PROJECT DRAWDOWN

REDUCING BLACK CARBON:

A TRIPLE WIN FOR CLIMATE, HEALTH, AND WELL-BEING

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November 2023

Special thanks to: Dr. Daniel Mendoza (University of Utah), Dr. Perry Hystad (Oregon State University), and the Project Drawdown Science team for their constructive reviews. We also thank King Philanthropies for their generous support of Project Drawdown.

Suggested citation
Jameel, Y., West, P.C., & Jasper, D. (2023). Reducing black carbon: A triple win for climate, health, and well-being. Project Drawdown. https://doi.org/10.55789/y2c0k2p3

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EXECUTIVE SUMMARY

Black carbon – also referred to as soot – is a particulate matter that results from the incomplete combustion of fossil fuels and biomass. As a major air and climate pollutant, black carbon (BC) emissions have widespread adverse effects on human health and climate change. Globally, exposure to unhealthy levels of particulate matter, including BC, is estimated to cause between three and six million excess deaths every year. These health impacts – and the related economic losses – are felt disproportionately by those living in low- and middle-income countries. Furthermore, BC is a potent greenhouse gas with a short-term global warming potential well beyond carbon dioxide and methane. Worse still, it is often deposited on sea ice and glaciers reducing reflectivity and accelerating melting, particularly in the Arctic and Himalayas.

Therefore, reducing BC emissions results in a triple win, mitigating climate change, improving the lives of more than 2 billion people currently exposed to unclean air, and saving trillions of dollars in economic losses.

Co-benefits of implementing clean cooking across sub-Saharan Africa. *Data source: Khavari et al 2023.*

Today, the majority of BC emissions stem from just a handful of sectors and countries. Over 70% of BC comes from the residential and transportation sectors, with the latter being the dominant source in high-income countries and the former driving emissions in low- and middle-income nations. On a country-level, China and India are the biggest emitters accounting for one-third of global BC emissions. When combined with Brazil, Indonesia, and Nigeria, these five countries alone emit 50% of all BC. While BC emissions trends over the past twenty years have been inconsistent globally, there has been a notable decline in Europe, North America, and China. Conversely, emissions have been rising in regions like Africa, South Asia, and Central Asia.

The Intergovernmental Panel on Climate Change recommends deep reductions in BC emissions by 2030 to achieve the Paris Climate Agreement goal of limiting warming to below 1.5°C, yet very few countries have addressed BC in their climate plans.

Fortunately, solutions that can rapidly reduce BC emissions by the end of this decade are readily available. By implementing the right policies, deploying targeted interventions in hotspots, and redirecting climate finance, policymakers and funders can mitigate the climate effects of BC while saving millions of lives and trillions of dollars. Below are key recommendations to achieve these aims based on the findings of this report:

1. **Urgently implement clean cooking solutions**
   Providing clean cooking fuels and technologies in sub-Saharan Africa and South Asia, especially in the hotspots of the Indo-Gangetic Plains, Nigeria, and Uganda, can significantly reduce BC emissions. Countries with low penetration of clean cooking fuel must urgently develop policies that make clean cooking a priority for health and climate.

2. **Target transportation to reduce current – and prevent future – emissions**
   Retrofitting older diesel engines with diesel particulate filters can remove up to 95% of BC. Countries around the world must implement policies to phase out polluting vehicles, set emission standards, and accelerate the uptake of EVs and hybrids, especially in urban regions where transportation demand is growing rapidly. A successful shift to EVs demands national investments complemented with international financing and private capital. Multilateral development banks need to play a pivotal role in this transition, with strategies like concessional finance to fast-track key projects and stimulate private sector investment.

3. **Reduce BC from the shipping industry**
   BC emissions from the shipping industry must be urgently reduced to protect the Arctic ecosystem. Shifting shipping away from heavy fuel oil and equipping ships with diesel particulate filters is a cost-effective approach that would quickly and significantly reduce emissions.

Use of heavy fuel oil in the shipping sector results in large emissions of black carbon. *Credit: Junak / iStock*

4. **Regulate air quality**
   Stringent emissions standards, clean air laws, baselines, and mandatory monitoring programs can effectively reduce BC emissions. Such policies have already resulted in large reductions in Europe, North America, and, more recently, China. However, several low- and middle-income countries have no legal protection for ambient air quality and lack legislatively-mandated standards. Implementing strong and legally binding policies can result in a large decrease in BC emissions, particularly across the transportation and industry sectors.

5. **Include BC in nationally determined contributions and the UNFCCC**
   Only twelve countries have explicitly addressed BC in their nationally determined contributions (NDCs). This limited focus on BC is partly due to its omission from the United Nations Framework Convention on Climate Change's (UNFCCC) list of climate pollutants, an oversight that should be reconsidered given that reducing BC would save countless lives and rapidly slow global warming. As nations review their NDCs by 2025, they must incorporate BC reduction efforts to meet climate and well-being targets.

6. **Improve BC measurements and estimates**
   BC estimates are plagued by uncertainties. Therefore, there is an urgent need for more accurate inventories in order to develop better emission reduction plans. Stakeholders must collaborate to develop a consistent BC measurement protocol, prioritize the collection of high-quality data, and use state-of-the-art models to enhance estimates and reduce uncertainties.

1. BLACK CARBON: A DUAL THREAT

Black carbon (BC) – also referred to as soot – is a particulate matter that results from the incomplete combustion of fossil fuels and biomass in industries, vehicles, cooking stoves, residential heating, and gas flaring. It is also emitted during forest fires and agricultural burning. As a major climate and air pollutant, BC emissions have widespread adverse effects on human health and climate change.

BC causes respiratory diseases and increased all-cause mortality. Recent epidemiological studies suggest that exposure to BC in particular, as opposed to undifferentiated particulate matter (PM2.5), can increase the risk of cardiovascular disease by six to twenty-six times, and reducing exposure to BC can increase life expectancy by four to nine times compared to PM2.5.

Globally, exposure to unhealthy levels of particulate matter – including BC – is estimated to cause between three and six million excess deaths every year. Out of 1,000 excess deaths from exposure to PM2.5, about 35 deaths can be attributed to BC alone. Country-level analyses in China, India, and the United States have shown that BC causes thousands of premature deaths every year.

These health impacts of BC are felt disproportionately by those living in low- and middle-income countries, notably in South Asia and sub-Saharan Africa, where solid fuel is used by 2.3 billion people for residential energy. The incomplete combustion of these fuels produces BC and a dangerous cocktail of other pollutants causing household indoor air pollution (HAP) that in some cases exceed World Health Organization (WHO) recommended levels by up to 100 times. Globally, HAP is estimated to cause about half of all the premature deaths associated with air pollution.

Black carbon emissions from a traditional mud stove. Unclean cooking fuels are a major source of global black carbon emissions.
Credit: Chalabala / iStock

By increasing health expenditures and removing people from the workforce, BC has significant economic ramifications. Estimates from China show that in 2017 short-term BC exposure caused economic losses of US$7.5 to $13.2 billion, and long-term exposure led to losses of US$53 to $93.2 billion – equivalent to between 0.4% and 0.8% of China's GDP that year. According to the World Bank, reliance on unclean cooking fuels – the largest source of BC – results in global economic losses in excess of US$2.4 trillion each year.

BC also contributes to climate change through two distinct modes. First, by absorbing solar energy. BC is an extremely potent warming agent with a global warming potential (GWP) estimated to be several times greater than carbon dioxide. Over short timeframes, BC causes more warming than any other climate pollutant as shown in Figure 1.1. According to the Intergovernmental Panel on Climate Change (IPCC) AR6 report, the current warming attributed to BC is roughly 0.1°C when compared to pre-industrial times, although there exists significant uncertainty surrounding this estimate.

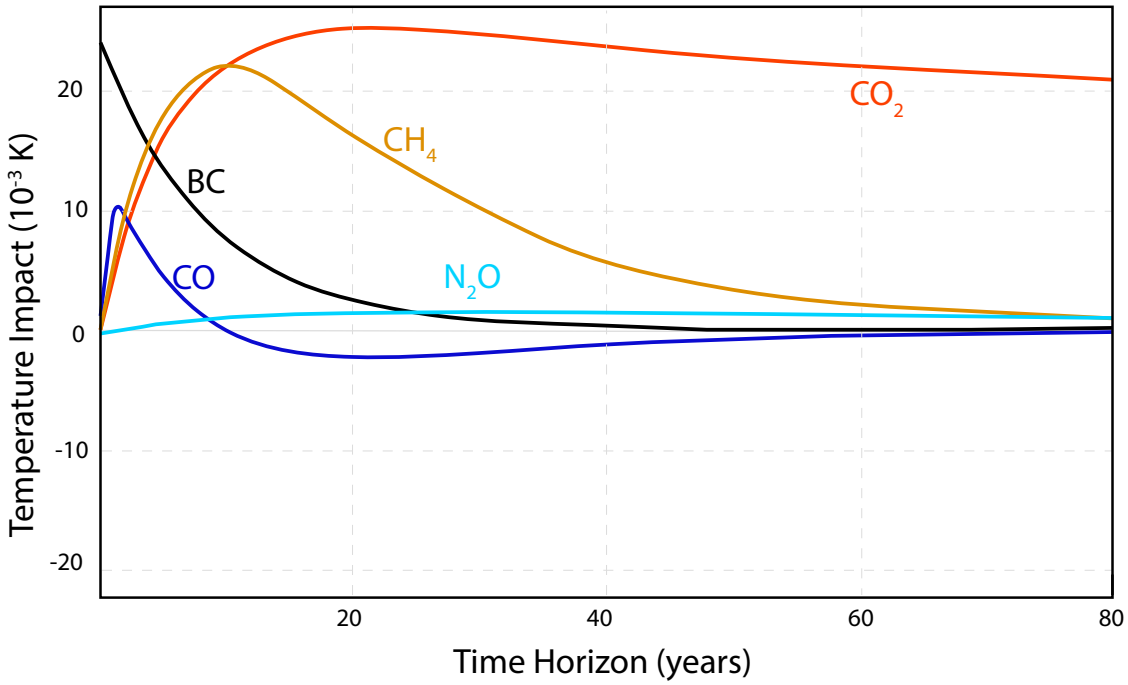

Figure 1.1: Temperature response by component for total anthropogenic emissions for a one-year pulse. In the short term, methane and black carbon dominate warming, while in the long run, carbon dioxide is the dominant warming agent. *Reproduced from IPCC AR6 report (Figure 8.33).*

Second, BC ends up deposited onto ice which reduces albedo as it absorbs sunlight, thereby increasing snow melt and accelerating climate warming in snow-covered regions. This impact is felt acutely in the Arctic and Himalayas. In the Arctic, where temperatures increased by 1.5°C between 1976 and 2007, it has been estimated that increased atmospheric BC alone may have contributed 0.4°C of warming. Recent findings from the Himalayas and Hindu Kush mountains indicate that over 50 percent of the acceleration in glacier and snow melt can be attributed to BC deposits. In addition, BC emissions have been linked to alterations in the monsoon patterns across the Indian subcontinent and Tibetan Plateau.

Black carbon and dust deposited on Nigardsbreen Glacier in Norway. Such deposits accelerate glacial melting. *Credit: J Wildman / iStock*

1.1 Reducing Black Carbon Emissions: A Win-Win for People and Climate

Reducing BC emissions will have significant human well-being, climate, and economic benefits. Targets to reduce BC have the potential to prevent approximately four to twelve million premature deaths between 2015 and 2030, mostly in South Asia and sub-Saharan Africa.

In sub-Saharan Africa – a hotspot of residential BC emissions – providing clean cooking fuel to reduce BC emissions could avert around 463,000 deaths every year (Figure 1.2). Furthermore, the socio-economic benefits far outweigh the cost of implementation as providing clean cooking fuel to every household in Africa could result in a total net benefit of US$78 billion, mostly in the form of improved health (Figure 1.2).

On average households can save nearly an hour a day by switching to clean fuel (Figure 1.2). This reduction in “time poverty” could provide family members, especially women and girls, the opportunity to pursue education and economic activities.

Figure 1.2: Co-benefits of implementing clean cooking across sub-Saharan Africa. *Data source: Khavari et al 2023.*

Transitioning to clean cooking fuel has additional co-benefits. For example, unsustainable wood harvesting for cooking fuel has resulted in deforestation and biodiversity loss in South Asia and sub-Saharan Africa. East African countries such as Eritrea, Ethiopia, Kenya, and Uganda are a major hotspot of depleting sustainable woodfuel resources. In the Democratic Republic of Congo – the largest sub-Saharan country – 84% of harvested wood is used for charcoal or firewood. Therefore, solutions aimed at curbing BC can also reduce deforestation in these regions.

In urban areas, vehicle emissions stand out as a primary contributor to air pollution and the predominant source of BC, irrespective of whether it is a high-, middle-, or low-income country. For example, in the urban megalopolises of Delhi and Nairobi, transportation contributes more than 80% of BC for the majority of months. Similarly, in France and China, studies have shown strong correlations between road transportation and BC concentration. A major difference however between high- and low- and middle-income countries, is the significantly higher concentration of BC in cities in low- and middle-income countries compared to the high-income countries.

Reducing BC emissions from transportation has the potential to substantially mitigate related morbidity and mortality, particularly in rapidly expanding urban areas in low- and middle-income countries which are seeing an exponential increase in vehicle demand.

The high short-term GWP of BC means that it can result in immediate climate impacts. The IPCC recommends deep reductions in BC emissions by 2030 to achieve the Paris Climate Agreement goal of limiting warming to below 1.5°C, yet very few countries have addressed BC emissions in their climate plans.

Targeted reductions in BC can also result in regionally important climate improvements. Significant reductions in short-lived climate pollutants – including BC – can reduce Arctic warming between 2041 and 2050 by 0.4°C, which is vital for preserving the region's ecosystems and avoiding critical environmental tipping points. Similarly, implementing rapid BC emissions reduction policies in South Asia can immediately slow glacier melting in the Himalayas and the Hindu Kush, preserving water security for billions of people living in the Indo-Gangetic Plains of Bangladesh, India, Nepal, and Pakistan as well as mitigating the associated risks with rapid melting such as floods and landslides.

Additionally, reducing BC goes hand-in-hand with the reduction of other climate and air pollutants such as methane, carbon dioxide, particulate matter, and volatile organic compounds (VOCs). For example, universal access to clean cooking in Africa could lead to an annual greenhouse gas emissions reduction of 586 million tons of CO2-eq – approximately 1% of global yearly emissions.

2. SOURCES, REGIONAL PATTERNS, AND TRENDS

The primary sources of black carbon (BC) emissions are the residential, transportation, and industrial sectors. The residential sector is the largest contributor to BC emissions, accounting for approximately 48% of global BC emissions in 2017 (Figure 2.1). Residential sector BC largely comes from the use of solid fuels such as wood, charcoal, agricultural residues, dung, and coal for heating and cooking, which is still widespread in low- and middle-income countries, where approximately 2.3 billion people, or one-third of the global population, rely on it.

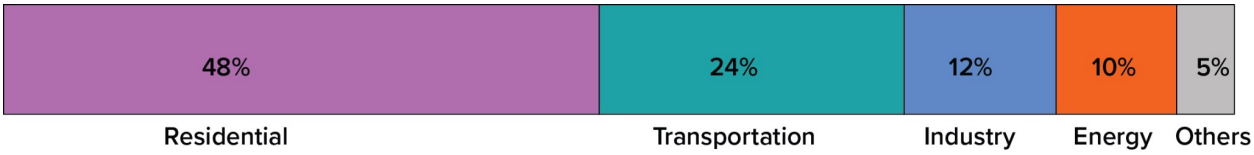

Figure 2.1: Anthropogenic sources of BC emissions. *Data source: CEDS GBD-MAPS*

The transportation sector is the next largest source of BC, accounting for 24% of global emissions. It is emitted from a variety of sources, but most of the emissions are from diesel vehicles – including ships – which produce higher levels of BC due to their combustion process. BC emissions from transportation can be significantly reduced by retrofitting older diesel engines with diesel particulate filters (which can remove up to 95% of BC), using low-sulfur fuels, or replacing diesel with hybrid and electric vehicles.

Industrial BC emissions arise mainly from brick kilns, industrial boilers, and coke ovens used in iron and steel production. China, India, and countries in Central and South America are the primary contributors to industrial BC emissions. Industries in developed countries have managed to reduce BC by adopting a combination of measures including fuel switching, enhanced combustion processes, and strict air quality regulations. Industrial emissions could be reduced by phasing out beehive coke ovens, transitioning from traditional brick kilns to vertical shaft brick kilns, and promoting end-of-pipe dust removal facilities.

Open biomass burning, wildfires, and controlled agricultural burning are also significant contributors to BC emissions. Wildfires, in particular, introduce substantial quantities of BC particles into the atmosphere, especially in the Arctic. In parts of Asia, Africa, and South America, agricultural burning releases large amounts of BC into the atmosphere.

Black carbon and other pollutants being emitted from the burning of a dry rice paddy in India. *Credit: rvimages / iStock*

To identify geographical sources and trends we chose two recent datasets – the Community Emissions Data System ($CEDS_{GBD\text{-}MAPS}$) and the Peking University global emissions inventory (PKU-FUEL) – that provide country-level and sectoral BC emissions from 1970 to 2017.

BC emissions inventories have a notable amount of uncertainty due to a variety of factors constituting a significant barrier to mitigating emissions. While there is an urgent need to improve estimates, existing inventories can still be useful, particularly when developing short-term mitigation strategies. We have provided a brief comparison between the two inventories used here and other major inventories here.

2.1. Highest Emitters

There are large country variations in BC emissions – both in terms of the amount and sources of emissions. Global BC emissions are dominated by China and India, which together account for one-third of global anthropogenic emissions, followed by Brazil, Indonesia, and Nigeria. These five countries together account for half of total global BC emissions, as shown in Figure 2.2. For India, Nigeria, Indonesia, and Brazil, the proportional sectoral contributions between the two datasets (PKU-FUEL and $CEDS_{GBD\text{-}MAPS}$) are in broad agreement with each other. However, for China, according to the PKU-FUEL inventory, industrial BC emissions are the country's single largest source of BC. But according to the $CEDS_{GBD\text{-}MAPS}$ inventory, China's residential and energy sectors are a substantially larger source of BC emissions than industry. This discrepancy might result from the low emissions factors used in the $CEDS_{GBD\text{-}MAPS}$ inventory for the industrial sector.

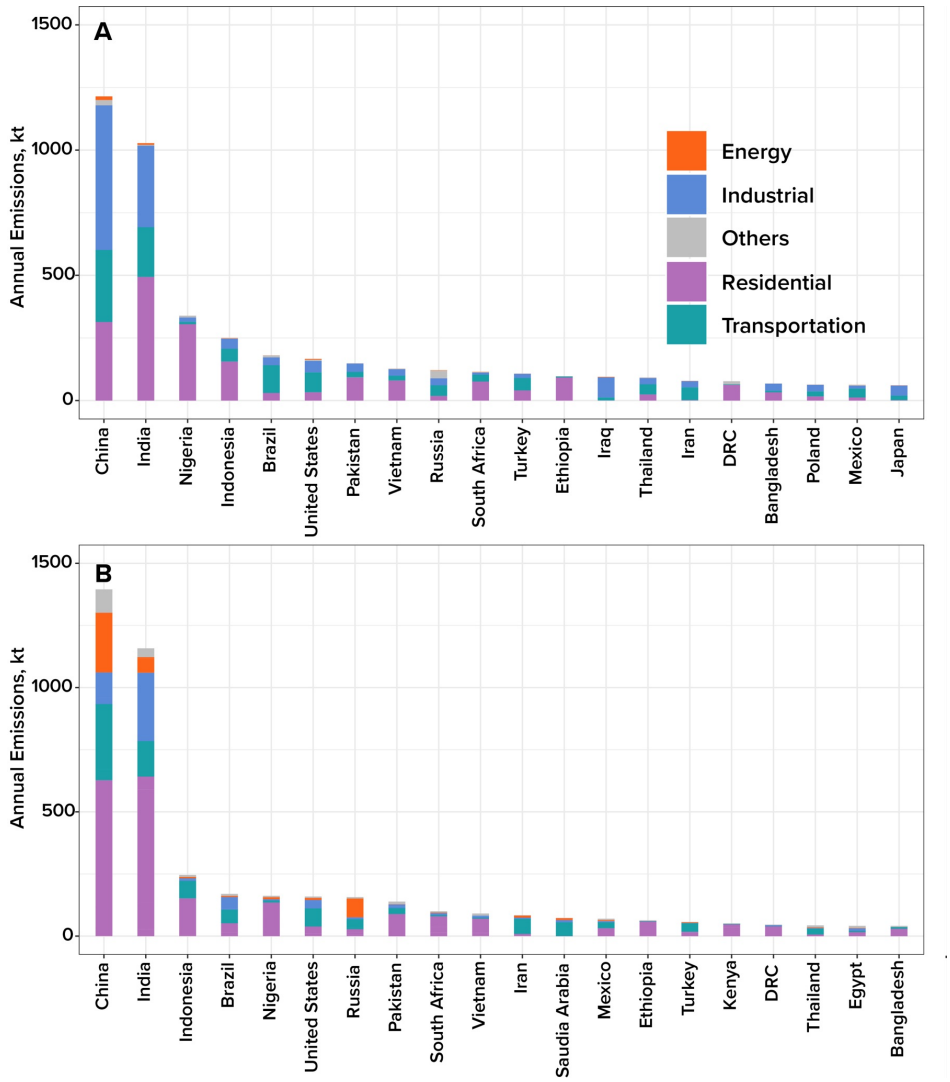

Figure 2.2: Black carbon emissions broken down by sector for the top 20 highest-emitting countries in 2017. *Data: (A) PKU-FUEL and (B) CEDS$_{GBD\text{-}MAPS}$. (DRC: Democratic Republic of Congo)*

In several countries, such as the Democratic Republic of Congo (DRC), Angola, Russia, Indonesia, Brazil, and Canada, forest fires – natural and uncontrolled – and agricultural burning are also significant sources of BC (Figure 2.3). For example, it has been estimated that Siberian fires contributed almost half of all BC deposited in the Arctic over a 12-year period from 2002 to 2013. Similarly, a recent study reveals that savannah burning in sub-Saharan Africa is a significant contributor to BC emissions.

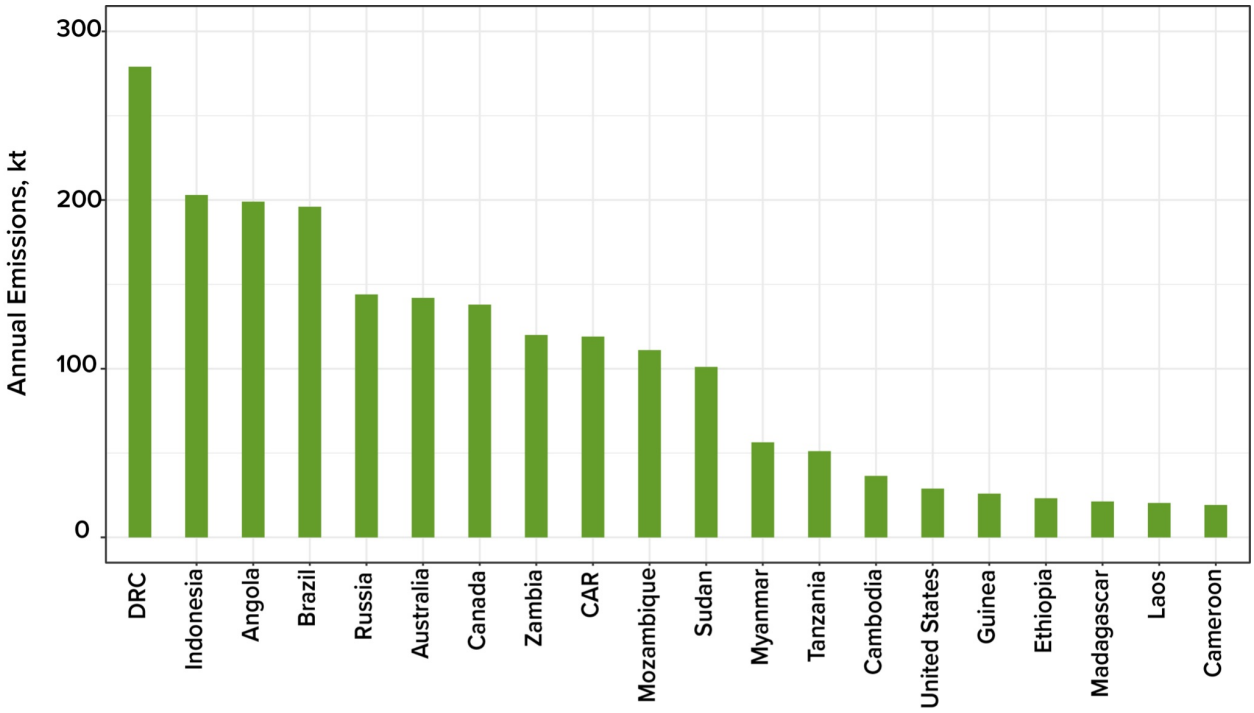

Figure 2.3: Wildfire-related black carbon emissions for the top 20 highest-emitting countries in 2017.
Data: PKU-FUEL. (DRC: Democratic Republic of Congo; CAR: Central African Republic)

2.2. Regional Patterns

Aggregating countries reveals large variation in the sources of BC emissions at a regional level. Transportation is the largest contributor to BC emissions in North and South America, Europe, North Africa, and Central Asia, accounting for approximately half of total emissions, as shown in Figure 2.4.

- In East Asia, BC emissions are relatively equal across all three major sources – transportation, residential, and industry.

- In the Middle East, BC emissions are dominated by the transportation and industrial sectors, the latter being associated with fossil fuel activities in the region's oil-rich Gulf countries.

- In South Asia and sub-Saharan Africa, which together account for about 38% of global BC emissions, the residential sector stands out as the primary source of BC. Notably, the residential sector in sub-Saharan Africa is responsible for more than 75% of the region's BC emissions due in large part to the combustion of unclean fuels for cooking and heating.

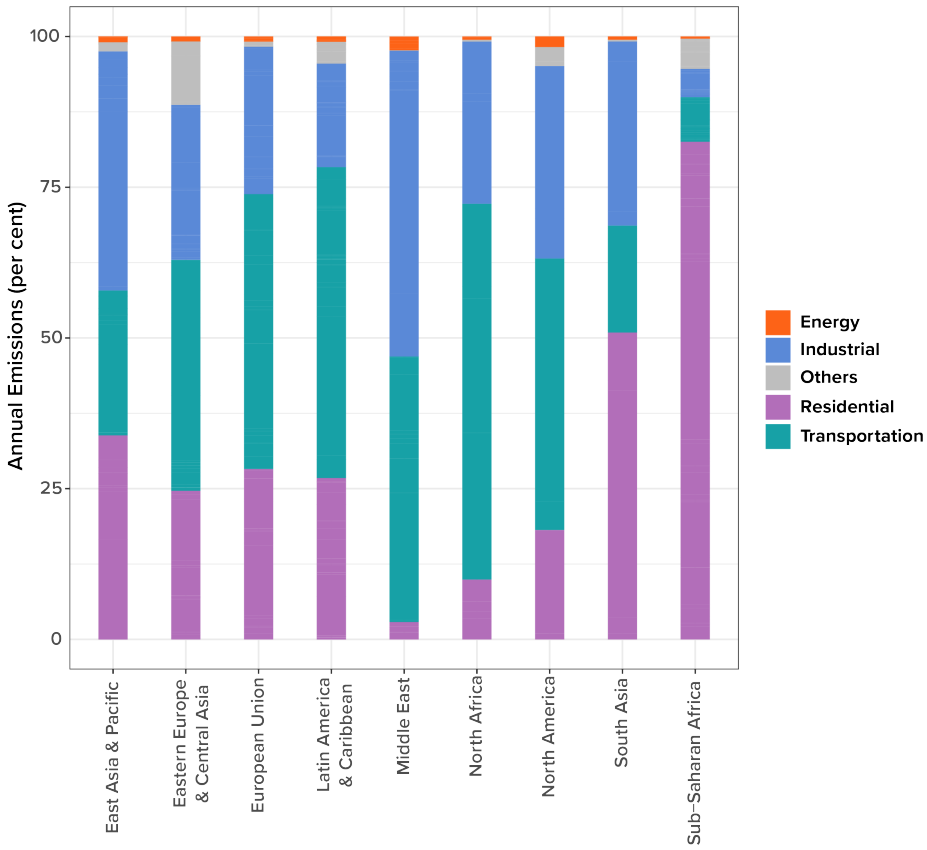

Figure 2.4: Percent contribution of various sectors to 2017 black carbon emissions by region. *Data:PKU-FUEL*

2.3. Black Carbon Hotspots

A small number of locations are responsible for a disproportionately large amount of BC emissions. For example, as shown in Figure 2.5, around 20% of global BC emissions are concentrated in eastern China and the Indo-Gangetic Plain. By elucidating the regional and sectoral hotspots of BC emissions, stakeholders can take a targeted approach to deploying solutions that will quickly and significantly reduce BC while maximizing human and environmental well-being.

In China, industrial activities, residential fuel combustion, and transportation all contribute heavily to BC emissions. The Indo-Gangetic Plain, encompassing regions in northern India, Pakistan, and Bangladesh, emerged as the most substantial hotspot for residential emissions, accounting for approximately 25% of the sector's BC emissions globally. Reductions across the Indo-Gangetic Plain will not only reduce BC exposure for more than 60 million people but would also reduce BC deposition in the Himalayas and the Hindu Kush mountains thereby slowing glacier melt. Residential hotspots are also observed in densely populated regions of eastern Indonesia and southern Nigeria.

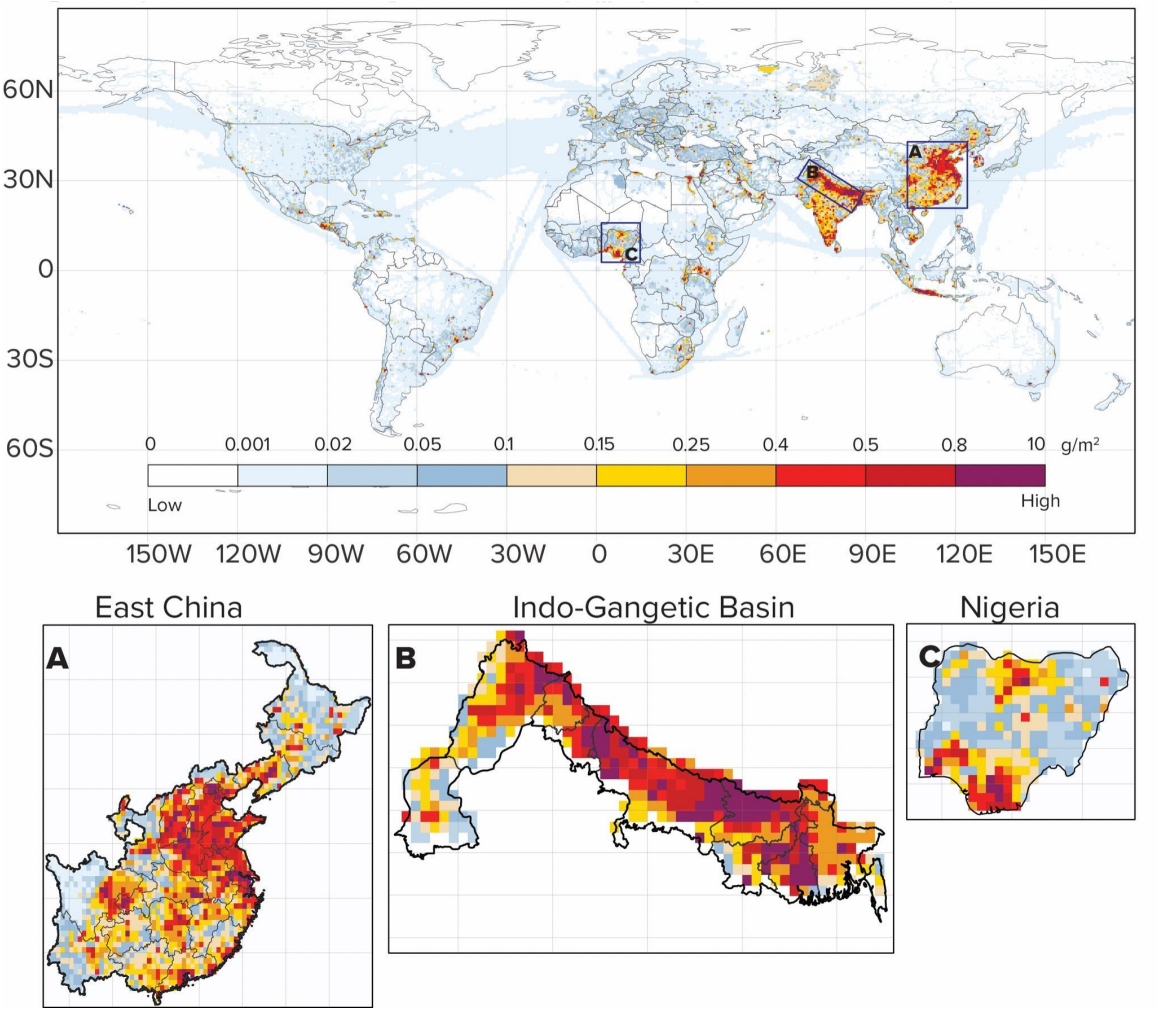

Figure 2.5: Spatial distribution of global annual black carbon emissions in 2017. *The light blue lines in the ocean are black carbon emissions associated with global shipping. A, B, and C: Hotspots in eastern China, the Indo-Gangetic Basin across India, Bangladesh, and Pakistan, and Nigeria respectively. Data: CEDS$_{GBD\text{-}MAPS}$.*

Urban metropolises situated in Uganda, Egypt, Ethiopia, and South Africa represent significant anthropogenic BC hotspots within the African continent, with residential and transportation activities being the predominant sources of emissions. Collectively, these locations account for a significant portion of Africa's overall emissions.

Oil-producing Gulf countries like Qatar, the United Arab Emirates, and Iraq exhibit high BC emissions from the oil and gas sector which is co-emitted with methane. Notably, per capita emissions are particularly high for these countries, underscoring the disproportionate impact of oil and gas operations on BC emissions.

Shipping is responsible for approximately 2% of global BC emissions which would make it the fifth largest contributor if it were a country. The impact of shipping-related BC is particularly

pronounced in the Arctic and northern latitudes, where these emissions have detrimental effects on fragile ecosystems and Indigenous communities. Worryingly, the quantity of BC emitted within the Arctic region has doubled between 2015 and 2021, primarily due to increased shipping activity in adjacent waters.

Finally, major urban centers globally, such as Rio De Janeiro, New York City, Mexico City, and London, are BC hotspots due to the extensive number of vehicles operating within these metropolises.

2.4. Global Trends

Human activities resulted in emissions of about 5 terragrams (Tg) of BC per year between 2000 and 2017. During the same period, wildfires and agriculture burning are estimated to have contributed between 2–2.5 Tg of BC per year. BC emissions have not shown a consistent increasing or decreasing trend over the last two decades, as shown in Figure 2.6. According to the PKU-FUEL dataset, global anthropogenic BC emissions have remained consistent at around 5.7 Tg per year. In contrast, according to $CEDS_{GBD\text{-}MAPS}$, BC emissions increased from 5.2 to 6 Tg per year between 2000 and 2010 and then witnessed a small decline of 0.3 Tg between 2010 and 2017. Nonetheless, both datasets suggest that global reductions in BC emissions are not on track as recommended by the IPCC to achieve the Paris Climate Agreement goal of limiting warming to below 1.5°C.

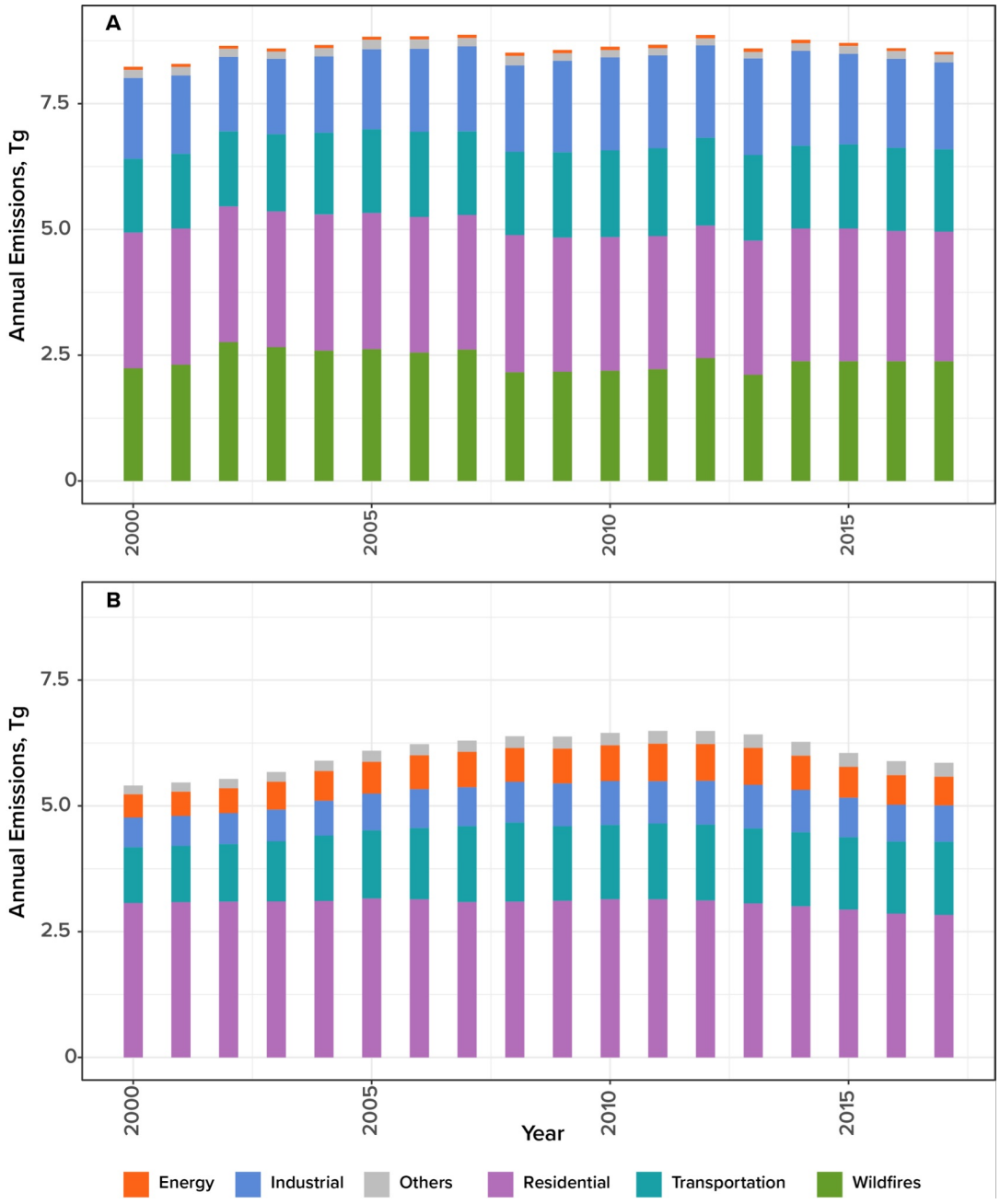

Figure 2.6: Global black carbon emissions and relative contributions by sector from 2000 to 2017. (A) PKU-FUEL and (B) $CEDS_{GBD\text{-}MAPS}$. *Note: $CEDS_{GBD\text{-}MAPS}$ does not include emissions from wildfires.*

When examining emissions at the regional level as opposed to the national level, substantial disparities become evident. BC emissions have declined in Europe, North America, China, and other developed countries, as shown in Figure 2.7. Much of the recent decline in the northern hemisphere is attributable to China, where emissions dropped by 20% between 2010 and 2017. However, even with this decline, China accounted for approximately 18% of global BC emissions in 2017. In the United States, BC declined by 16% over that same timeframe primarily due to a

large drop in transportation-related emissions following the implementation of stringent vehicle emission standards. In the European Union, BC emissions decreased by 6% over those seven years. However, this decrease was not uniform across member states. BC decreased by more than 15% in Italy, Norway, Sweden, Greece, and Belgium, but much lower in larger countries, such as Germany and France.

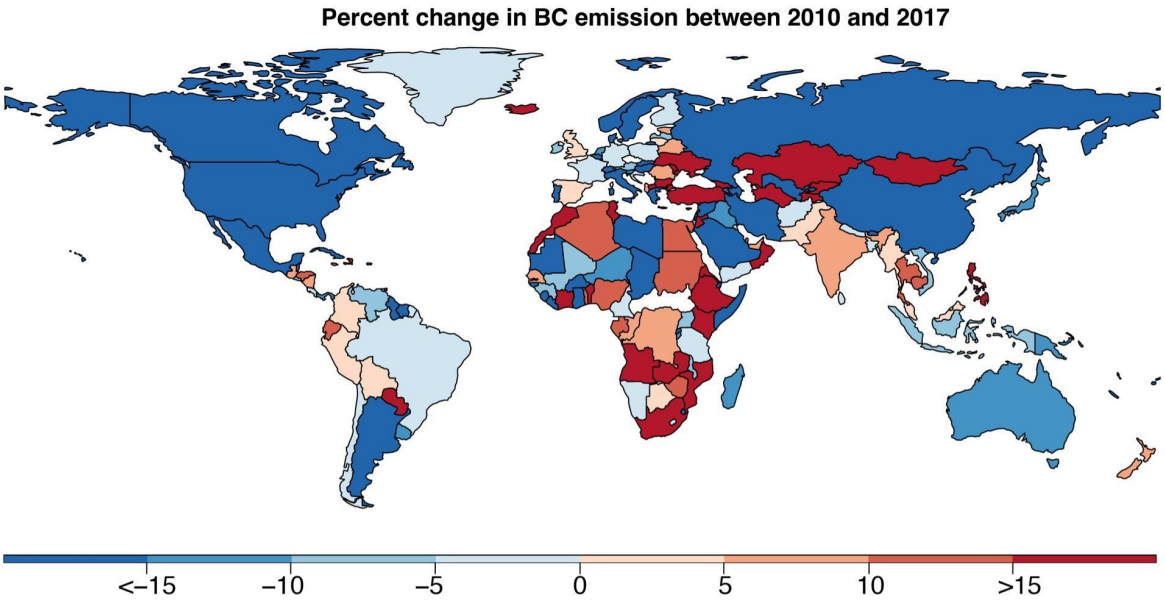

Figure 2.7: Percent change in country-level anthropogenic black carbon emissions between 2010 and 2017. This does not include emissions from wildfires. *Data: PKU-FUEL.*

BC emissions across some low-and middle-income countries including Mexico, Algeria, Chad, Chile, and Mauritania also declined by more than 15% over the study period. Notably, Mexico and Chile are two of the few countries that have included reducing BC emissions in their Nationally Determined Contributions (NDC) report, which outlines how each individual country plans to address climate change under the Paris Climate Agreement.

Unfortunately, these declines in BC have been tempered by increases in emissions in countries throughout Africa, South Asia, Eastern Europe, and Central Asia. In South Asia and sub-Saharan Africa, which together account for 38% of total BC emissions, emissions increased by 8% between 2010 and 2017, mostly due to the consumption of unclean solid fuels for cooking and an increase in transportation. If emissions in these regions continue on a similar trend it will offset the gains made in North America, China, and the European Union making it unlikely that global BC will be significantly reduced by 2030, which is essential for reaching global net zero..

While Eastern Europe and Central Asia account for only 4% of global BC emissions, this region experienced an increase of 15% over the study period mostly stemming from the transportation and industry sectors. This is not surprising given that the average age of vehicles – older vehicles tend to be more polluting – is higher in these regions. For example, in all of Eastern Europe and

in the Central Asian country of Kyrgyzstan the average car is more than 15 years old. By comparison, the average age of vehicles in Germany and China are 10 and 5 years, respectively.

Based on recent trends, such as the widespread adoption of electric and hybrid vehicles as well as the replacement of gas-powered residential heaters with electric heat pumps, it is likely that BC emissions in the European Union, North America, and China have continued to decline between 2017 and 2023.

However, BC emissions could still be on the rise in South Asia and sub-Saharan Africa. According to one study, global access to clean cooking fuels increased by a paltry 2% between 2015 to 2020, and the latest assessment by the Sustainable Development Solutions Network reveals that growth has been stagnant in sub-Saharan Africa. Meanwhile, transportation is growing rapidly in many places. This suggests that a decline in BC emissions between 2017 and 2023 is unlikely.

3. PATHWAYS TO REDUCE BLACK CARBON

Efforts to reduce black carbon (BC) are lagging as emissions rise in low- and middle-income countries. Global action on BC has been hindered by a lack of comprehensive and binding international agreements specifically addressing the issue. Despite its detrimental impact on climate change and human well-being, BC is not included in the United Nations Framework Convention on Climate Change (UNFCCC) list of climate pollutants and is therefore often excluded from national climate plans.

Fortunately, there is a way forward if immediate and science-backed action is taken. Deployment of proven technologies in high-emitting sectors, targeted interventions at hotspots, strong multinational policies, enhanced environmental regulations, and international cooperation among governments, international organizations, and civil societies can rapidly reduce BC emissions by 2030.

To reduce global BC, it is imperative that policies and actions, such as those explored below, be implemented to curb emissions.

3.1. Rapidly Adopt Clean Cooking Fuels

Target Residential Hotspots

Forty-two percent of global residential BC emissions emanate from India, Pakistan, Bangladesh, Nigeria, Uganda, Ethiopia, and South Africa due to the use of unclean cooking fuel. The Indo-Gangetic Plains is the largest hotspot of residential emissions, followed by densely populated regions in Nigeria and Uganda. Targeted interventions in these regions can drastically reduce global BC emissions, improve the lives of billions of people, and rapidly reduce deforestation across East Africa.

Incentivize Adoption Through Favorable Policies

Several years of research has shown that favorable policies, government subsidies that support affordability, and infrastructure that allows for the reliable replacement of unclean fuel is vital for the adoption of clean cooking fuels.

Out of more than 40 countries where a large portion of the population do not have access to clean cooking, only eight have advanced policies to promote its adoption. Favorable policies can result in rapid uptake of clean cooking fuels. India, for instance, has benefited from the Pradhan Mantri Ujjwala Yojana (PMUY) scheme which has resulted in free liquified petroleum gas (LPG) connections to 96 million households living below the poverty line.

A woman cooking food on a mud stove exposing herself to black carbon and other pollutants. *Credit: ephotocorp / Alamy*

While the initial success of the PMUY scheme is commendable, the initiative has been hindered by below-average refueling rates of the LPG[1] cylinders by more than 50% of the recipients. This indicates that the long-term penetration of clean cooking fuel is challenging, so related policies should be dynamic and adjusted as needed to increase adoption and utilization.

As electricity availability and capacity increases in low- and middle-income countries, electric cooking can and must be expanded quickly in urban areas. According to the International Energy Agency (IEA), in the most cost-effective and realistic scenario to provide universal access to clean cooking by 2030, electric cooking plays a major role by becoming the main choice for 12% of households. It is imperative that governments promptly implement policies that facilitate the seamless adoption of electric cooking.

Policymakers in nations with low penetration must make clean cooking a national priority. There are a range of mechanisms that they can employ, including targeted subsidies to improve affordability, using diverse and culturally acceptable clean cooking fuels and stoves, integrating clean cooking across cross-sectoral planning, tapping into the rapidly growing carbon market,

[1] *Even though LPG is a fossil fuel, it is the best option to reduce BC and CO_2 emissions from the residential sector in low- and middle-income countries due to its affordability, reliability, and availability. The IEA recognizes LPG as a clean cooking fuel option as these countries transition away from unclean alternatives.*

educating people on the benefits of clean cooking fuels, and eliminating taxes and levies on clean cooking fuels and appliances.

Prioritize Climate Finance Investments in Clean Cooking

Clean cooking solutions offer a unique opportunity to simultaneously address climate change, health, and development challenges. Yet clean cooking initiatives in sub-Saharan Africa are vastly underfunded and investments remain several magnitudes lower than the US$8–10 billion required annually for a universal transition by 2030. For a long time, clean cooking solutions have suffered from a lack of investments by private finance. International developmental banks must reevaluate their approach to clean cooking investment and adopt innovative strategies such as concessional and blended finance to attract more private capital to achieve universal access. Innovative funding mechanisms like the Spark+ Africa investment fund and Energy Sector Management Assistance Program (ESMAP) provide viable pathways to deliver the necessary financing for a clean cooking transition.

3.2. Promote Cleaner Transportation to Reduce and Prevent Emissions

In the last decade, transportation-related BC emissions have declined in the United States, European Union, and China due to stricter air quality regulations and improvements in diesel engines. For example, in the United States, vehicular emissions of BC have decreased by 60% in the past 30 years due to regulations focused on particulate emissions from diesel vehicles. In these countries, BC is expected to decline even further due to the rapid deployment of hybrid and electric vehicles (EVs).

In contrast, BC emissions from the transportation sector have been increasing in South Asia due to rising populations and growing demand for vehicles, a trend that will likely continue unless significant action is taken to reduce emissions.

Though transportation-related emissions in sub-Saharan Africa are currently several times lower than residential sources, this could rapidly change in response to growing transportation demand. Indeed, under current policy, Africa could account for more than one-third of global transportation BC emissions by 2040. Such an increase could offset the gains - if any - made by reducing residential emissions.

Black carbon and smoke being emitted from a bus that is likely fueled by polluting diesel. *Credit: JarnoVerdnok / iStock*

Rapidly Expand Cleaner Diesel Vehicles and Low-Sulfur Fuel

BC emissions from diesel vehicles can be significantly reduced by using diesel particulate filters (DPF). Vehicles following recent standards (Euro 6 and Euro 4 standards for heavy and light duty vehicles, respectively) are capable of removing more than 90% of BC emissions from exhaust. Global adoption of high-efficiency DPF can result in a significant reduction in transportation BC by 2040. Yet, the majority of the countries have not adopted the latest standards for new diesel vehicles.

Countries need to urgently adopt policies that phase out older vehicles, establish updated regional standards, and raise awareness of the harms of BC vehicle emissions. Adopting cleaner vehicles can be costly, however, they result in significant societal benefits. According to the International Council on Clean Transportation (ICCT) rapid adoption of Euro 6 and Euro 4 vehicle standards can avoid up to $7 trillion in societal costs from 2020 to 2050.

Target Clean Transportation in Urban Metropolises

Globally, transportation-related BC emissions are highest in urban areas. Rapidly adopting EVs and hybrid vehicles in urban areas of low- and middle-income countries can reduce current BC emissions and prevent future increases as vehicle demand grows. Expanding such vehicles in urban areas is also easier due to a higher degree of electrification and a greater ability to develop the required infrastructure.

Currently, the proportion of EVs in low- and middle-income countries is minimal. Policies that subsidize hybrids and EVs and increase investments in essential infrastructure for public charging are urgently needed. Strategic approaches that prioritize the electrification of high-efficiency, high-occupancy modes of transportation, like bus rapid transit (BRT) systems, as well as electric-

powered two-wheeled scooters and three-wheeled rickshaws which are significantly cheaper and widely used in low- and middle-income countries can reduce costs while maximizing benefits. Kenya, for instance, has expressed its intention to incorporate electric buses into the Nairobi Bus Rapid Transit system, while Rwanda has implemented tax exemptions for EV sales.

Improved air quality from reduced tailpipe emissions will have significant health co-benefits, especially in densely populated areas, which can help offset the cost associated with implementing these solutions. For example, a nationwide transition to 100% zero-emission passenger vehicles in the United States by 2035 and medium- to heavy-duty trucks by 2040, could result in US$1.2 trillion in public health benefits from 2020 to 2050 including preventing 110,000 premature deaths due to improved air quality. The benefits of this transition will be much bigger in low- and middle-income countries.

Leverage Innovative Financing

To ensure widespread transitions to EVs, national investments alone will not suffice. International finance, private capital, collaboration, and knowledge sharing is imperative. Funding for clean electricity projects in low- and middle-income countries is urgently required to support local EV startups and promote technological advancement. Unfortunately, investments in such projects in Africa are constrained due to substantial risks associated with high upfront costs, currency fluctuations, and inadequate patient capital.

To address these challenges and enable large-scale investment, innovative financing structures must be implemented. One such approach could involve concessional finance through multilateral development banks to expedite crucial projects, thereby encouraging subsequent private investment. Alternatively, risk-sharing arrangements can be established to alleviate concerns among risk-averse investors.

Reduce BC from the Shipping Industry

With new shipping routes opening in the Arctic Sea due to melting sea ice, it's imperative that BC emissions from the shipping industry be urgently reduced to prevent a positive feedback loop in which even more sea ice melts as passing ships deposit heat-absorbing BC. According to the Clean Arctic Alliance, shifting Arctic shipping from heavy fuel oil to cleaner distillate fuel can result in a 44% reduction in BC emissions. Additionally, by equipping all ships with DPF BC emissions could be further reduced by as much as 90%.

Emissions from the shipping industry can be easily reduced by existing technologies through policies such as expanding or establishing emission control areas, prohibiting the use of heavy fuel, and establishing a BC emissions standard for ships.

Use of heavy fuel oil in the shipping sector results in large emissions of black carbon. *Credit: Junak / iStock*

3.3. Enact Air Quality Policies and Establish a Monitoring System

Enact Stringent Emissions Standards

BC emissions from the industrial and agricultural sectors cannot be reduced without enacting strong emissions standards, legislating clean air laws, setting robust baselines, and establishing mandatory monitoring programs.

For industrial emissions, stronger regulations can include replacing beehive coke ovens with improved ovens, modernizing traditional brick kilns, mandatory installation of emission control technologies, and regular monitoring and reporting requirements to ensure compliance. The benefits of strong emissions standards are visible in the European Union, North America, and, to a lesser extent, in China where the installation of dust removal facilities, robust monitoring systems, and transition to mechanical coke ovens have significantly reduced industrial BC emissions.

BC emissions from agricultural burning can be reduced by explicitly prohibiting the practice. Employing a "deterrent and incentive" model, where penalties and fines are imposed on farmers who violate the regulations while those who adopt alternative practices such as composting, mulching, or bioenergy production are financially rewarded, can accelerate cleaner disposal of agricultural waste. This combined approach can lead to a significant reduction in agriculture-related BC emissions.

Legislate Clean Air Quality Laws

Various measures aimed at enhancing air quality can simultaneously reduce BC emissions. As per the Intergovernmental Panel on Climate Change (IPCC), air quality and climate change are intrinsically interconnected. Simultaneously addressing both holds the potential for substantial synergistic effects and economic advantages, while also circumventing policy measures that ameliorate either issue at the expense of exacerbating the other. For example, in China, measures to improve air quality in regions with high pollution significantly reduced BC emissions and contributed to improving public health.

According to a 2021 UN Environment Program (UNEP) report, 34% of countries – mostly in sub-Saharan Africa – have no legal protection for ambient air quality, lacking legislatively-mandated standards. Among these countries, 86% have no air quality standards in place, while the remaining 14% have air quality standards that are limited in scope. Legislating air quality standards in these countries can curb current and future BC emissions.

Traditional brick kilns are a major source of industrial black carbon emissions. *Credit: Tariq Sulemani / iStock*

Target Industrial Hotspots in China

China accounts for about one-third of global industry-related BC emissions (PKU-FUEL). Industrial hotspots are concentrated in China's highly populated and industrialized eastern states. Although China, which produces more than half of the world's coke, has made significant strides in reducing BC emissions by installing dust removal facilities and upgrading mechanical coke ovens, the PKU-FUEL data suggests that industrial emissions have not been declining as quickly as those from the residential and transportation sectors. A rapid reduction in industrial BC emissions from China is vital to achieve a global reduction of 30% by 2030.

Reduce Oil and Gas Related Emissions

Oil-producing Gulf countries like Qatar, the United Arab Emirates, and Iraq exhibit high industrial BC emissions primarily from the oil and gas sector resulting in markedly high per capita emissions. Worse still, these BC emissions are often co-emitted with methane. Fortunately, this means that targeted interventions will significantly reduce both BC and methane emissions from the region.

3.4. Opportunities for Integrating Black Carbon in National Climate Plans and Funding Initiatives

Surprisingly, only twelve countries – Costa Rica, Chile, Canada, Mexico, Zimbabwe, Micronesia, the United States, Ghana, Uganda, Bangladesh, Nigeria, and Eswatini. Notably, Mexico, Colombia, Chile, and Bangladesh – have explicitly addressed BC in their nationally determined contributions (NDCs). Notably, Mexico, Colombia, Chile, and Bangladesh have committed to reduce emissions by more than 25% by 2030. The lack of momentum to reduce BC emissions can be attributed, in part, to its exclusion from the list of climate pollutants covered by the UNFCCC, an oversight that the organizations should reconsider given the extensive health and climate benefits of reducing BC.

Notwithstanding this exclusion, countries should still consider including BC reductions in their climate strategies. As countries conduct comprehensive reviews of their NDCs and seek to enhance their mitigation efforts by 2025, they have a unique opportunity to introduce or improve targets, policies, and actions specifically aimed at addressing BC emissions. By doing so, each country stands to reduce their impact on the climate while improving human well-being.

Climate funding agencies can play a crucial role to accelerate reductions in BC emissions. First, they should incorporate short-lived climate pollutants, including BC, into their decision-making processes when evaluating grant proposals. This entails a comprehensive assessment of the total emissions reduction potential of each project and prioritizing projects that target SLCPs alongside CO_2. Second, they should also prioritize projects that result in large improvements in human health and well-being. This approach would yield immediate and sustained benefits for the climate while also delivering unparalleled co-benefits to low- and middle-income countries.

Funding institutions like the World Bank and Global Environmental Facility (GEF) have taken initial steps to prioritize projects that address CO_2 and BC, however these initiatives need to be rapidly scaled through close collaboration with governments, private funders, impact investors, and philanthropic organizations.

3.5. Improvement in Black Carbon Measurements and Estimates

BC estimates suffer from large uncertainty that arises due to various factors including an incomplete understanding of emission sources, complex atmospheric processes, limitations in measurement techniques, and a lack of consensus on what constitutes BC and how to measure it. Addressing these underlying issues is critical to develop a comprehensive and accurate inventory of BC emissions as well as to design effective emission reduction plans. As with efforts to improve global methane estimates, there is an urgent need for stakeholders to come together to develop a framework that establishes a consistent measurement protocol and identifies opportunities and pathways for improving BC estimates while reducing uncertainties, such as by collecting higher-quality data and better integrating satellite and ground-based observations.

4. CONCLUSION

Black carbon (BC) is a triple threat as it warms the planet while severely degrading human and environmental health. In mitigating BC emissions, both immediate and sustained benefits can be achieved. These encompass improvements in public health outcomes, minimization of economic losses, reduction in climate warming, and the safeguarding of critical ecosystems, notably the Arctic and Himalayan regions. The Intergovernmental Panel on Climate Change has called for action to reduce BC emissions as part of a broader strategy to mitigate climate change, yet global efforts have lagged and emission reduction efforts are nowhere close to where they need to be to reach existing targets. Rapidly reducing BC is possible using existing technologies and solutions, however, it requires a coordinated effort on local, national, and international levels. Countries must seize the opportunity to incorporate BC reductions into their Nationally Determined Contributions (NDCs) as they submit an updated NDC in 2025. Simultaneously, climate finance needs to prioritize projects that also target BC along with other climate pollutants. By addressing BC emissions, we can take significant strides toward mitigating climate change while also improving the lives of more than 2 billion people and saving trillions of dollars in economic losses resulting from BC.