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CSTEP CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY
BERKELEY AIR MONITORING GROUP
ORBIS AIR

THE CASE FOR ACTION ON **BLACK CARBON**

Avoiding climate tipping points, building resilience and delivering clean air

CONTENTS

1. EXECUTIVE SUMMARY

Black carbon, a pollutant emitted from the incomplete combustion of fossil fuels, biomass and waste, sits uniquely at the centre of climate and health crises. Black carbon emissions affect global warming, snow and ice melt, monsoon and weather patterns, flood risk, heat stress and public health. The potential benefits of reducing the emissions are felt most strongly close to the source. The dual nature of black carbon as a climate and air pollutant has resulted in neither of these fields taking full ownership. Therefore, black carbon remains largely absent from mainstream climate and health agendas.

Reducing black carbon emissions is critically important for fast climate mitigation and building resilience to the effects of climate change. The most significant effects of black carbon emissions are on sensitive cryosphere ecosystems that are subject to irreversible climate tipping points. Black carbon deposition on snow and ice accelerates the melting of the Arctic, the Himalayan and the Andes glaciers as well as other cryosphere regions. Midlatitude black carbon emissions warm the surrounding air, which is then transported poleward and contributes to Arctic warming. Black carbon emissions in Asia and Africa have contributed to more unpredictable monsoons that decrease water and energy security, reduce agriculture productivity and cause catastrophic flooding. Black carbon and other dark aerosols also worsen the impact of heatwaves, which are getting more frequent in this warming climate.

Reducing black carbon emissions can also improve public health and advance environmental justice close to the sources. Black carbon is a significant part of fine particulate matter (PM2.5), the largest environmental health risk that claims millions of lives each year. The worst health impacts of black carbon fall on at-risk marginalised and indigenous communities. For example, women and children are found to be most at risk from inhaling emissions from residential biofuel and kerosene burning. Industrial black carbon sources, such as those from brick kilns, can be the dominant polluter of ambient air in some cities and impact the health of workers. Diesel engine emissions contribute to environmental injustice, where highly polluting vehicles are concentrated in areas with marginalised communities. Wildfire emissions, made worse by a warming climate, are reversing decades of progress in improving air quality in the United States, as well as melting the Himalayan glaciers and playing havoc with monsoons.

But solutions exist to cut black carbon emissions, with near-immediate benefits. Black carbon is an extremely short-lived climate forcer with an estimated lifetime of just 1-2 weeks. Black carbon emission reductions, complementary to essential deep decarbonisation, offer a practical, fast way to avoid crossing irreversible climate tipping points, improve air quality, and enhance resilience. The case studies in this report show that existing cost-effective policy levers can reduce black carbon, co-emitted air pollutants and greenhouse gases while yielding large, localised benefits.

What is black carbon?

Black carbon is a **short-lived climate pollutant** and a major component of particulate matter that has both air quality and climate impacts. It is the sooty black material emitted alongside other air pollutants during incomplete combustion. For example, diesel engines, coal-fired power plants, wildfires and other sources that burn fossil fuels, biomass and waste emit black carbon.

RECOMMENDATIONS

To realise these benefits:

- **National governments must include black carbon targets and additional actions to achieve them in their revised nationally determined contributions (NDCs).** Nations can exhibit increased ambition in the 2025 global stocktake, demonstrate the Paris Agreement principle of climate action done in the context of sustainable development and poverty eradication and gain access to both mitigation and adaptation financing.
- **Multilateral development banks (MDBs), development agencies and other funders must provide grants and concessional finance to support countries to reduce emissions from black carbon-rich sectors and take targeted action on the remaining sources.** Targeted funding and projects to reduce black carbon emissions will provide multiple other development benefits, including clean air, improved health and improved water and energy security. These projects can satisfy both climate mitigation and climate adaptation goals.
- **More work needs to be done on the measurement and modelling of black carbon and its co-pollutants to resolve scientific bottlenecks.** Considering the urgency and scale of the climate crisis, scientific uncertainty over the precise impact of black carbon needs to be overcome to prevent it from paralysing the accelerated action that the planet needs. Improved emissions inventories, an updated integrated assessment and a closer look from the World Health Organization and health experts are needed.

We must reduce black carbon emissions for fast climate action and to help billions of people around the world breathe cleaner air. The solutions are available now. The time for action is now.

Reducing black carbon emissions is critically important for fast climate mitigation and building resilience to the effects of climate change.

2. BLACK CARBON AT A GLANCE

Regional climate

Black carbon disrupts hydrological cycles over monsoon systems and accelerates regional warming, particularly over the cryosphere. Its effects are felt most strongly closest to its source.

- Black carbon deposition on snow contributes up to 39% of total glacier melting and 10% of glacier mass loss due to reduced precipitation as observed over the Tibetan Plateau.
- Black carbon accelerates the retreat of the Himalayan glaciers, decreases Arctic sea-ice cover in summer, advances the western United States melting season, and increases run-off in the Andean glaciers.
- Black carbon fuels the feedback loop driving Arctic amplification, which has broader effects disrupting the Indian monsoon and the aridification of California.

Climate tipping points

Black carbon warms the atmosphere and snow- and ice-covered land surfaces by absorbing incoming solar radiation, pushing the world closer to critical climate tipping points in cryosphere ecosystems and monsoon systems.

- The Arctic is warming three to four times faster than the global rate, leading to the irreversible retreat of ice sheets. As the radiation-reflecting ice layer melts, darker layers of land and water are exposed, which hasten the melting rate.
- The retreat of the Himalayan glaciers has accelerated by 50% because of black carbon warming and snow darkening. This will have feedback effects on the Indian monsoon.
- The radiative effect of human-induced biomass burning and associated black carbon affects precipitation over the West Africa monsoon region.

Health

Black carbon is a major component of PM2.5, is directly harmful to human health and is co-emitted with other health-harming air pollutants.

- As a component of PM2.5, black carbon contributes significantly to the estimated 4 million premature deaths from outdoor air pollution and 3 million deaths from household air pollution each year, with the greatest burden on low- and middle-income countries.
- Black carbon is strongly correlated with increases in blood pressure levels, a high-risk factor for cardiovascular disease.
- Exposure to black carbon during pregnancy has been linked to multiple adverse birth outcomes including low birth weight.
- Assuming equal toxicity for all components, black carbon is associated with 150,000 excess deaths worldwide.
- If black carbon is significantly more toxic, widespread mitigation has the potential to reduce premature mortality by as much as 400,000 deaths each year over the Indo-Gangetic Plain alone.

Resilience

The influence of black carbon on the hydrological cycle, particularly in monsoon-sensitive countries, increases the risk of extreme rainfall events such as floods, which have devastating impacts on lives, livelihoods and infrastructure.

- Reducing black carbon emissions can help communities to adapt to the climate crisis – turning down temperature rise, reducing heat stress and improving human and ecosystem health.
- Reducing black carbon emissions will improve the food, energy, and water security of billions of people in the Global South who rely on glacier-fed rivers and monsoon rain for their livelihoods.
- Vulnerable communities are disproportionately affected by the impact of black carbon emissions. Thus, addressing black carbon emissions can contribute significantly to climate justice.

Impacts

Extreme rainfall

Food insecurity

Melting of ice

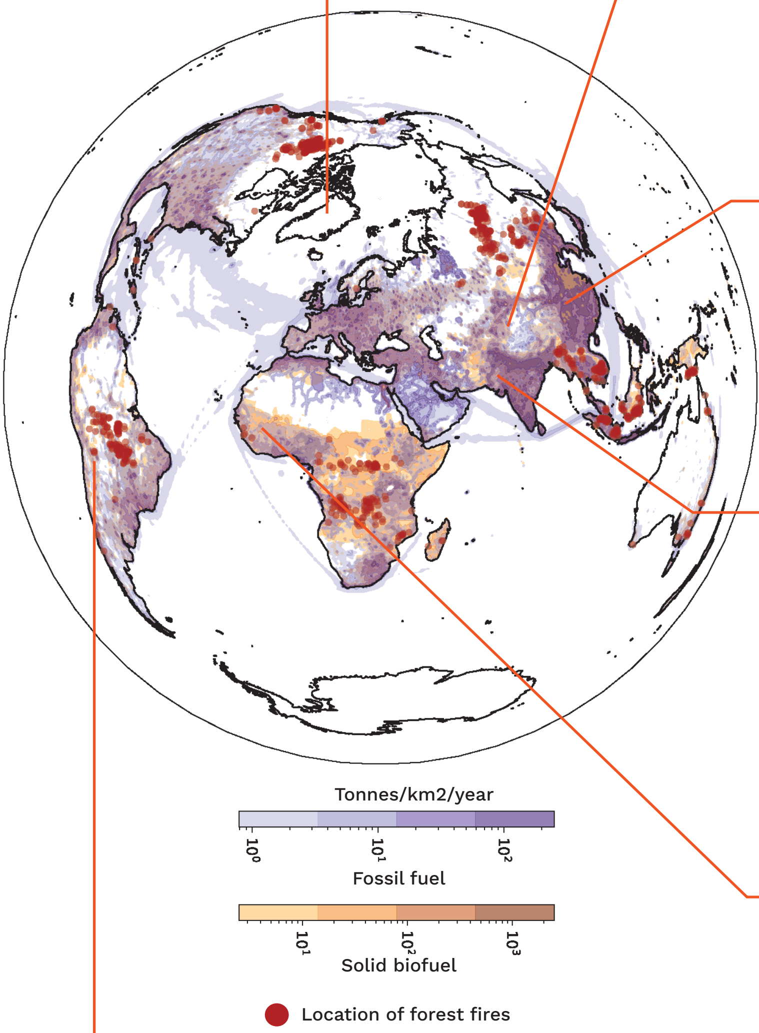
Poor health

Air pollution

Regional effects of black carbon

Arctic

- Black carbon deposition from near-emission sources – for example, gas flaring and shipping
- Poleward heat transport – for example, forest fires and domestic emissions
- Direct impact on European heatwaves, Indian monsoon, and so on



Himalayan glacier retreat

- Near emission source – for example, domestic energy and brick kilns
- The retreat of the Himalayan glaciers accelerated by 50% due to black carbon warming and snow darkening – this will have feedback effects on the Indian monsoon
- Affects regional circulation and monsoon shift

Flooding over Asia

- Extreme rainfall events lead to flooding, for example, in China and India
- Black carbon emission reductions will aid in adapting to floods in a warming climate

Asian monsoon disruption

- Northward shift of tropical rain clouds
- Unseasonal extreme rainfall and disruptions in agriculture and livelihoods
- Early onset also predicted due to black carbon emissions

West Africa monsoon shift

- Decreased monsoon rainfall over West Africa and increased rainfall over north-eastern Africa
- Disruption to agriculture and ecosystems

Americas

- Black carbon snow- and ice-darkening effects
- Advanced melting over western United States
- Increased runoff in the Andean glaciers corresponding to the peak fire season in the Amazon
- Disruption of water availability
- Flood risk and regional hydrology risks

Source: Community Emissions Data System (CEDS)

3. WHY BLACK CARBON?

Gaseous and particulate emissions from human and natural sources fuel climate change and pose global health and environmental risks. These pollutant species are captured to varying extents across climate and environmental policy. Yet, despite the important role it plays, black carbon has fallen between the gaps of climate and air quality frameworks.

Climate policy has emphasised action on carbon dioxide (CO2) and other well-mixed greenhouse gases that are vital climate warming species, and these species are the focus of international target setting and agreements. Conversely, attention on black carbon has lagged. Only a small number of countries have incorporated black carbon targets within their nationally determined contributions (NDCs), and black carbon is not part of any climate protocol, revealing a significant gap in climate strategy.

On the other hand, air quality guidelines focus on PM2.5, nitrogen oxides (NOx), sulphur dioxide (SO2) and other pollutants to reduce air pollution. PM2.5 is composed of many species, primarily sulphates, nitrates, organics, black carbon and dust. Thus, reductions in NOx and SO2 can lead to reductions in PM2.5, and this has been the focus of many successful air quality interventions (for example, fuel sulphur standards). The World Health Organization has highlighted the potential impact of black carbon on health and calls for more studies but has not set guidelines for black carbon, and so national and regional air quality standards do not specifically target black carbon. Regional compacts, such as the Gothenburg Protocol, acknowledge black carbon as a crucial constituent of PM2.5 but do not mandate emissions reporting, and its applicability is geographically confined.[i]

Therefore, despite its role in climate change, awareness, funding and action on black carbon has lagged behind other pollutant species. Scientific complexity has caused uncertainty and stagnation, meaning specific and widespread action on black carbon in the form of targeted regulation and mitigation actions has not materialised. Meanwhile, black carbon emissions are rising in many places and are not diminishing quickly enough in others. This is despite the ready availability of fuels and technologies that can rapidly reduce black carbon emissions; it is technically feasible to reduce global emissions by 70% by 2030 from 2016 levels.[1] The need for mitigation is immediate and urgent. Hence, this policy brief:

- Provides an update on the latest scientific understanding regarding black carbon and its role in climate change, public health and resilience.
- Highlights practical solutions and strategies to reduce or eliminate black carbon emissions.
- Outlines a set of targeted recommendations for governments and funding bodies to ensure fast and widespread adoption of interventions to reduce black carbon emissions.
- Calls for more research to reduce remaining uncertainties in our understanding of the multifaceted impacts of black carbon.

i Black carbon targets are also absent from the ASEAN Agreement on Transboundary Haze Pollution, the Malé Declaration on Air Quality, the UN ESCAP Regional Action Programme, the Latin America and Caribbean Regional Air Quality Action Plan and the West African Nairobi, Lusaka and Abidjan Agreements, yet all offer opportunities to include that.

4. THE LATEST SCIENCE

Influence on global warming

Black carbon affects atmospheric radiative forcing through three distinct mechanisms: aerosol[ii]-radiation interactions, aerosol-cloud interactions, and snow darkening.[iii] The most recent assessment by the IPCC, the Sixth Assessment Report (AR6),[2] projects that black carbon emissions have contributed substantially to historic warming, with a mean global radiative forcing of +0.11 W/m^2 and a range from –0.20 to +0.42 W/m^2. Most of the global average uncertainty is due to the low confidence for aerosol-cloud effects in AR6. However, the effect of emissions from all black carbon-rich sources on near-surface warming and the darkening of snow and sea ice – both crucial to cryosphere and monsoon climate tipping points – is positive forcing with high confidence.[2,3]

Warming the cryosphere

Cryosphere ecosystems hold important climate tipping points crucial to water and energy security, regional climate and agriculture. Black carbon significantly influences regional surface temperatures, particularly in the Arctic,[4] and has a substantial warming effect on the cryosphere, estimated to be approximately three times more potent than that of CO2.[3,5] Black carbon fuels a climate feedback loop of decreased snow and ice cover and increased regional warming, also called Arctic amplification. The Arctic is estimated to be warming three to four times faster than the planet as a whole.[6,7] This has global-scale climate impacts, including affecting the Indian monsoon and the aridification of California.[8] Additionally, black carbon-induced snow-darkening effects have directly hastened glacier retreat in the Himalayas (causing 39% of pre-monsoon melting), advanced the melting season in the western United States with significant impacts on regional hydrology, and increased run-off in the Andean glaciers during the peak fire season in the Amazon (leading to 4.5% of annual glacier melt).[4,9,10]

Effect on rainfall patterns

Climate effects are not just limited to surface temperature changes but involve changes to rainfall patterns and monsoon systems. Black carbon is a significant contributor to regional precipitation changes[11] and has been shown to drive the slowdown of the hydrological cycle, leading to drier conditions.[12] The impact of black carbon on global hydrological sensitivity is nearly twice as much as that of CO2,[13] and extreme weather events are more sensitive to aerosols, specifically black carbon.[14] Black carbon emissions disrupt Asian[15,16] and West African[17] monsoon precipitation, which affects agriculture through increased flooding, damages infrastructure and impacts lives and livelihoods. Black carbon emissions exacerbate rainfall extremes over regions such as India and China.[14,18] The exact impact of black carbon on regional precipitation patterns requires focussed research because of many complexities such as local energy balances, moisture changes and cloud effects.[19–21]

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ii Particulate matter in the climate context is also referred to as aerosols.

iii The three mechanisms are (1) direct radiative forcing through absorption of sunlight estimated at +0.28 W/m^2 (high confidence), (2) deposited black carbon warming/enhanced melting of snow/ice with feedback estimated at +0.07 W/m^2 (high confidence) and (3) indirect effects of black carbon through its ability to form clouds, which changes reflectivity and distribution of clouds and estimated at -0.13 W/m^2 (central estimate; medium likelihood). Indirect effects are the largest source of uncertainty to estimates of black carbon climate impacts[2,46].

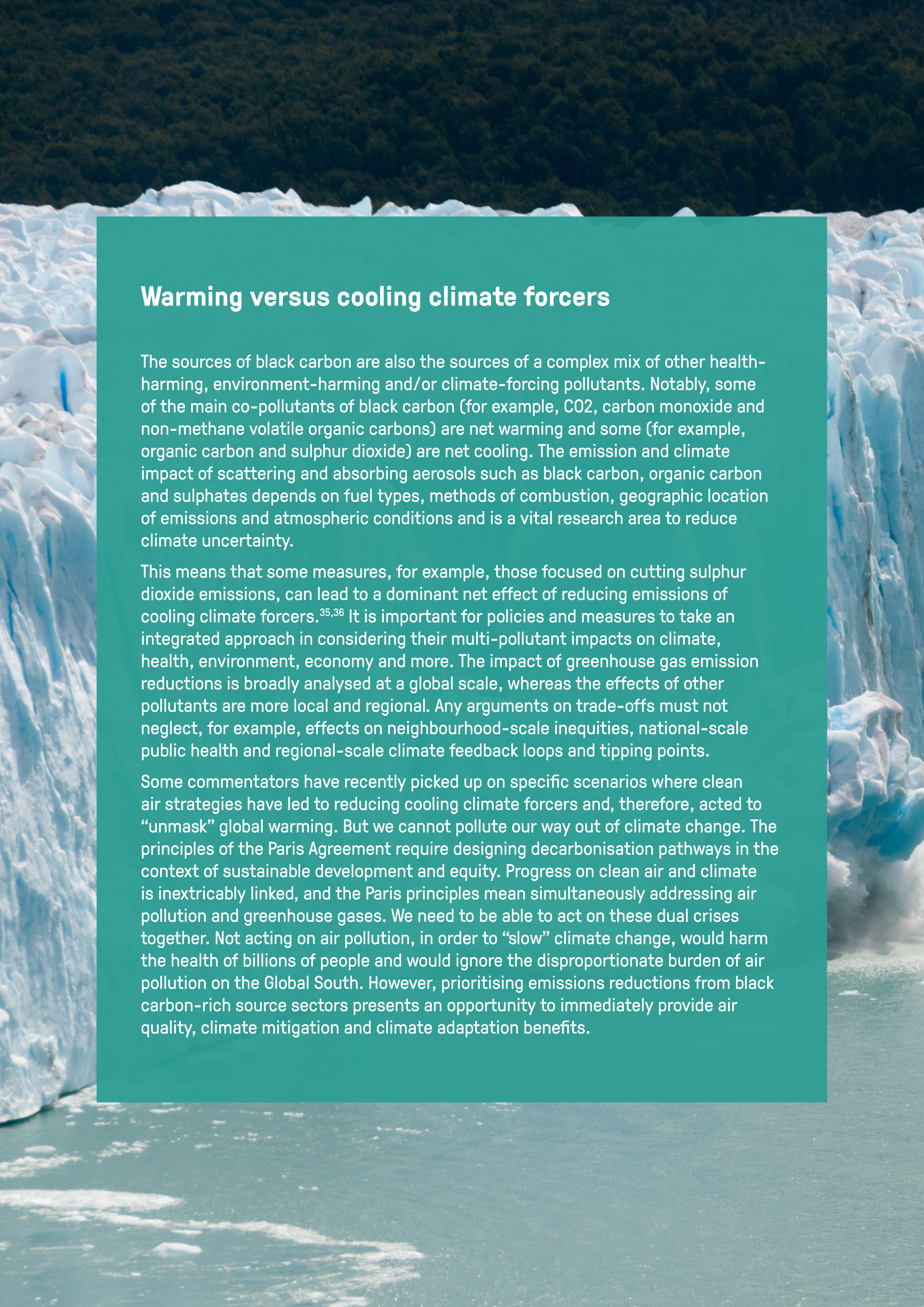
Health effects

Black carbon is a major component of PM2.5 pollution, often making up 10-30% of measured PM2.5 concentrations.[22] As a harmful air pollutant, black carbon significantly contributes to the 4 million premature deaths from outdoor air pollution, the 3 million deaths from household air pollution and the trillions of dollars of economic cost (6% of global GDP)[23] each year.

There is growing evidence on the health impacts of exposure to black carbon specifically, which builds on a plethora of evidence on PM2.5 more broadly. Assuming all components of PM2.5 are equally toxic, outdoor/ambient black carbon exposure is estimated to be responsible for 150,000 excess deaths annually worldwide[24]; black carbon mitigation measures would also reduce co-emitted organic carbon, leading to as much as eight times more avoided deaths.[25] These estimates are biased low since they do not include household air pollution. Residential biofuel use is a significant source of black carbon and a prime target for mitigation measures. Black carbon has been found to correlate more strongly than PM2.5 with high blood pressure levels, contributing more to the burden of cardiovascular morbidity and mortality than other components of PM2.5.[26] As a result, the impact of black carbon reductions could be even higher. A recent study estimated that an 87% reduction of black carbon emissions over the Indo-Gangetic Plain alone could reduce premature mortality by as much as an estimated 400,000 lives annually.[27] Exposure to black carbon in pregnancy has been found to impact on the development and health of newborns and is associated with reduced birthweight.[28]

As with air pollution more broadly, the health risks of black carbon are felt more acutely by the most vulnerable communities in society. Inequities exist in the exposure to many of the major sources of black carbon, including low-income communities often living closer to busy roads with high numbers of diesel trucks and buses[26] and women and children receiving a higher burden of exposure to the harmful emissions from kerosene lamps and stoves.[29]

Black carbon can also worsen extreme heat conditions and increase the risk of heatwave-related mortality. Black carbon has been linked to the increased temperature of heatwaves.[30,31] Also, exposure to elevated levels of air pollution and black carbon has been shown to increase the risk of mortality from heatwaves.[32–34] It is estimated that when particulate matter concentrations were high, heatwaves caused 36% and 106% more deaths in the 75-84 and 85+ age groups, respectively.[32]



Warming versus cooling climate forcers

The sources of black carbon are also the sources of a complex mix of other health-harming, environment-harming and/or climate-forcing pollutants. Notably, some of the main co-pollutants of black carbon (for example, CO2, carbon monoxide and non-methane volatile organic carbons) are net warming and some (for example, organic carbon and sulphur dioxide) are net cooling. The emission and climate impact of scattering and absorbing aerosols such as black carbon, organic carbon and sulphates depends on fuel types, methods of combustion, geographic location of emissions and atmospheric conditions and is a vital research area to reduce climate uncertainty.

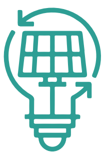
This means that some measures, for example, those focused on cutting sulphur dioxide emissions, can lead to a dominant net effect of reducing emissions of cooling climate forcers.[35,36] It is important for policies and measures to take an integrated approach in considering their multi-pollutant impacts on climate, health, environment, economy and more. The impact of greenhouse gas emission reductions is broadly analysed at a global scale, whereas the effects of other pollutants are more local and regional. Any arguments on trade-offs must not neglect, for example, effects on neighbourhood-scale inequities, national-scale public health and regional-scale climate feedback loops and tipping points.

Some commentators have recently picked up on specific scenarios where clean air strategies have led to reducing cooling climate forcers and, therefore, acted to “unmask” global warming. But we cannot pollute our way out of climate change. The principles of the Paris Agreement require designing decarbonisation pathways in the context of sustainable development and equity. Progress on clean air and climate is inextricably linked, and the Paris principles mean simultaneously addressing air pollution and greenhouse gases. We need to be able to act on these dual crises together. Not acting on air pollution, in order to “slow” climate change, would harm the health of billions of people and would ignore the disproportionate burden of air pollution on the Global South. However, prioritising emissions reductions from black carbon-rich source sectors presents an opportunity to immediately provide air quality, climate mitigation and climate adaptation benefits.

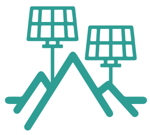
5. SOLUTIONS TO REDUCE BLACK CARBON EMISSIONS

The geographic distribution of black carbon-rich emission sectors exhibits marked variability[3] ,with South Asia predominantly influenced by residential energy consumption and brick kilns, Africa and Southeast Asia principally driven by forest fires and residential energy consumption and the western hemisphere chiefly marked by emissions originating from diesel-powered vehicles and, more recently, wildfires. Close to the Arctic, gas flaring and shipping are also major sources that need urgent attention, with increases in black carbon emissions from shipping despite the urgency of tackling Arctic amplification.[37]

Solutions exist to reduce black carbon emissions across all these priority sectors and regions. The challenges facing many of these solutions are not technical constraints but often relate to financing, business models and policy intervention. Increased funding, building local capacity, sharing lessons learnt and scaling best practices on these solutions can have a quick and tangible effect on black carbon emissions. Case studies of effective interventions, close to climate-sensitive cryosphere and circulation regions, for tackling black carbon-rich sources are provided below.

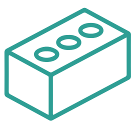


LIGHTING AFRICA



HARNESSING RENEWABLES NEAR THE ARCTIC

DOUSING THE FIRE



SWITCHING TO ZIGZAG

LIGHTING AFRICA

The problem

Around the world, approximately 675 million people still lack access to electricity,[47] 80% of whom live in sub-Saharan Africa. In regions with limited electricity, kerosene wick lamps are a prevalent illumination source and a major source of indoor air pollution as their particulate emissions are composed almost entirely of black carbon. The implications of black carbon are particularly pronounced in West Africa, where its impacts extend to the modulation of monsoon patterns.

The solution

The World Bank's Lighting Africa and Lighting Global programmes have been supporting access to affordable high-quality off-grid solar lighting since 2009, displacing the use of kerosene wick lamps and eliminating the emissions of black carbon. Working in collaboration with governments, the private sector, development partners, financial institutions and others, Lighting Africa and Lighting Global have developed a comprehensive approach to catalyse sustainable off-grid solar markets.

Approximately **32.4 million** high-quality off-grid solar lighting products have been sold across sub-Saharan Africa in the last decade. These Tier 1 and below products are typically used for lighting and displace the use of kerosene lamps.

These products have provided about **415.5 million** people access to clean, safe lighting since 2016.

Displacing kerosene lighting has avoided **24,000 metric tonnes** of black carbon emissions.

Millions of Tier 2 and above products, which include greater solar power generation capacity and can displace kerosene lighting and larger appliances, have also been sold under the programme and has contributed towards SDG7 (access to clean energy).

Financing and opportunities for scaling up

These significant reductions in residential black carbon emissions were realised through expanded access and affordability of high-quality off-grid solar lighting devices – particularly in those areas where reliance on kerosene lamps was the highest. Managed by the Energy Sector Management Assistance Program (ESMAP), the programmes' off-grid energy experts work within the World Bank's energy access teams to support government policy interventions and financial instruments. Scaling programmes such as Lighting Africa and Lighting Global are needed to further expand access. It is estimated that off-grid solar solutions-basic solar lighting products with cellphone chargers (Tier 1) and larger solar home systems (Tier 2 and above)-have the potential to provide clean, affordable electricity to approximately 464 million sub-Saharan Africans by 2030, but additional investments are needed to support the market to deliver on this opportunity.

Financing and affordability continue to be among the most significant barriers to increased uptake. Implementing innovative financing solutions such as microloans or pay-as-you-go models and collaborating with local banks, microfinance institutions and mobile payment platforms can facilitate wider access to these financing options. Additionally, subsidies or grants from governments and international donors can reduce initial costs and encourage adoption, including innovative results-based climate finance schemes. Ensuring that these financial solutions are widely available and tailored to the local economic context can significantly increase the uptake of solar lighting solutions, providing a sustainable alternative to kerosene lamps.

> "After 100 years of conventional grid expansion across sub-Saharan Africa, approximately half of the population remains unelectrified. Off-grid solar provides an opportunity for African nations to accelerate universal access to electricity while mitigating many of the negative environmental impacts unleashed by the use of fossil-fuel-based lighting."
>
> — Erik Fernstrom, Practice Manager, Africa East Energy, Energy Global Practice, World Bank

Impacts

Food insecurity | Poor health | Air pollution

HARNESSING RENEWABLES NEAR THE ARCTIC

The problem

Many near-Arctic communities rely heavily on diesel generators that emit black carbon, which is deposited in the Arctic, leading to the faster melting of Arctic ice. The transport of diesel to these communities also increases costs to the community and shipping emissions.

The solution

A switch from diesel to renewable solar or wind power to meet energy requirements is an effective intervention to mitigate black carbon emissions in the region. Launched in 2018, the Canadian Clean Energy for Rural and Remote Communities (CERRC) programme is meant to reduce diesel reliance for heat and power among indigenous and remote communities[38] in 8 years. An example is the village of Old Crow, an indigenous community in Yukon, Canada, which installed a solar farm in 2021 that meets 25% of the community's electricity demands.

With support from ATCO Electric Yukon and $1.8 million from CERRC, this community-led grassroots project consists of a **940-kilowatt** solar array and **616-kilowatt** battery energy storage system that saves up to **190,000 litres** of diesel annually – the equivalent of removing 140 cars from the road.

This avoids emissions of about **680 tonnes** of CO2 and **40 kg** of black carbon each year.

Financing and opportunities for scaling up

CERRC is supported by over $160 million from the Government of Canada; the programme supports over 100 such projects across Canada. Similarly, other countries in the Arctic also have off-grid renewable energy programmes. For example, the USA has implemented the Renewable Energy Fund[39] in Alaska, where $250 million supports 73 projects currently in operation. Such programmes also exist in Russia, Norway and Sweden. Not only are such programmes viable in the Arctic, but they can also be implemented in cryosphere-adjacent regions elsewhere in the world such as Nepal, India and the Hindu Kush region in Pakistan and Afghanistan.

> "This project is a great example of how international, national and local policy all intersect, with great outcomes for local communities and people and for the planet. You have Canada as part of the Arctic Council committing to a black carbon target, incorporating black carbon into its NDC under the Paris Agreement and then developing a national programme and significant funding for off-diesel electrification for rural and remote communities to deliver on its commitments. And you have the local government taking a leadership role on the ground and driving very innovative change in challenging circumstances. A win for local health, a win for local development and a win for the climate, especially the sensitive Arctic environment, which is already under severe stress."
>
> — Dan McDougall, Former Climate Change Ambassador, and Assistant Deputy Minister, Strategic Policy Branch, Environment and Climate Change Canada

Impacts

Melting of ice

Poor health

Air pollution

SWITCHING TO ZIGZAG

The problem

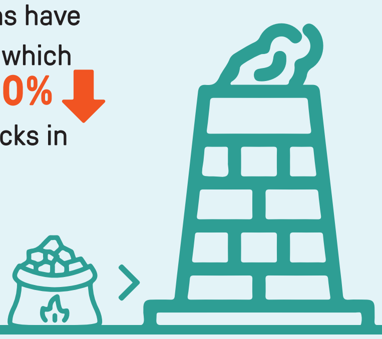
Brick production can be a significant source of black carbon emissions.[40] Nepal has about 1,300 traditional brick kilns, which emit an estimated 1,200 tonnes of black carbon and 1.3 million tonnes of CO_2 per year.[41] In Kathmandu Valley, brick factories are estimated to contribute to about 40% of air pollution.

The solution

The International Centre for Integrated Mountain Development (ICIMOD), in collaboration with the Federation of Nepal Brick Industries (FNBI), facilitated the transition to cleaner zigzag kiln technology.[41, iv] The opportunity to transition to zigzag kilns came following the 2015 earthquake that damaged about 40% of the traditional brick kilns in Nepal.

In 2015, ICIMOD also launched the "Design Manual: Improved Fixed Chimney Brick Kiln", which focused on earthquake-resistant, energy-efficient and eco-friendly kiln design. This was followed by a memorandum of understanding between 12 brick kiln entrepreneurs and FNBI, outlining reconstruction responsibilities.

As of 2023, **476** traditional kilns have been converted to zigzag kilns, which reduces coal consumption by **20%** and produces better-quality bricks in a cost-efficient manner.



When properly operated, zigzag kilns are estimated to reduce emissions of

PM2.5 by 40%

Black carbon by 60%

CO_2 by 12%

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iv True zigzag technology includes four essential elements working in unison: zigzag chimney design, electric blowers/ air circulators, enhanced kiln insulation and fuel management. Interventions that do not include all four aspects may not see similar results to those reported.

Zigzag kilns are important in the transition to cleaner electric kilns, which unfortunately are not yet widely used due to their high investment costs.

ICIMOD's successful intervention in Nepal emphasises the importance of adopting better technologies to create a significant social impact, and this programme has been expanded to Pakistan.

Financing and opportunities for scaling up

The ICIMOD project in Nepal was supported by $1 million from Climate and Clean Air Coalition and $1.2 million from the UK Department for International Development. Only an initial investment to convert from traditional to zigzag kilns is required. Zigzag kilns are more cost-efficient to operate and yield superior "A" grade bricks, which generate higher incomes for the workers, thus making it more sustainable in the long term. However, nonfinancial (technical and business) support for brick kiln owners and worker retraining may be needed for optimal zigzag kiln construction and operation[42].

Similar programmes are underway in Pakistan, India and Bangladesh. In Bangladesh, a government ban on the use of fixed chimney kilns led to 50% of these kilns being converted to zigzag kilns without external funding. These interventions can also be adopted in Latin American countries where 45,000 brick producers operate[40].

> "ICIMOD has pioneered a transformative model for brick kilns in South Asia. This model has also emphasised gender and social inclusion, focusing on aspects such as the health and safety of workers, as well as education for their children. One of the key successes of this approach has been the adoption of a Social Code of Conduct, co-developed with ICIMOD, by the Federation of Nepali Brick Industries (FNBI)."
>
> — Ms Bidya Pradhan, Senior Atmospheric Environment Specialist at ICIMOD

Impacts

Extreme rainfall | Food insecurity | Melting of ice | Poor health | Air pollution

DOUSING THE FIRE

The problem

There has been a significant increase in the area and frequency of wildfires worldwide, including in West Africa. The wildfires are often the result of human actions. Increasing wildfires lead to higher greenhouse gas and black carbon emissions, which contribute to rising global temperatures and poor air quality. Rising temperatures in turn increase the likelihood of wildfires and increased emissions, creating a vicious feedback loop.

The solution

In 2017, Form International and Form Ghana developed the Forest Landscape Restoration Program, an Integrated Community Fire Management Project that included fire service, community fire volunteers, traditional authorities and community leaders.[43] An outright ban on agricultural fires that was previously in place was repealed, and controlled fires were allowed again under revised bylaws but only under the supervision of trained and equipped community fire volunteers who work according to a set of operating procedures. A new operational procedure was developed that combined good traditional working practices along with new ones such as the use of a fire danger index. Awareness and capacity-building programmes were also implemented that bolstered the monitoring, operation and communication between the various local and government authorities.

Within 4 years of implementing the Community Fire Management Project, the number of wildfires was reduced by **78%**.

In Ghana, wildfires contribute 8,000 tonnes/year of black carbon or almost half of the country's emissions.

So, if the fire management project was scaled nationally, it could avoid emitting about **6,000 tonnes/year** of black carbon.

Financing and opportunities for scaling up

The success of the initial project led to its adoption by a private forest restoration service. Funds were received from organisations such as Partnership for Forests and DOB Ecology to design and implement the project.

Wildfires can be monitored using satellite data. ICIMOD[44] in Nepal has launched such a wildfire alert service, and the same method can be used to track the effectiveness of fire management programmes. Properly managing fires around the Himalayas may require regional cooperation between the Hindu Kush Himalaya countries.

> "By taking a community-based approach that focuses on fire prevention rather than suppression, uncontrolled forest fires can be drastically reduced in number and size in rural areas. It all begins with open and transparent discussions between all land users so that the challenges at the governmental, social, environmental and organisational levels become clear. By implementing an improved operational structure by adapting traditional working practices and by adding new measures, people on the ground, in the villages, can be empowered to take back responsibility and control over wildfires. Both governments, the private sector and other parties in the landscape should collaborate to embed such an approach into national and regional fire prevention programmes."
>
> – Rosa Diemont, Landscape Restoration and Forestry Expert, Form International

Impacts

Food insecurity

Melting of ice

Poor health

Air pollution

6. CASE FOR ACTION

The Arctic is now warming three to four times faster than the rest of the planet, rushing towards dangerous tipping points and affecting global climate feedback loops. Glaciers are melting faster than ever in the Himalayas, the Andes and the Alps. Monsoons have become more unpredictable and result in more extreme flooding, causing significant loss of life and damage to infrastructure.

The severity of the climate crisis is getting starker. Policy makers are looking for levers to pull that will hold back temperature rises and slow progress towards irreversible tipping points while the deep and rapid CO2 emissions cuts, essential to longer-term planetary survival, are being implemented. The family of gases and particles that cause health-harming air pollution and contribute intensely to climate change is a key place to look. Reducing short-lived climate pollutants, from methane to black carbon to tropospheric ozone, is a smart way to curtail near-term warming.

Consensus has emerged that action can and should be taken on methane, which offers the possibility of preventing 0.3°C of warming by 2050.[45] Now attention must also turn to other important climate pollutants. Black carbon, once a focus of climate endeavour, fell from attention amid political disputes and doubts over the significance of its contribution to warming. The latest science has made it clear that black carbon has a major impact on regional climate feedback loops, tipping points and weather patterns. Further research will pin down the exact magnitude of its contribution. But until then, the net warming effect, alongside the potential to build resilience in vulnerable regions and improve public health, is justification enough. A targeted approach on black carbon is an urgent, necessary and effective tool for combatting dangerous climate change.

Accordingly, black carbon should be a part of the mainstream climate agenda and climate strategies. The good news is that action to reduce black carbon emissions is possible now, using existing technologies and established practices. The short atmospheric lifetime of black carbon means that the benefits of reducing its emissions will be near immediate.

Furthermore, black carbon is not just a climate mitigation issue. Cutting black carbon emissions can build resilience, help communities adapt to a warming climate and improve public health, with these benefits felt most strongly close to the source of emissions. Targeted and fast action on black carbon can reduce the risk of extreme rainfall events and floods, reduce heat stress and improve people's ability to cope with extreme heat while increasing food and water security. It can also help us achieve clean air, preventing millions of deaths per year, and undo longstanding environmental injustices.

Alongside deep decarbonisation, we need to take a closer look at critical non-CO2 climate forcers. The case for action is clear: strategically tackling black carbon-rich emission sources within climate strategy presents a near-immediate way to secure fast climate mitigation and achieve sustainable development and social and health benefits that are aligned with the principles of the Paris Agreement.

7. RECOMMENDATIONS

Recommendations are provided below for policy makers and funders and to advance the latest science and research. These steps can help avoid crossing irreversible and fast-approaching climate tipping points and deliver clean air for billions of people. More specific actions and sectoral interventions are outlined in Annex A.

Policy making and regulation

Leadership and fast action on non-CO2 pollutants such as black carbon are fundamental to mitigating the worst effects of climate change within the next few years, alongside deep decarbonisation. Building on the momentum from the methane movement, policy makers must grasp the opportunity to show ambition on these crucial climate forcers. Yet the Climate and Clean Air Coalition (CCAC) has recognised just 17 national governments that have included black carbon in their national targets, with fewer committing to dedicated and directed actions to reduce these emissions.

All countries must commit to new, additional controls on black carbon emissions with concrete action plans that will result in measurable emission reductions as quickly as possible. As black carbon reductions have such fast-acting impacts on the climate system and air quality, speed of implementation must be the essential metric.

- All countries should include black carbon in their 2025 NDCs in a way that reduces black carbon emissions beyond what would be achieved with decarbonisation and methane mitigation actions alone. This approach will demonstrate the Paris Agreement principle of climate action done in the context of sustainable development and poverty eradication.
- Countries should (1) prioritise deep decarbonisation of black carbon-rich sources such as brick kilns, diesel engines and kerosene lamps; (2) support community-led forest fire management and (3) promote black carbon-free alternatives to residential biofuel use through policies, regulations, monitoring and funding measures.
- Countries of the Arctic Council should resume and enhance the ambition they have already demonstrated in addressing black carbon with an aggressive post-2025 black carbon reduction target. The Arctic Council should also engage with all observer countries and "observer-aspirant" countries to commit to a complementary black carbon target, individually or collectively.
- Countries should develop integrated greenhouse gas and air pollutant inventories and include short-lived climate forcers in their national inventory reports to the UNFCCC.
- Leadership organisations in other cryosphere regions, such as the Association of Southeast Asian Nations (ASEAN), Economic and Social Commission for Asia and the Pacific (ESCAP) and ICIMOD, should adopt and adapt the Arctic Council approach to collectively reduce black carbon emissions and drive climate and health benefits for their region.
- Countries should engage and support subnational jurisdictions in their efforts, particularly cities as they are concentrated sources of black carbon impacts and solutions.
- Efforts should be made to engage and include the health and medical communities in developing black carbon action plans that can be translated into strengthened NDCs. Similarly, those working on climate justice and climate equity issues should also be engaged, given the environmental justice impacts of black carbon and co-emitted air pollutants.

Funding

The aforementioned black carbon reduction efforts should be supported by donor countries, multilateral development banks (MDBs) and philanthropic foundations through grants and concessional development financing so that recipient countries do not suffer debt distress as in the past.

- **Donor countries** funding decarbonisation efforts under Article 6.2 or other bilateral agreements should prioritise projects that simultaneously have the greatest potential to reduce black carbon emissions.
- **MDBs** should scale up financing for air quality programmes that target black carbon-rich sectors, expand GHG accounting to include all short-lived climate pollutants (SLCPs) for ongoing and new projects and engage with the Green Climate Fund to explicitly include black carbon in their finance instruments. Adaptation finance can open a new avenue of resourcing for black carbon reductions, with a type of finance that is more grant-based.
- **Philanthropies** should engage with the World Bank, the Global Environment Facility and regional MDBs to integrate black carbon into their programming and operations. They can support Non Governmental Organisations to develop awareness campaigns, build capacity for black carbon reduction efforts and develop sector-specific or city-specific black carbon mitigation plans. Critically, philanthropies can fill gaps in financing for mitigation actions where market forces or other financing mechanisms are insufficient or unlikely to reach.

Science and research

Our recommendations are based on well-understood effects of black carbon on snow and ice, hydrological cycles and human health. Granting bodies (public or private) should support further scientific research to reduce the remaining uncertainties in our understanding of black carbon and other aerosols, especially their interaction with clouds. To overcome scientific bottlenecks, research efforts should include:

- An updated integrated assessment of black carbon, which was last conducted in 2011 by CCAC, United Nations Environment Programme and World Meteorological Organization could especially look at regional impacts that have become more prominent in the past decade.
- Tools to develop better emission inventories and automated, verifiable means of tracking the effectiveness of black carbon reduction measures, including the use of satellite data.
- The World Health Organization revisiting the health impacts of black carbon with a view to adding it to the air quality guidelines. A key roadblock has been the lack of long-term black carbon monitoring data that can support epidemiological studies. Making ambient black carbon monitoring more affordable and accessible to low- and middle-income countries would overcome this critical data gap.
- Metrics to assess and track climate progress must be developed to account for long-term, short-term and regional climatic impacts of all relevant pollutant species to simultaneously reduce tipping point risks and manage near- and long-term warming.
- More regional climate modelling is needed to better understand the more localised and regional impacts of these pollutants. If in-country or regional expertise is not available, that should be developed through capacity building and infrastructure support.

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