projects taxonomy, and a range of measures to reduce transport emissions." – Kazakhstan CCDR, pg. 15

"Landscape based carbon sequestration needs more study but has significant potential to provide an important net carbon sink that can offset the more expensive abatement from hard-to-abate sectors and reduce the cost of achieving net-zero. Based on the existing information, the potential for sequestration in rangelands, pasturelands, and forests in 2060 could be between a conservative estimate of 20 million tCO2-e/year to an ambitious estimate of 40 million tCO2-e/year, and would cost US$ 62-124 million per year from 2022-2060." *– Kazakhstan CCDR, pg. 22*

"In recent years, however, the government has assumed a strongly proactive stance toward climate change. As a consequence, climate change-relevant policy is being strengthened. Despite its infancy, the five-year-old Ministry of Climate Change (MoCC), established in 2017, has already assumed and centralized several major responsibilities and gained oversight of key functions of environmental action and disaster risk management (…). In 2021, a revised NCCP was launched, linking climate action and economic growth, with a strong focus on mainstreaming and integrating climate change policy with other policies. There have been several other meaningful developments. For example, a number of new sectoral policies that support decarbonization effort were adopted. Additionally, the 2019 Alternative Renewable Energy (ARE) Policy aims at creating an environment and framework for sustainable growth of Pakistan's ARE sector. Energy efficiency and conservation are now supported by the Strategic Plan for Energy Efficiency & Conservation (2020–2023), and the National Electric Vehicle Policy (NVEP) 2020–

2025 is promoting the development of the transport supply chain (for example, reduced import duties on batteries and charging equipment) and the use of electric vehicles (EVs)." – *Pakistan CCDR, pg. 25*

3. **Impacts on health, competitiveness, etc.**

"Prioritizing actions to reduce air pollution: Several key measures to reduce GHG emissions, such as shifting away from coal power, reducing traffic congestion, reducing transport emissions, and improving farming and livestock practices, can also significantly reduce air pollution. That, in turn, can improve human health and labor productivity. This expected co-benefit was considered in the CGE model by assuming that a one percent decrease in air pollution augments labor productivity by 0.3 percent. As shown in Table 4, that would result in GDP being 0.8 percent higher in the NZP in 2030 than in the BAU scenario. In 2040, GDP would still be lower than in the BAU scenario, but only by one percent, instead of 2.2 percent. Prioritizing actions in areas with severe air pollution, such as around Hanoi, can heighten the economic benefits of decarbonization" – *Vietnam CCDR, pg. 36*

"Türkiye has made progress in reducing air pollution, but health costs remain high relative to higher income countries. Although the growth in nitrogen dioxide (NO2) and particulate matter less than 10 micrometers in diameter (PM10), has been stable or declining relative to Türkiye's economic growth, sulphur dioxide (SO2) and particulate matter less than 2.5 micrometers in diameter (PM2.5) emissions have increased, but at a slower rate than economic growth. Given its link to human health, the growth in PM2.5 is concerning, and its economic cost is equivalent to more than 5 percent of GDP." – *Turkiye CCDR, pg. 21*

"Improving waste management can reduce GHG emissions and generate significant positive environmental and health outcome. Decreasing open dumping by 50 percentage points by 2035 could reduce GHG emissions from improperly managed waste by 85 percent compared with 2020. Substantial co-benefits would include reduced soil and marine pollution; better local health and environmental outcomes; improved quality and access to a basic local government service; a more integrated informal sector; enhanced public environmental awareness; and stronger local economic development, city competitiveness, and livability conditions." – *Turkiye CCDR, pg. 46-47*

"The elimination of subsidies and the increase in the carbon price entails GHG emission reductions as well as other co-benefits, such as the reduction of deaths related to air pollution and road fatalities. The simulated policy of explicit subsidies removal and an increase in the carbon tax to $31/tCO2e in 2022 would imply different GHG emissions reduction relative to the baseline, which varies according to the way carbon tax revenues are recycled. For instance, subsidies 'removal implies a 15 percent GHG emissions reduction in 2030 relative to the baseline, while the increase in the carbon price (in a savings scenario) implies another 12 percent of emissions reduction. Other revenue recycling option entails different GHG emission reduction path, given their different impacts on GDP growth. Besides, in the period 2023-2030, nearly 4,600 premature air pollution deaths and 3,400 road fatalities could be avoided." – *Argentina CCDR, pg. 71*

"There are significant income and health co-benefits of decarbonization (such as improved air quality and health, increase energy efficiency and security, reduced food loss and waste). Demand and supply side energy efficiency can reduce overall costs reduce waste and increase incomes. Public investment in public mass transit and modal shifts could alleviate potential pressures on existing public transport systems. Improving livestock productivity can increase incomes and reduce emissions. But the biggest co-benefits come from improved air quality. A comprehensive Clean Air Program will have substantive impact on improved health conditions, while also reducing GHG emissions and Short-Lived Climate Pollutants (SLCPs) (Black Carbon and methane). While further analysis would be needed, annual costs of air pollution have been estimated at around 9 percent of GDP. By implementing sector policies that simultaneously improve air pollution control and lower emissions, Bangladesh could reduce premature deaths from air pollution by 44 to 50 percent (nearly 1 million lives) up to 2030, with complete elimination of mortality and morbidity related to air pollution by 2041. An expanded action plan to address Air Pollution could spell out priority actions and systematically build the alignment and synergies with climate action." – *Bangladesh CCDR, pg. 8*

"(…) carbon pricing has a potential to reduce inequality in Honduras. The preliminary analysis using partial consumption data for Honduras shows that a carbon price from the Paris Aligned scenario (assuming no recycling of additional revenues) would reduce inequality in Honduras but would also reduce consumption (an average consumer surplus loss) by at least 2.5% percent of total consumption across the income spectrum in the "Paris Aligned" scenario (0.27% in the Low scenario). Urban households would face a larger impact from the carbon price relative to rural ones." – *Honduras CCDR, pg. 46*

"The reduction in GHG emissions due to the carbon charge under the Paris Aligned scenario could avert near 700 deaths related to respiratory diseases by 2030. Moreover, carbon pricing policies can reduce ambient air pollution from the co-emission of GHGs and local pollutants from burning fossil fuels, that, in turn, could reduce mortality and morbidity. Achieving NDC's commitment to reduce firewood consumption in families by 39 percent by 2030 would yield a reduction of premature deaths by 1.5 thousand and more than 11 thousand averted deaths." – *Honduras CCDR, pg. 7*

4. **Co-benefits and interventions**

"(…),by implementing the NZP together with all these supporting measures, Vietnam could reduce GHG emissions by more than 70 percent in 2040 relative to the BAU scenario, while increasing GDP by 1.7 percent in 2030 and 3.3 percent in 2040. The cumulative output gain for 2022–2040 relative to the BAU scenario would be $80 billion — which, as noted above and shown in Table 3, means that the NZP would effectively pay for itself. While the energy and agriculture sectors would still see output reductions, transport, industries, and other sectors (mainly services) would enjoy gains. Resources would be allocated better, and workers would shift from high- to low-emitting sectors, with limited crowding out of other productive investments. Further gains in manufacturing would be generated by improved competitiveness and labor productivity increases." – *Vietnam CCDR, pg. 38*

"Scale up investment in carbon sinks to achieve net-zero targets: The value of ecosystem services provided by primary tropical forests in Vietnam is estimated at $2,077 per hectare per year, on average. Climate regulation services that include carbon sequestration are estimated at $381 per hectare. Measures to reduce emissions from land use, land-use change, and forestry are relatively low-cost compared with those in the industry, transportation, and energy sectors. Some measures, such as reforestation, forest conservation, and sustainable soil management, are considered win win solutions, with broad climate, ecological, and development benefits. In addition, activities in conservation, protection and sustainable management of existing forest areas can potentially benefit from carbon payments under Reducing Emissions from Deforestation and Forest Degradation (REDD+) programs." – *Vietnam CCDR, pg. 51*

"A clean air program for carbon dioxide (CO2), black carbon (BC) and methane (CH4) could result in significant co-benefits in Bangladesh, reducing GHG emissions while improving health outcomes. CH4 emissions contributed approximately 42 percent of Bangladesh's total GHG emissions in 2018 and Black Carbon (BC) contributes to 13 percent (IPCC AR 5). Reducing PM2.5 emissions would have a substantial impact on reduction of GHG emissions, ground level ozone (O3) and CH4. A clean air program could reduce GHG emissions through targeted interventions in several areas: a) Reducing CO2 emissions: Interventions in (i) power and heating plants (reduction up to 20 million tons of CO2 emissions by 2030);

(ii) industrial combustion (in the 2041 scenario) and (iii) industrial processes (both in the 2030 and 2041 scenarios); b) Reducing BC emissions: Interventions in (i) residential combustion (can reduce up to 30 kilo tons of BC emissions by 2030); (ii) agriculture, (iii) heavy duty vehicles – diesel, and (iv) industrial combustion; c) Reducing CH4 emissions: Interventions in (i) agriculture (can reduce up to 768 kilo tons of CH4 emissions by 2030), (ii) waste (can reduce up to 122 kilo tons of CH4 emissions by 2030 and 540 kilo tons by 2040) and (iii) residential combustion sector (can reduce to 150 kilo tons of CH4 emissions by 2030). (…) By 2030, the health co-benefits of a clean air program could reduce 50 percent of annual premature deaths, while reduced SLCP emissions like BC and CH4 could improve crop yields across the heavily air polluted Indo-Gangetic Plain" *– Bangladesh CCDR, pg. 74*

"There are numerous co-benefits to climate action in the transport sector. Improved urban transit could reduce congestion and lower the carbon footprint of cities while improving access to job opportunities, markets, health, education, and other services, simultaneously raising productivity." *– Brazil CCDR, pg. 12*

"Phasing out fossil fuel subsidies can generate substantial savings to the budget to offset the adverse impacts of price changes on the poor. Gradually phasing out fossil fuel subsidies until 2030 implies significant increases in prices compared to the baseline. Gasoline prices would be 82 percent, coal 68 percent and diesel 27 percent higher, for instance. These adjustments can potentially raise US$3.3 billion in 2030 and close to US$15.4 billion over the period 2023-2030. This frees up considerable resources that can be used to offset the impact of fuel price increases on households and support needed public investments." *– Kazakhstan CCDR, pg. 48*

"Decarbonizing the energy system (power, heat, transport, industry), which generates over 80 percent of emissions, is key to achieving the 2030 NDC and the 2060 net zero goals. The power sector is the priority due to the ready availability of cost-effective renewable energy and the old generation fleet, although actions are needed across the sectors to prepare the ground for future decarbonization – including electrification of transport and industrial applications, and energy efficiency." *– Kazakhstan CCDR, pg. 62*

"Fiscal savings from reform of long-standing subsidies could be repurposed as 'smart subsidies 'to poorer farmers to promote resilient farming practices. There is legitimate need for support to smallholders." *– Pakistan CCDR, pg. 40*

"The cost of air pollution on Pakistan's economy is 6.5 percent of GDP annually. Pollution-related economic losses are assessed through its negative impacts on the labor force (ages 20–64 years) through two channels, (a) GDP losses associated with mortality and years lived with disability (YLD) attributed to pollution, and (b), premature mortality using the value of statistical life (VSL). These indicators are derived for exposure to outdoor and indoor PM2.5, and the share of households using solid fuels for cooking. Additionally, the health impacts of Ozone (O3) pollution are also considered. Addressing air pollution would also bring significant climate co-benefits as the associated pollutants (for example, methane, black carbon) are also potent global warming agents." *– Pakistan CCDR, pg. 24*