BLACK CARBON MITIGATION AND THE ROLE OF THE GLOBAL ENVIRONMENT FACILITY:

A STAP Advisory Document

Scientific and Technical Advisory Panel

An independent group of scientists which advises the Global Environment Facility

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ACKNOWLEDGEMENTS
This document benefited greatly from the contributions of Patrick Kinney (Columbia University Mailman School of Public Health), Andrew Eil (Independent Consultant), and Danny Malashock (Independent Consultant). The authors would also like to thank the following people for their peer review of the report: Nathan Borgford-Parnell, Sandra Cavalieri, Amanda Curry-Brown, Laurent Granier, Yekbun Gürgöz, Philip Hopke, Zbigniew (Zig) Klimont, Johan Kuylenstierna, Sunday Leonard, Mike MacCracken, Pradeep Monga, Jacob Moss, Martina Otto, Jamie Schauer, Noah Scovronick and Durwood Zaelke. Special thanks to Bob Dixon of the GEF Secretariat for having encouraged STAP to develop this Advisory Document. Thanks also to Lev Neretin of the STAP Secretariat for his thoughtful guidance and review, and to STAP Secretariat Intern Mindi Depaola for assistance in developing case studies and additional support throughout the process.

Editor: Mark Foss
Design and Layout: Dammsavage Inc.
Cover photo: Crispin Hughes/Panos

CITATION
Sims, R., V. Gorsevski and S. Anenberg (2015). Black Carbon Mitigation and the Role of the Global Environment Facility: A STAP Advisory Document. Global Environment Facility, Washington, D.C.

ABOUT STAP
The Scientific and Technical Advisory Panel comprises seven expert advisors supported by a Secretariat, who are together responsible for connecting the Global Environment Facility to the most up to date, authoritative and globally representative science.

http://www.stapgef.org

ABOUT THE GEF

The Global Environment Facility (GEF) unites 183 countries in partnership with international institutions, civil society organizations (CSOs) and the private sector to address global environmental issues, while supporting national sustainable development initiatives. An independently operating financial organization, the GEF provides grants for projects related to biodiversity, climate change, international waters, land degradation, chemicals and waste.

FOREWORD

The primary objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to "avoid dangerous anthropogenic interference with the climate system". To achieve this, the global community will have to use every means available and focus on all climate-changing emissions to the atmosphere. This list includes short-lived climate pollutants (SLCPs) such as black carbon (BC), methane (CH_4) and other precursors of tropospheric ozone (O_3). Reducing the emissions of SLCPs can help slow the rate of global warming – particularly over the next two to four decades. In so doing, it would increase the probability of staying below the target of a 2°C maximum global temperature rise above pre-industrial levels as agreed to by the 195 parties to the UNFCCC at the 16th Conference of the Parties at Cancun in 2010.

The "business as usual" pathway that continues to increase atmospheric concentrations of greenhouse gases (GHGs), especially carbon dioxide (CO_2), the most important greenhouse gas, will likely lead to about a 4°C temperature rise by the end of this century. All parties to the UNFCCC and many scientific groups, as well as leaders of the G-7 countries[1], have therefore called for a limit on the temperature increase to 2°C. This will require a rapid transition away from a global energy system based on fossil fuels as well as a reduction in SLCP emissions. The state of knowledge regarding the impacts of SLCP emissions is rapidly advancing, and the Intergovernmental Panel on Climate Change (IPCC), World Bank, UNEP, and others have recently released a number of pertinent studies. The increasing recognition of the importance of reducing emissions of SLCPs in achieving short-term climate benefits, while simultaneously continuing efforts to mitigate long-term CO_2 emissions, provides the main impetus for this report.

STAP initially drew attention to the role of SLCPs and their mitigation potential for the GEF Partnership in its 2012 report entitled "Climate Change: A Scientific Assessment for the GEF". Subsequently, the GEF included SLCP mitigation in the GEF – 6 Climate Change Mitigation Program (GEF/R.6/20/Rev.04). It also sought STAP's assistance in recommending how to embed the mitigation of SLCPs in the GEF project portfolio, as well as to provide guidance to Implementing Agencies on mitigation technologies and measuring protocols and methods.

In response to the GEF's request, this report provides in-depth information on one major SLCP – black carbon. Emissions of BC, from a range of sources, cause a net increase in radiative forcing and their mitigation could slow the rate of climate change in the near term. In addition, controlling BC emissions through carefully selected measures could support sustainable development while simultaneously improving air quality, human health, and food and water security, particularly for local communities.

1 Leaders' Declaration of the G-7 Summit, 7-8 June, 2015
https://www.g7germany.de/Content/DE/_Anlagen/G8_G20/2015-06-08-g7-abschluss-eng.pdf?__blob=publicationFile

Unlike long-lived and well - mixed CO_2, BC concentrations in the atmosphere are highly variable across regions, as are their impacts on local populations and ecosystems. The opportunities for abatement also vary; several emission reduction measures targeting black carbon and ozone precursors are already available and in use in some parts of the world. If implemented globally, these measures alone could reduce warming by about 0.2°C by 2050; avoid millions of deaths annually from indoor and local outdoor air pollution exposure; reduce millions of workdays lost to illness; and reduce losses of crop yields[2].

The GEF is a champion of the global commons dedicated to promoting innovation for global environmental benefits. Since 1991, it has funded projects in more than 165 developing countries to address global environmental issues, including climate change. The GEF, therefore, is uniquely positioned to build knowledge and awareness of BC sources, their impacts, and to integrate means of reducing BC emissions in projects, and into the broader GEF portfolio.

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2 UNEP/WMO (2011). Integrated Assessment of Black Carbon and Tropospheric Ozone: Summary for Decision Makers. United Nations Environment Programme/World Meteorological Organization. http://www.unep.org/dewa/Portals/67/pdf/BlackCarbon_report.pdf

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ACRONYMS AND ABBREVIATIONS

ABC	Atmospheric brown cloud
AMAP	Arctic Monitoring and Assessment Programme
BAU	Business as usual
BC	Black carbon
BCFSG	Black carbon finance study group
BrC	Brown carbon
CCAC	Climate and Clean Air Coalition
CCM	Climate change mitigation
CLRTAP	Convention on Long-Range Trans-boundary Air Pollution
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CH_4	Methane
DPF	Diesel particulate filter
EC	Elemental carbon
ESP	Electrostatic precipitators
FAO	Food and Agriculture Organization of the United Nations
FD	Forced draught
FSP	Full-size project
GEB	Global environmental benefits
GEF	Global Environment Facility
GHG	Greenhouse gas
GTP	Global temperature potential
GWP	Global warming potential
HAPIT	Household Air Pollution Intervention Tool
HFC	Hydrofluorocarbon
IADB	Inter-American Development Bank
IAP	Integrated Approach Pilot
IC	Improved cook-stoves
ICCI	International Cryosphere Climate Initiative
IHME	Institute for Health Metrics and Evaluation
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IPCC AR5	Intergovernmental Panel on Climate Change Fifth Assessment Report
LD	Land degradation
LEAP	Long range energy alternatives planning
LEDS	Low emission development strategy
LL-GHG	Long-lived GHGs
LPG	Liquid petroleum gas
MODIS	Moderate resolution imaging spectro-radiometer
MSP	Medium-size project

NAAQS	National Ambient Air Quality Standards
NMVOC	Non methane volatile organic compounds
NOx	Nitrogen oxides
OC	Organic carbon
OCRB	Open crop residual burning
O_3	Ozone
PDF	Project development framework
PIF	Project identification Form
PM	Particulate matter
$PM_{2.5}$	Fine particulate matter
POPs	Persistent organic pollutants
RF	Radiative forcing
SDGs	Sustainable Development Goals
SEI	Stockholm Environment Institute
SFM	Sustainable forest management
SLCP	Short-lived climate pollutant
SLCF	Short-lived climate forcer
SO_2	Sulfur dioxide
STRUCE	Surface temperature response per unit of continuous emissions
SUMS	Stove use monitors
TDM	Travel demand management
TEEMP	Transportation Emissions Evaluation Model for Projects
UND	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UPOPs	Unintentional persistent organic pollutants
USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency
VOCs	Volatile organic compounds
VSBK	Vertical shift brick kiln
WB	World Bank
WHO	World Health Organization
WMO	World Meteorological Organization

EXECUTIVE SUMMARY

Black carbon (BC) is formed by the incomplete combustion of fossil fuels and biomass. It is the most strongly light-absorbing component of fine particulate matter, and a local and regional air pollutant. It is also a short-lived climate pollutant (SLCP) with a lifetime of only days to weeks after release into the atmosphere. During that short period, it can have significant direct and indirect radiative forcing (warming) effects that contribute to anthropogenic climate change at regional and global scales. Black carbon also accelerates the rapid melting of the cryosphere, particularly in the Himalayas and the Arctic, adding urgency to the need to decrease emissions into the atmosphere. All SLCPs should be considered since the impact of each species is highly complex on the local and global atmosphere, and demands specific options for emissions control and measurement techniques. This guidance note concentrates solely on black carbon to impart a more in-depth review of this important species.

Several studies have demonstrated that carefully selected measures to prevent the release of microscopic BC particulate products arising from the incomplete combustion of fossil fuels and biomass can reduce near-term warming and improve human health. BC is not the only substance emitted from incomplete combustion, and the climate impacts depend on the full range of co-pollutants emitted from a particular source. The challenge facing the Global Environment Facility (GEF) is how best to operationalize BC mitigation measures into its portfolio of projects.

The GEF – 6 Strategy (2014 – 2018) specifically highlights the need to incorporate BC, as well as other SLCPs including methane, hydrofluorocarbons (HFCs) and tropospheric ozone (O_3) into climate change mitigation projects[1]. Since the GEF provides support for partner countries to address global environmental issues, it is well-positioned to support BC mitigation measures across all relevant sectors where appropriate. However, it does not provide direction on how to accomplish this in practice. In this regard, the Climate and Clean Air Coalition (CCAC) has prepared a guidance note for countries wishing to include BC in their Intended Nationally Determined Contribution (INDC) to the UNFCCC[2] and some countries have already begun considering measures to reduce BC emissions. For example, in its INDC Mexico has included a 51% reduction by 2030 of its current BC emissions[3].

This report provides an overview of BC emissions, including co-emitted species, their sources, impacts, and potential mitigation approaches. It summarizes the state of current knowledge; provides specific recommendations to the GEF Partnership about BC mitigation options; identifies the multiple benefits from reducing BC emissions, including improved human health and reduced crop losses; and highlights various ways in which GEF investments can catalyze future action and realize these co-benefits.

BC and carbon dioxide (CO_2) are co-emitted during fossil fuel and biomass combustion. Hence displacing these fuels with alternatives will help reduce both short-lived and long-lived GHGs. Similarly, reducing fossil fuel demand by improved energy efficiency measures (to achieve the same energy services while burning less fuel) can also reduce both types of GHGs. A methodology for incorporating all GHG and SLCP emissions into a single climate impact assessment has yet to be developed. Meanwhile, the methods for reducing BC emissions as outlined in this report will enable the GEF to consider the implications of mitigation for its project portfolio.

1 This is also supported by the CCAC/World Bank Black Carbon Finance Study Group report (World Bank, 2015).

2 *Guidance Note on Short-Lived Climate Pollutants for Intended Nationally Determined Contributions*, Ver. 09-03-2015. Prepared by the *Supporting National Planning for Action on SLCPs (SNAP) Initiative Lead Partners* in consultation with members of the Scientific Advisory Panel (SAP), Climate and Clean Air Coalition. www.ccacoalition.org.

3 http://www4.unfccc.int/submissions/INDC/Published%20Documents/Mexico/1/MEXICO%20INDC%2003.30.2015.pdf

KEY MESSAGES:

- BC is the most strongly absorbing component of fine particulate matter ($PM_{2.5}$) and contributes to regional and global climate change in the near-term (over months to a few decades). Reducing BC emissions can help slow the rate of climate change, reduce local air pollution, improve human health and security of food and water supplies, and support achieving the Sustainable Development Goals (SDGs).

- Moderating the pace and magnitude of global climate change will require aggressive efforts to reduce CO_2 emissions (mainly through lowering energy demand and decarbonizing energy systems) which will affect the climate system over centuries, as well as reduce BC and other SLCPs, which would have a more immediate climate effect.

- The scientific knowledge and understanding of BC emissions and atmospheric concentrations, their measurement, impacts and mitigation options, continue to advance rapidly. Emissions from solid-fuelled cook-stoves and from the combustion of diesel and other transport fuels, as well as from the flaring of natural gas, burning of crop residues and forests, and heating of brick kilns, can be reduced by appropriate interventions.

- The most promising mitigation opportunities in a given region depend on local circumstances, such as the major sources of BC emissions and the feasibility of each individual technological and social mitigation strategy and policy. The main emitting sectors of BC in developing countries are open biomass burning and residential solid fuel combustion for cooking, whereas in developed countries transport dominates BC emissions. In East Asia, most emissions stem from industrial use of coal.

- Where the presence of BC indicates inefficient combustion, then more efficient cook-stove or heating appliance designs will reduce emissions and lower fuel costs. This, in turn, contributes to family well-being, poverty alleviation and other such benefits. Also, reduced fuel consumption in more efficient residential cook-stoves can lead to a decrease in fuelwood demand, resulting in improved ecosystem health and enhanced carbon storage.

- The emission of 1 tonne of BC can have different impacts on health and climate depending on the source, location and the extent of co-pollutants, especially those that result in climate-cooling. Therefore, the avoidance of 1t of BC emissions cannot always be a common metric when used across various interventions. So, unlike having a common approach for GHG emission abatement, financing BC abatement needs to be customized to match the specific circumstances.

- The Black Carbon Finance Study Group Report 2015 of the CCAC and World Bank[4] concluded that unlocking funding requires the development of BC performance standards and metrics. This will allow financiers to understand the impact of mitigation actions on health and climate benefits when evaluating and screening potential project proposals.

4 See World Bank, (2015) and http://www.unep.org/ccac/Publications/Publications/BlackCarbonFinanceStudyGroupReport2015/tabid/1060194/Default.aspx

Black carbon accelerates the rapid melting of the cryosphere, particularly in the Himalayas and the Arctic.

- Direct emissions of BC from a single point source (such as a diesel vehicle exhaust pipe or a biomass plant chimney flue) can be measured with a reasonable degree of accuracy. However, any changes in atmospheric loadings from reducing BC emissions as part of a typical, accredited mitigation project are usually too small to measure. These can only be evaluated by modeling techniques.

- Atmospheric BC loadings can be measured, or estimated using widely proven and innovative methods at multiple scales[5]. Several tools are under development to quantify changes in climate, health and agricultural impacts resulting from reducing BC and other related pollutant emissions.

5 See for example, http://www.unep.org/NewsCentre/default.aspx?DocumentID=26840&ArticleID=35403

KEY RECOMMENDATIONS:

The GEF strives to utilize its resources and network to introduce innovation in the design of programs and policies in a manner that encourages early adoption and scaling up to support the stewardship of the global environmental commons[6]. As such, the GEF is well positioned to channel financial and technical resources to help address near-term climate warming by operationalizing BC mitigation as a complementary strategy to its climate change mitigation program and the Integrated Approach pilots (IAPs)[7]. Based on the current state of knowledge concerning BC emissions and related climate impacts, STAP recommends the GEF Partnership take the four following areas of actions:

1. Mainstream BC mitigation measures into the GEF project portfolio, including the Integrated Approach Pilots (IAPs).

- Include interventions to reduce BC emissions[8] and support methods for measuring, monitoring and impact evaluation to more fully characterize the co-benefits.

The GEF finances numerous projects aimed at reducing CO_2 emissions across the residential, transport, industrial, forestry and agricultural sectors (see Boxes in sections 3 and 4 of this report). Many of the projects, including the IAPs on food security and sustainable cities, support measures such as clean and efficient design solutions for cook-stoves, more efficient brick kilns and low-carbon transport modes. In

6 See the Vision Statement of the GEF CEO at https://www.thegef.org/gef/sites/thegef.org/files/publication/GEF-vision-Ishii.pdf.

7 See https://www.thegef.org/gef/GEF-6-integrated-programs for more information on the Integrated Approach Pilots (IAPs).

8 Based on a suite of control measures that reduce BC as proposed in the UNEP (2011) Synthesis Report.

addition to reducing emissions of long-lived CO_2, these projects could also reduce amounts of BC and other co-emitted short-lived climate pollutants (SLCPs) released into the atmosphere. Information on the extent to which a project or program will have an expected impact on BC emissions could be included at the early concept stage, for example, in the Project Information Form (PIF) or the Program Framework Document (PFD).

- Give priority to GEF climate change mitigation projects that reduce both long-term and short-term climate forcers.

Given the large climate change mitigation potential of using cleaner and more efficient cook-stoves, which also provide co-benefits such as reduced demand for fuelwood and improved local air quality and public health, the GEF should scale up financial support for clean cook-stove design initiatives. Ongoing GEF support for sustainable low-carbon urban development and transport could also be expanded to include specific BC control measures. Examples of such measures include improving the quality of diesel fuel and the installation, and regular maintenance of diesel particulate filters for both on- and off-road vehicles.

2. Support programs and stand-alone projects that focus on the reduction of BC emissions.

- Projects could emphasize the importance of financing integrated BC-reducing solutions that consist of monitoring and assessment, technology transfer, policy and regulatory support, capacity building and awareness raising among countries and cities that are major BC emitters.
- The selection and design of specific control measures for BC emissions could be based on the assessment of benefits and trade-offs among different project objectives (e.g. climate mitigation potential, air pollution control, public health benefits). These, in turn, are driven by the enabling environment, including technologies, policies, measures and regulations, and the financial and geographical conditions of the region and country where mitigation measures are planned.

3. Measure, account for and report on the amount of BC emissions avoided or reduced as a result of GEF-funded projects.

- The GEF should begin to introduce reporting on near-term climate change mitigation impacts from BC emissions into GEF–6 projects. A project proposal could consider the amount of BC emission reductions expected to be achieved (taking into account co-emitted species, if any) as a co-benefit of climate mitigation financing. Project-specific interventions and emission reductions could be consolidated into the GEF's reporting activities on its programming to the UNFCCC and other relevant entities.
- Measurement and monitoring methods continue to be developed to quantify BC emissions, as well as changes to atmospheric concentrations. The GEF should be aware of, and actively participate in, discussions regarding methods and tools available and under development for measuring and monitoring BC and any co-emitted pollutants. It could support financially the development of an indicator (or indicators) and methodologies for measuring BC emission reductions.

Woman in Rajasthan, India carrying buffalo dung to dry and use for cooking, a source of local air pollution in many rural areas.

Therefore, the GEF should liaise closely with the Climate and Clean Air Coalition (CCAC),[9] World Bank, UNEP and others to assess the practicality of future measuring systems as they are developed and improved.

- An additional area for GEF support is the development and use of BC performance standards (such as the emerging ISO standards for cook-stoves or fine particulate matter emission standards for clean transport). This would help direct capital towards BC mitigation technologies.

- GEF tracking tools developed for climate change mitigation projects, such as the New Guidelines on Greenhouse Gas Emission Accounting and Reporting for GEF Projects (GEF/C.48/Inf.09), could be updated. New versions could include additional emission reductions of BC as a co-benefit (together with any co-emitted pollutant emission reductions where feasible and applicable). This should be completed by the time GEF's methodology for BC accounting (as described above) becomes available.

9 For example, the CCAC is assisting countries such as Bangladesh, Mexico, Colombia and Ghana to develop national plans through the use of a toolkit on emissions and scenarios that estimates changes in all co-emitted species.

- Monitoring and reporting on BC emissions in GEF projects should be done separately from reporting on GHG emissions. Any approach to estimate the associated net climate impacts designed to address BC requires using modeling approaches. These should also include co-emitted species that lead to cooling, such as organic carbon (OC) and sulfur dioxide (SO_2), as well as those that lead to additional warming, such as brown carbon (BrC) and methane (CH_4). Measuring and monitoring the performance of mitigation measures for BC, either as emissions, concentrations, or exposure to impacts, can theoretically be undertaken at various points along the "impact chain".

- There is currently no general consensus as to the most appropriate climate impact metric to use for BC, OC and other such aerosols. If a GEF project, other than reporting on GHG emissions, is only monitoring BC, then it should be understood that BC emissions alone will not indicate either the direction or the magnitude of the climate impact resulting from the project. Therefore, a project should also assess emission reductions from any co-emitted pollutant. Where feasible and applicable to do so, project proponents should assess at least BC and OC baseline

emissions (since OC is the main counter-acting, co-emitted, pollutant). Alternative scenario emissions (in terms of tonnes of BC and OC reductions) could be undertaken at the ex-ante, mid-term and terminal evaluation stages using the methods outlined in this advisory document, or more appropriate alternatives as they become available.

4. Increase awareness and engage with stakeholders involved in national, regional and international efforts to address BC mitigation.

- The GEF Secretariat, agencies and recipient countries are advised to collaborate with organizations such as the CCAC and Global Alliance for Clean Cook-stoves to coordinate GEF activities relating to BC more effectively with ongoing international efforts. Resulting benefits could include exchanging information and lessons learned, leveraging other related activities and financial resources, including identifying bankable projects and improving future project design. Several GEF Agencies are members of the CCAC and already prioritize SLCP mitigation in their activities.[10] [11]

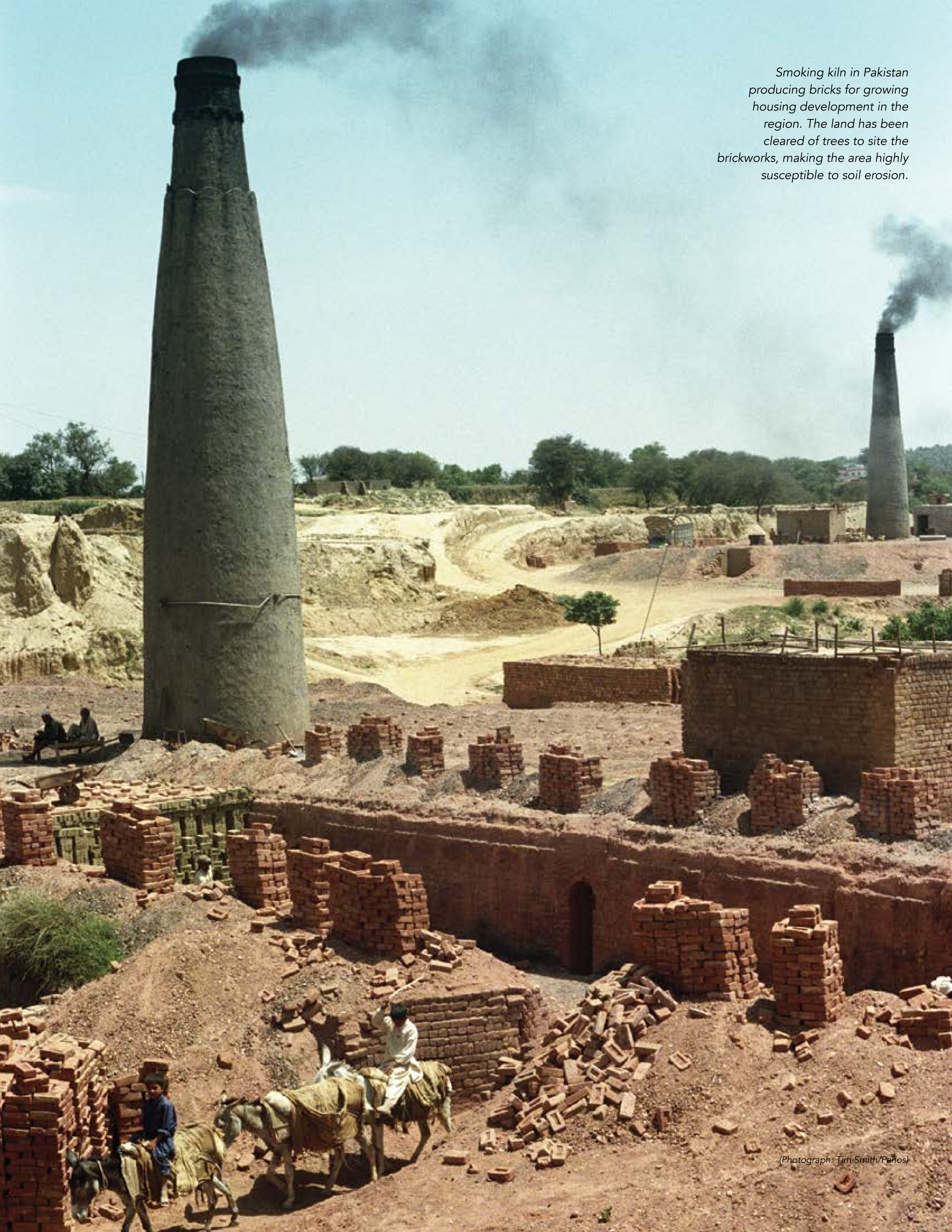
- The GEF could also consider analyzing the broad landscape of development finance used by its Implementing Agencies to assess whether a portion could be channeled to BC abatement through financing strategies identified in the CCAC/World Bank Black Carbon Finance Study Group report (World Bank, 2015).

- The GEF Independent Evaluation Office, in collaboration with GEF partners including STAP, should support knowledge management efforts to evaluate the environmental, health and economic impacts of a select set of GEF projects that result in reduced BC emissions. These would include, for example, "soot-free" alternatives to high BC-emitting diesel engines to better understand the full costs and benefits of supporting these types of projects.

- BC-reducing activities should be scaled up in the GEF portfolio by raising awareness of the multiple benefits of BC mitigation among GEF partners. The GEF Secretariat could consider developing incentive mechanisms for BC emission reduction projects to provide the necessary impetus for action. The Country Support Program and various communication activities could be used to increase awareness among the GEF's recipient countries and stakeholders.

10 GEF Agencies participating in the CCAC include the following: World Bank, United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), United Nations Industrial Development Organization (UNIDO), Food and Agriculture Organization of the United Nations (FAO) and the Inter-American Development Bank (IADB).

11 Some organizations such as the UN Environment Programme (UNEP) have made air pollution a priority and are using near-real time data to capture and display global data flows on air quality through UNEP Live (www.uneplive.org).



Smoking kiln in Pakistan producing bricks for growing housing development in the region. The land has been cleared of trees to site the brickworks, making the area highly susceptible to soil erosion.

(Photograph: Tim Smith/Panos)

1 INTRODUCTION

In addition to long-lived greenhouse gases (GHGs), some pollutants that are short-lived in the atmosphere also contribute a substantial portion of the additional radiative forcing that is causing anthropogenic climate change. These pollutants, including black carbon (BC) and tropospheric ozone, affect global and regional temperatures; are associated with a range of deleterious health effects, including premature death (Jerrett *et al.*, 2009; Krewski *et al.*, 2009; Janssen *et al.*, 2011; Lepeule *et al.*, 2012); can accelerate melting of ice and snow in the cryosphere; and can disrupt water cycles and reduce agricultural yields (UNEP/WMO, 2011; World Bank and ICCI, 2013). BC differs from long-lived GHGs in a number of ways:

- BC mainly absorbs solar radiation, while GHGs mainly absorb infra-red radiation.
- The radiative (warming) influence of BC after it is emitted lasts only days to weeks, whereas for long-lived GHGs it can last for centuries or longer.
- The climate impacts of BC can differ depending on where it is emitted (as opposed to long-lived GHGs that are well-mixed in the atmosphere).
- A mixture of warming and cooling pollutants are co-emitted with BC.
- BC is a component of fine particulate matter, which directly affects human health.

A boy in Beijing, China wears a mask to cover his nose and mouth in an attempt to guard against air pollution.

Recent studies show that both long-lived GHGs and short-lived climate pollutants (SLCPs) will need to be controlled to increase the chance of keeping global warming below 2°C, although they provide their benefits on different time scales (UNEP/WMO 2011; Shindell *et al.*, 2012; Shoemaker *et al.*, 2013).

Particulate matter (PM) is a mixture of particles suspended in the air that form during incomplete combustion of fossil fuels, biofuels and biomass. BC is the most strongly light-absorbing component of fine particulate matter (known as $PM_{2.5}$ because the particles are typically 2.5 microns or less in diameter), BC is often co-emitted with long-lived GHGs, as well as other short-lived pollutants, including organic carbon (OC), brown carbon (BrC), nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOC), carbon monoxide (CO) and sulfur dioxide (SO_2) (Anenberg *et al.*, 2012). While some co-emitted pollutants (especially OC and SO_2, which forms sulfate particles) lead to atmospheric cooling, $PM_{2.5}$ as a whole (including the full mixture of these components) is deleterious to human health. Therefore, the full mixture of emissions changes must be taken into account to understand the net climate and health impacts of any emission source or mitigation measure (UNEP/WMO, 2011).

Approaches to controlling emissions that achieve near-term climate benefits are available for a number of source categories, including diesel and gasoline engines, stationary industrial sources, residential cooking and heating, and open biomass burning in the field or forest. If implemented

widely, these mitigation strategies could help slow the rate of climate change, and would at the same time improve public health, increase energy efficiency and reduce environmental damage. Because BC is short-lived in the atmosphere, these benefits would accrue nearly immediately after the mitigation measures are implemented; they would be mainly experienced locally and regionally near where the mitigation action was taken. In addition to near-term climate and health benefits, implementing mitigation measures that reduce both BC and long-lived GHGs like carbon dioxide would slow both the rate of climate change in the near term (over years to decades) and reduce the magnitude of climate change in the long term (over centuries). International efforts such as the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) are underway to realize these multiple benefits by facilitating further implementation of, among other actions, BC mitigation measures that are already employed and encouraged in many parts of the world (CCAC, 2014a).

Given its unique role in financing actions to address global environmental issues, the GEF has an opportunity to help mitigate near-term climate warming and address other development challenges by operationalizing measures that reduce BC emissions within project selection and implementation. This document aims to provide the GEF and Implementing Partner Agencies with the latest scientific knowledge of BC sources and impacts and recommendations on incorporating BC mitigation measures into GEF programming.

- **Section 2** provides a primer on BC, including source categories and emissions; impacts on the climate, environment and health; and regional impacts.
- **Section 3** describes the multiple benefits of mitigation and available measures to reduce BC emissions in each major emitting sector.
- **Section 4** summarizes methods for measuring and monitoring BC emission reductions.
- **Section 5** provides guidance to the GEF Partnership on how to encourage and account for BC mitigation actions within projects and programs.
- **Section 6** summarizes key findings and recommends options for the GEF to enhance awareness of all aspects of BC among the GEF Partnership and encourage efforts to implement measures to mitigate BC and track results.

Pollution emitted from a cargo ship. Emissions from Arctic ships are likely to increase the mass of BC deposited on sea ice and snow surfaces.

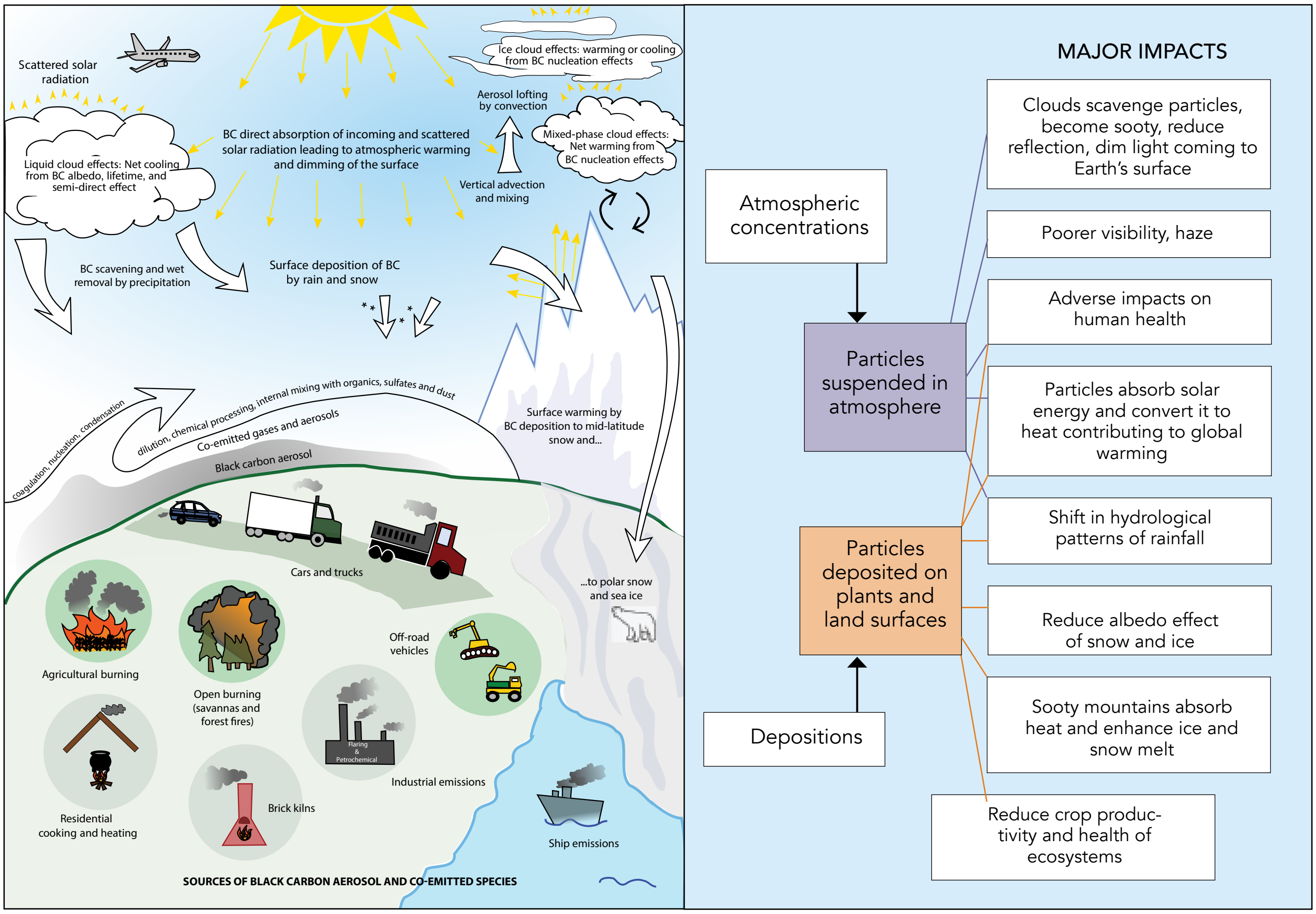
2

A PRIMER ON BLACK CARBON

BC is typically formed by the incomplete combustion of fossil fuels and biomass (Fig. 1; Bond *et al.* 2013). It is the most strongly light-absorbing component of fine particulate matter known as $PM_{2.5}$ [12] (U.S. EPA, 2012). Fine particles can travel deep into the human respiratory tract, causing short-term health effects (such as throat and lung irritation, coughing, sneezing, runny nose and shortness of breath) and longer-term respiratory and cardiovascular problems (such as chronic bronchitis, asthma, lung cancer and heart disease). Several recent scientific assessments have detailed the multiple impacts of BC on climate change, public health and the environment, and have identified the benefits from taking action to mitigate BC emissions (UNEP/WMO, 2011; U.S. EPA, 2012; Arctic Council, 2013; Bond *et al.*, 2013; IPCC, 2014). These assessments generally conclude that emissions of short-lived BC, other short-lived climate pollutants (SLCPs), and long-lived GHGs, will all need to be reduced significantly to avoid a dangerous level of temperature rise and severe climate change impacts.

12 $PM_{2.5}$ refers to the particulate material in the air that is made up of particles that are less than 2.5 microns (10^{-6} m) in aerodynamic diameter.

FIGURE 1
Primary sources of BC emissions and the processes that control the distribution of BC in the atmosphere and its role in the climate system.



Source: Based on U.S. EPA, 2012 and Bond *et al.*, 2013.

This section summarizes what is known about the sources and emissions of BC and the impacts of BC on global and regional climate change, human health and the environment for different world regions.

2.1 BLACK CARBON SOURCES AND EMISSIONS

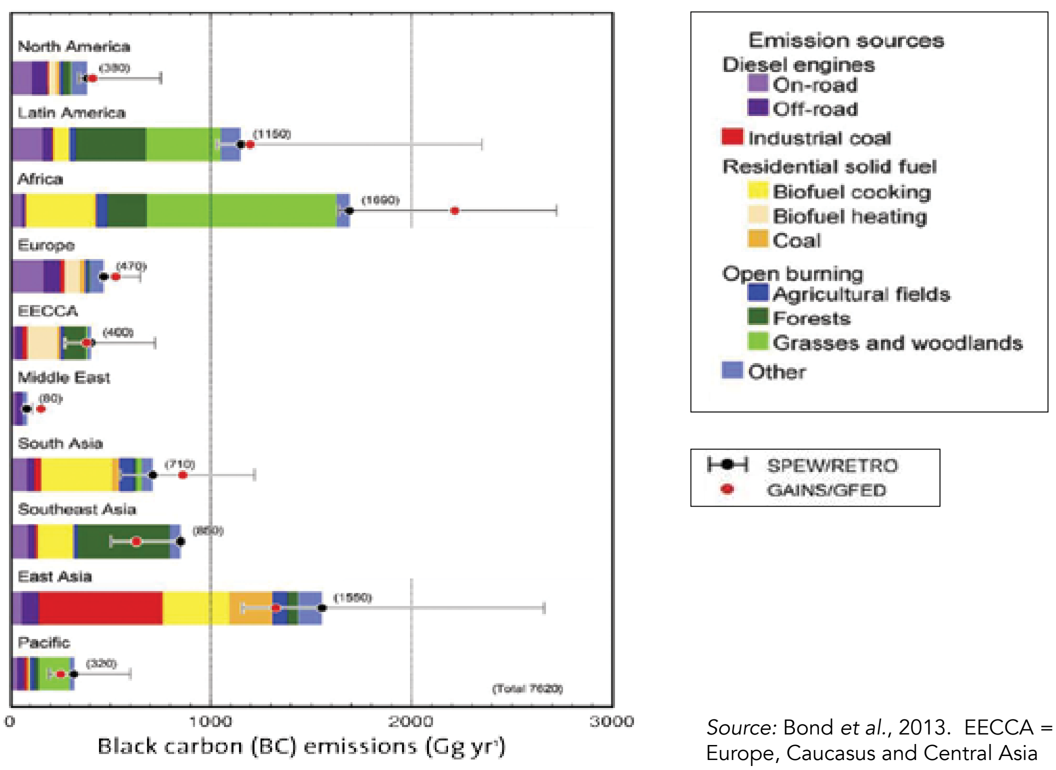
Globally, approximately 8,400 kt of BC were emitted to the atmosphere in 2000 (Fig. 2), the latest year for which a consistent global inventory is available (U.S. EPA, 2012). Details on specific locations and timing of BC emission estimates are uncertain, particularly in developing countries. Current calculations derived from observations in the atmosphere, however, allow large-scale estimates of the major global sources of BC emissions by region and sector. Asia (40%), Africa (23%) and Latin America (12%) contribute approximately 75% of global BC emissions (Fig. 2). The main emitting sectors in developing countries are open biomass burning and residential solid fuel combustion, whereas transport dominates in developed countries and industrial use of coal in East Asia (Table 1; Lamarque *et al.*, 2010).

TABLE 1
Main sectors contributing to global BC emissions and their share of total.

Source	Description	Share of total global emissions
Open biomass burning	Natural wildfires and anthropogenic forest fires, grass-land fires, and burning of agricultural waste.	36%
Residential cooking, heating and lighting	Burning of solid fuels (coal and biomass) in open fires or rudimentary stoves for cooking and heating, as well as kerosene lanterns for lighting; woodstoves for space heating in developed countries.	25% (of which 4% is from woodstoves in developed countries)
Transport	Diesel engines used in on- and off-road vehicles (including heavy-duty and light-duty trucks, construc-tion equipment and farm vehicles); gasoline engines, including cars and motorcycles; ships and aircraft.	19%
Industry	Stationary sources, including brick kilns; iron and steel production; thermal power generation plants; industrial boilers; gas flaring.	19%

Source: Lamarque *et al.*, 2010.

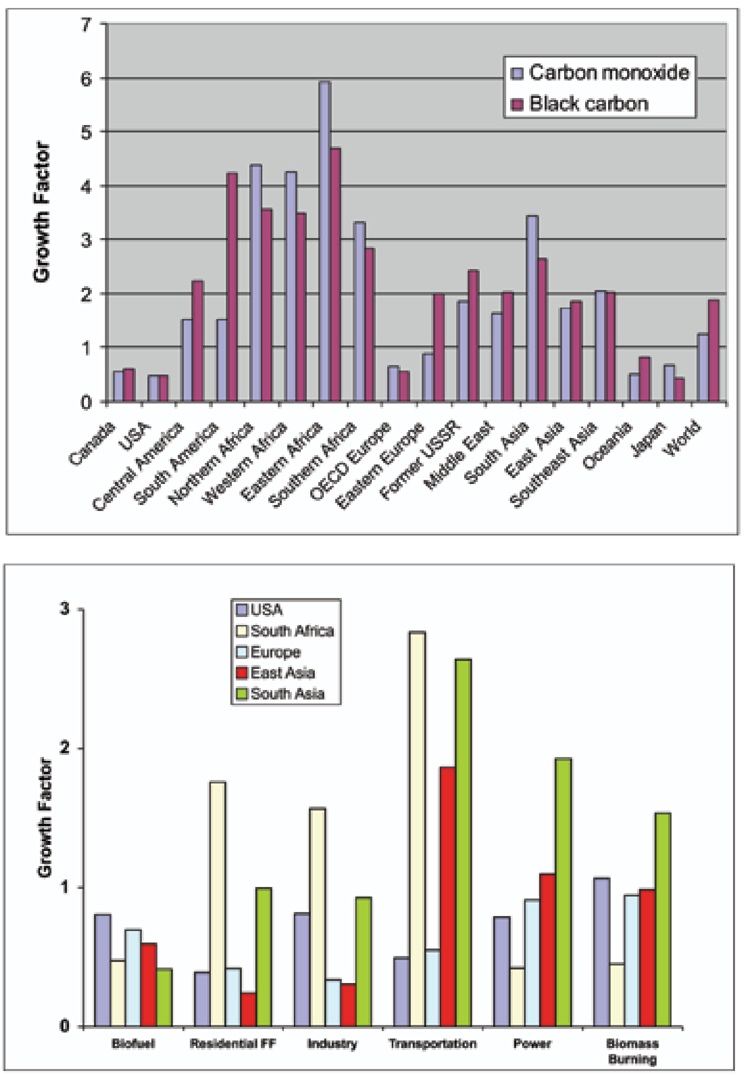
FIGURE 2
Black carbon emissions (kt / year) by region and source sector in 2000.



Source: Bond *et al.*, 2013. EECCA = Eastern Europe, Caucasus and Central Asia

Air pollution emissions are closely linked with economic development; emissions tend to increase with population and income growth in the early stages of development before declining once higher income levels are reached, tolerance for pollution diminishes and effective policies to control pollution are enacted (World Bank and ICCI, 2013). The same is generally true for BC. However, emissions can be drastically impacted by fuel selection and the availability and application of control technologies. BC emissions have been decreasing over the past decades in many developed countries due to stricter air quality regulations (U.S. EPA, 2012). By contrast, BC emissions are increasing rapidly in many developing countries that do not regulate air quality tightly; if policies are not enacted to control emissions, they will likely continue to rise as economies develop and urbanize (Fig. 3; Jacobson and Streets, 2009; UNEP/WMO, 2011).

FIGURE 3
Black carbon emission growth factors from 2000 to 2030 by selected world regions and by source sector.



Based on IPCC future emissions scenario A1B.

Source: Jacobson and Streets, 2009.

The net climate impact of any individual emission source is driven by the full mixture of emissions, including both warming and cooling pollutants integrated over shorter and longer time-scales. Thus, it is important to understand not just the amount of BC and brown carbon emitted by any individual source (Table 1), but also the amount of co-emitted cooling pollutants (e.g. organic carbon and sulfur dioxide), as well as other warming pollutants (e.g. nitrous oxide, methane and carbon dioxide). In terms of impact to climate, reducing the most BC-rich sources of $PM^{2.5}$ emissions will usually lead to net cooling (Bond *et al.*, 2013); reducing even those sources with high reflecting emissions are likely to benefit the climate, particularly if emitted near areas of snow and ice. Bond *et al*. (2013) reported that major BC emission sources, (ranked in descending order of warming potential), include diesel engines, residential coal burning, small industrial kilns and boilers, combustion of wood and other biomass for cooking and heating, and open burning of biomass. Regardless of warming or cooling impacts, reducing BC emissions from any source, particularly when located near populated areas, will lead to health benefits from reduced $PM_{2.5}$ concentrations in the local atmosphere. In addition, because BC and CO_2 are co-emitted as a result of fossil fuel and biomass combustion, displacing these fuels with alternatives will usually help reduce both near-term and long-term climate change.

Once emitted, BC concentrations are influenced in the atmosphere by various processes (Fig. 1).

Since many of the major sources of BC emissions are produced directly by human activity and BC has a short atmospheric lifetime (days to weeks), BC concentrations are typically highest in urban areas where sources are densely located. This leads to very large numbers of people being exposed to health-damaging levels (U.S. EPA, 2012). In many rural areas, where solid fuel is used for residential cooking and heating and agricultural and municipal open burning is normal practice, concentration levels can be very high and also have significant impact on health. BC particles can also travel long distances in the atmosphere, and so can also affect public health far from the emission source (Shindell *et al.*, 2008; Anenberg *et al.*, 2014).

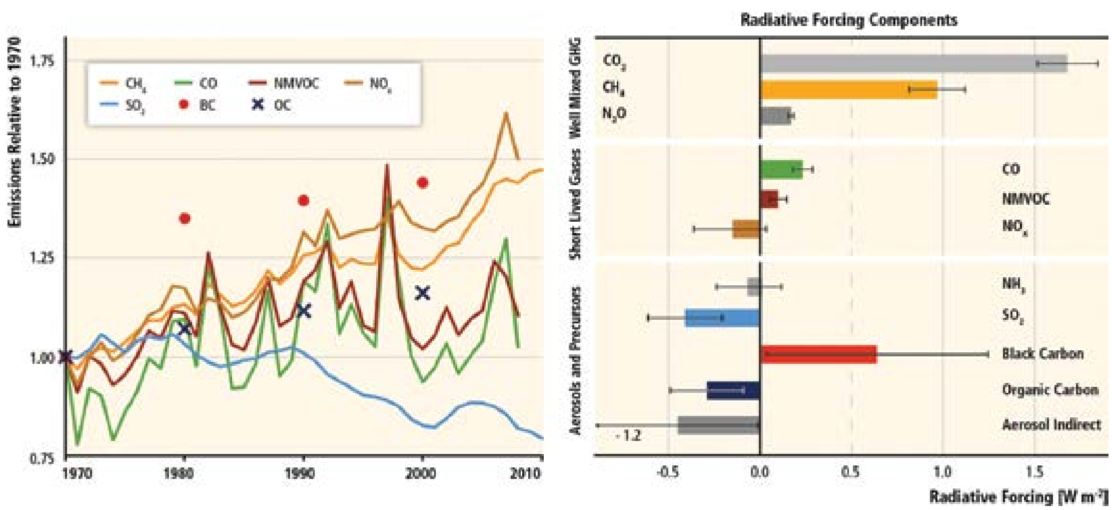
Annual average ground-level concentrations of BC range between <0.1 μg/m3 in remote locations to approximately 15 μg/m3 in urban areas (U.S. EPA, 2012).[13] However, daily and hourly concentrations can be significantly higher, depending on the time of day and proximity to emission sources, such as periods of increased vehicular traffic. In addition to these emissions that contribute significantly to ambient concentrations which affect health, BC emitted indoors from solid fuel cook-stoves also poses a significant risk to public health. In some areas of rural India, concentrations have been observed to reach 30 μg/m3 during peak periods of using solid fuel cook-stoves (Rehman *et al.*, 2011). As BC is just one component of $PM_{2.5}$, which is associated with deleterious health effects, total $PM_{2.5}$ levels are substantially higher than these BC concentrations. The magnitude of the difference depends on a number of factors, including the portion of emissions from nearby sources that is BC, as well as atmospheric transport and loss mechanisms. BC represents about 10% of PM mass globally (Bond *et al.*, 2013), but this share can be much higher for specific source categories such as from diesel engines at up to 80% (Bond *et al.*, 2007).

13 By way of comparison, the U.S. National Ambient Air Quality Standard for total $PM_{2.5}$ (of which BC is one component) is 12 μg/m^3 for the annual mean averaged over three years, and 35 μg/m^3 for the 98th percentile of the daily 24-hour average concentration averaged over three years. In the United States, BC typically comprises 5-10% of such total urban $PM_{2.5}$ concentrations.

2.2
IMPACTS OF BLACK CARBON ON GLOBAL AND REGIONAL CLIMATE

Radiative forcing (RF) is the difference between heat energy absorbed by the Earth from solar radiation and energy radiated back to space, resulting from a change in the concentration of a particular substance or the properties of the Earth's system (e.g. change in land surface albedo). Each species has a distinct associated radiative forcing value; the more positive the value, the greater the contribution of warming influence (and the more negative, the greater the cooling influence). However, the climate is influenced by the net change imposed by all species present, as well as existing conditions (e.g. leftover effects of previous radiative forcing that has not yet equilibrated). The global mean human-induced RF due to the change in BC emitted from fossil fuel and biomass combustion between 1750 and 2011 is estimated to have been 0.64 W/m2 (Myhre *et al.*, 2014). This large value makes BC the third-largest contributor to anthropogenic radiative forcing, after carbon dioxide (1.68 W/m2) and methane (0.97 W/m2) (Fig. 4). However, other estimates suggest BC has contributed even greater globally averaged forcing than previously estimated (Ramanathan and Carmichael, 2008; Bond *et al.*, 2013). One comprehensive assessment of the climate impacts of BC estimated the total industrial era BC radiative forcing is 1.1 W/m2 (Bond *et al.*, 2013). Uncertainty bounds are considerable for BC relative to CO_2, but there is high confidence that BC is a significant climate warming agent (Bond *et al.*, 2013). Annex 1 contains brief descriptions of CO_2 and other climate warmers.

FIGURE 4
Global trends for black carbon and other air emissions.



Global trends for black carbon and other air emissions, from anthropogenic and open field burning to 2010, normalized to 1970 values (left panel) and global average radiative forcing at the top of the atmosphere for each pollution species with the indirect effect of aerosols shown separately due to the uncertainty of the contribution from each species (right panel).

Source: Adapted from Myhre *et al.*, 2014.

Notes: Bars in right hand panel depict uncertainty levels. Much of the large uncertainty bounds for the estimates of BC radiative forcing are due to poor understanding of aerosol-cloud interactions.

Species in the right panel not included in the left panel are shown as grey bars and included for reference.

NMVOC = non-methane volatile organic compounds

BC affects the climate system through several different mechanisms (Fig. 1), including the following, which are ranked by level of understanding and relative effects:

a) directly absorbing incoming solar radiation, primarily in visible wavelengths;

b) darkening snow and ice, thereby reducing the albedo and so reducing reflection of solar radiation, which tends to accelerate melting; and

c) changing the number and composition of the small particles on which water vapor condenses, affecting the lifetime, reflectivity and stability of clouds (U.S. EPA, 2012; Bond *et al.*, 2013; IPCC, 2014).

While there are clearly effects resulting from each of these processes, the IPCC (2013) AR5 report indicated very high confidence in the understanding of aerosol-radiation interactions, but very low confidence in aerosol-cloud interactions and low confidence in effects of BC on snow (IPCC, 2014). Some studies suggest that current estimates of BC forcing could be understated due to errors in parameterizations of models used to estimate radiative forcing of aerosols (Myhre and Samset, 2015) and because models have not adequately accounted for brown carbon, a radiatively absorbing (and hence warming) portion of organic carbon (Bond *et al.*, 2013; Feng *et al.*, 2013; Saleh *et al.*, 2014).

BC is mainly a regional pollutant that exhibits strong spatial heterogeneity and temporal variability due to its particular set of sources and its short atmospheric lifetime. Its climate effects also vary by geographic region, depending on the location and season of emission, as well as whether the local climate is near or far from the moderating effect of oceans and other large water bodies. For example, 1 tonne of BC emitted near the Arctic from marine oil-fueled engines may have a much stronger influence on climate than 1 tonne emitted elsewhere from road vehicles. The Arctic region is sensitive to both atmospheric warming effects, as well as to the effects of BC deposition on snow and ice (Henze *et al.*, 2012). This contrasts with the impacts of longer-lived GHGs which are well-mixed in the atmosphere and exert essentially the same effect on climate regardless of the emission location or season of release, though the sensitivity of the climate to CO_2 varies by latitudinal band. Regional impacts of BC are described in greater detail in Section 2.4.

Sharply cutting emissions of CO_2 and other long-lived species is essential to holding down long-term climate change. However, sharply cutting emissions of BC, methane and the precursors of tropospheric ozone is essential for slowing the rate of climate change over the next few decades and keeping the increase in global mean temperature below 2°C (see Section 3; UNEP/WMO 2011; Shoemaker *et al.* 2013). A comprehensive assessment by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) found that fully implementing just 16 specific measures to mitigate BC and methane had the potential to reduce near-term global warming in 2050 by about 0.5°C (UNEP/WMO, 2011; Shindell *et al.*, 2012). With HFC mitigation, there is potential to reduce an additional 0.1°C at 2050 (Xu, 2013). The BC measures alone, which are listed in Table 2, were estimated to reduce warming by 0.2°C by 2050 (Shindell *et al.*, 2012). Assuming the measures can be fully implemented by 2030, they could halve the projected increase in global temperature from the present out to 2050 compared to a reference scenario based on current policies and fuel projections (UNEP/WMO, 2011;

GEF-STAP, 2012). However, controlling BC, methane and HFC emissions alone is not enough; reducing CO_2 simultaneously is necessary to meet climate stabilization goals (Fig. 5; UNEP/WMO, 2011; Shindell *et al.*, 2012; Bowerman *et al.*, 2013). Thus, SLCP and CO_2 mitigation should be undertaken in parallel, without delay (Shoemaker *et al.*, 2013).

2.3 IMPACTS OF BLACK CARBON ON HEALTH, AGRICULTURE AND THE ENVIRONMENT

TABLE 2 Selected key abatement measures for BC emissions.

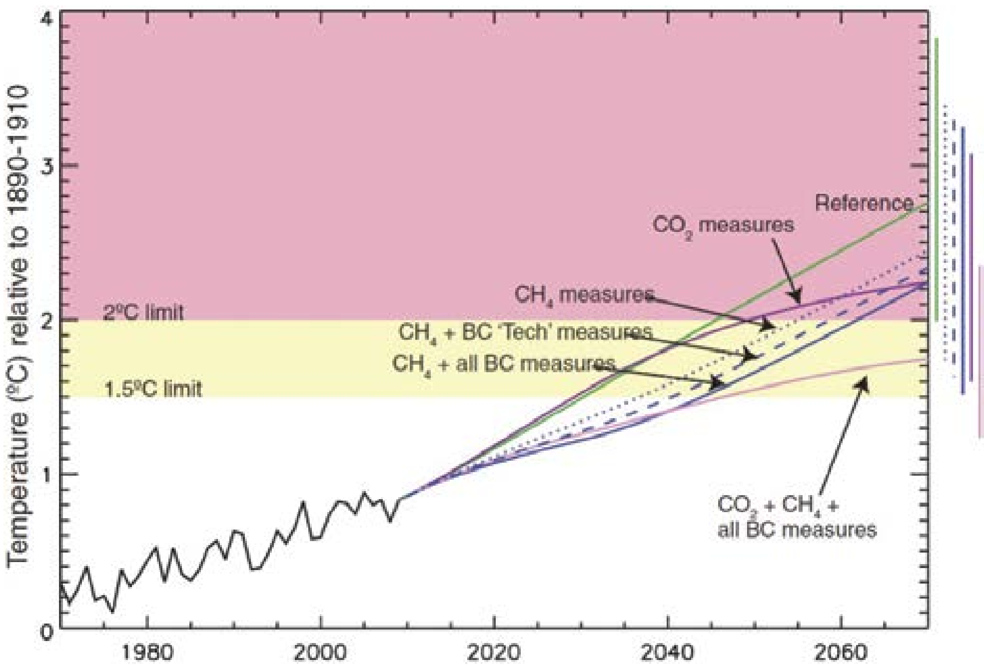
Measures	Sector
1. Standards for the reduction of pollutants from diesel vehicles (including adding particle filters to exhausts), equivalent to those included in Euro-6/VI standards, for on- and off-road vehicles.	Transport
2. Elimination of high-emitting vehicles in on- and off-road applications.	
3. Replacing lump coal with coal briquettes in cooking and heating stoves.	Residential
4. Replacing traditional fuelwood combustion technologies in the residential sector in industrialized countries with wood pellet stoves that use dry fuel produced from recycled wood waste or sawdust.	
5. Substitution of traditional biomass cook-stoves with stoves using clean-burning fuels such as bio-ethanol gel, liquefied petroleum gas (LPG) or biogas.1, 2	
6. Replacing traditional brick kilns with vertical shaft brick kilns.3	Industry
7. Replacing traditional coke ovens with modern recovery designs.	
8. Banning open burning of agricultural and forest wastes in the fields.1	Agriculture

1. *Motivated in part by the effect on health and regional climate, including impacts on areas of ice and snow, but noting the potential CO_2 impacts depending on the source of biomass and biogas.*
2. *For cook-stoves, given their importance for BC emissions, two alternative measures are included.*
3. *Zig-zag brick kilns would achieve comparable emission reductions to vertical-shaft brick kilns.*

Sources: UNEP, 2011; UNEP/WMO, 2011; World Bank and ICCI, 2013.

Note: See Annex 2 for more detailed information on these abatement measures.

FIGURE 5
Observed global temperature from 1970 to 2009 and projected temperature rise thereafter under various scenarios compared to the reference baseline and relative to the 1890-1910 mean.



Source: Shindell *et al.*, 2012.

Notes: Bars on right show 2070 ranges due to uncertainty in radiative forcing and climate sensitivity. BC 'Tech' measures cover reducing emissions from diesel vehicles, biomass stoves, brick kilns and coal ovens. 'all BC measures' include BC Tech measures plus regulations to ban agricultural waste burning, eliminate high BC-emitting vehicles, and provide modern cooking and heating options.

$PM_{2.5}$ aerosol emissions, including the BC component, are associated with a range of deleterious human health effects, including adverse respiratory and cardiovascular effects leading to morbidity and premature mortality. Globally, $PM_{2.5}$ pollution from household solid-fuel use is associated with around 3.7 million premature deaths annually (based on the 2010 world population), making it the fourth- largest health risk factor overall. An additional 3.2 million people were estimated to have died prematurely in 2010 due to ambient exposure to $PM_{2.5}$, the seventh-largest health risk factor in terms of premature deaths (Lim *et al.*, 2012). The World Health Organization (WHO) also estimated that in 2012, 7 million deaths annually, or one in eight of total global deaths, are attributable to air pollution.

Approximately 4.3 million and 3.7 million of these deaths were attributable to indoor and outdoor air pollution, respectively, with an overlap of approximately 1 million from outdoor air pollution originating indoors. Many countries now have health-based regulations to limit exposure to $PM_{2.5}$, such as the National Ambient Air Quality Standards (NAAQS) in the United States and European Union standards.

Several recent studies have examined the influence on human health of the individual $PM_{2.5}$ species or mixtures of constituent species. One

review paper suggested that, per unit concentration, BC may be more harmful than other constituents of $PM_{2.5}$ (Janssen *et al.*, 2011). Similar, and sometimes stronger, relationships between BC and health outcomes were observed than were for other $PM_{2.5}$ constituents. However, there was not enough information to determine whether BC is more or less toxic than other $PM_{2.5}$ constituents (Janssen *et al.*, 2011; U.S. EPA, 2012). Other studies have indicated that because BC represents a variable mixture of combustion-derived particulate material, it may not be directly toxic itself; instead, it may carry a wide variety of chemicals that are toxic to the respiratory and cardiovascular systems (WHO, 2012).

In addition to toxicity, the proximity of emission sources to potentially exposed populations can influence the magnitude of their impact on public health, as can the altitude where the $PM_{2.5}$ emissions occur. BC and co-emitted OC are directly emitted during combustion that is often located near population centers. BC and OC are also typically emitted at ground level rather than from tall smokestacks. This likely results in greater exposure and therefore larger health impacts per tonne of BC and OC emitted compared with aerosol precursors like nitrogen oxides and sulfur dioxide. According to one estimate, the impact per tonne of BC and OC emitted from all sources in the United States is 7 to 300 times greater than the impact from 1 tonne of nitrogen oxides or sulfur dioxide emitted (Fann *et al.* 2009). This suggests that emission controls targeting BC and OC may be particularly effective in protecting public health (U.S. EPA, 2012). However, the magnitude of the pollutant-by-pollutant difference in health impacts per tonne emitted depends on the specifics of the location, including the local emission sources and their proximity to large population centers.

$PM_{2.5}$ and associated pollutants such as tropospheric ozone can also damage crops and ecosystems which provide critical services such as producing food and raw materials, filtering air and water, and protecting against natural hazards like floods (UNEP/WMO, 2011; U.S. EPA, 2012; Burney and Ramanathan, 2014). In addition to directly affecting precipitation, $PM_{2.5}$ has been shown to affect crops and ecosystems by causing surface dimming (less sunlight passing through the atmosphere to the Earth's surface reduces evaporation and the driving energy for convection), by deposition on leaves (which can interfere with the biological processes of the plant), and indirectly by deposition in bodies of water which can be toxic for aquatic life (U.S. EPA, 2012). In one study, wheat yields in India were estimated to be around 36% lower in 2010 than they would have been without emissions of SLCPs (which were responsible for about 90% of the lower productivity) and SLCPs and BC had impacts on average temperature and precipitation, respectively (Burney and Ramanathan, 2014).

$PM_{2.5}$, including BC, can also impair atmospheric visibility and impact public safety, lifestyle and enjoyment of recreational activities. For example, impaired visibility can detract from hiking and bird-watching in national parks or other scenic viewing areas with aesthetic values. Furthermore, impaired visibility from biomass burning can diminish air quality and road safety. $PM_{2.5}$ also degrades materials such as stone, metal and paint by accumulating on the surfaces. Additionally, the deposition of BC and other particulates on homes, buildings, monuments and other structures may damage their aesthetic and/or monetary value.

Given the multiple impacts of BC on human health, agriculture and ecosystems, visibility and buildings, measures to reduce BC would clearly

have multiple benefits beyond simply limiting regional and global warming. BC mitigation can be integrated into local air quality management so as to simultaneously address climate, air quality and health goals (World Bank, 2015) and these multi-pollutant approaches can also yield energy savings and economic growth for jurisdictions (World Bank and ClimateWorks Foundation, 2014).

2.4 REGIONAL SOURCES AND IMPACTS OF BLACK CARBON

In contrast to long-lived GHGs, the impacts of BC concentrations in the atmosphere vary significantly across regions. This variability results in part from spatially heterogeneous BC loadings that are often highest near emission sources. In addition, the climate, health and agricultural impacts of BC depend on the vulnerability and susceptibility of the local environment and human population to BC exposure. For example, a one-time release of 1 tonne of BC near a population center would likely have a greater public health impact than in rural areas, whereas a similar release near rural areas would have a greater impact on agriculture. The climate is also more sensitive to BC emissions in some regions than others, driven by a variety of factors including latitude, annual timing of BC emissions (Putero *et al.* 2014), atmospheric transport and deposition pathways, regional meteorological properties (e.g. atmospheric stability, convection currents, precipitation), and surface type (e.g. snow/ice, desert, forest, ocean) and resulting reflectivity (Menon *et al.*, 2002; Rypdal *et al.*, 2009; Bond *et al.*, 2013). This section describes the emission sources and impacts of BC in specific world regions, including those where they may have a strong influence on other world regions, such as the Arctic and the Himalayas. Regional sources and impacts of BC are described further by UNEP/WMO (2011), UNEP (2011) and World Bank and ICCI (2013).

South Asia, India and the Himalayas:

South Asia and Southeast Asia together are estimated to emit 1,560 kt BC per year (Fig. 2; Bond *et al.*, 2013). By far, the greatest emission source of BC in India and much of South Asia is residential solid fuel use (typically biomass) for cooking and heating (Fig. 6; Venkataraman *et al.*, 2005; U.S. EPA, 2012). Household air pollution, of which BC comprises a large component, leads to an estimated 1.3 million premature deaths every year in South Asia; this is due both to the magnitude of emissions and the proximity to large populations, making it the third-highest risk factor overall in this region (Lim *et al.*, 2012).
As any pollution emitted indoors ventilates outdoors into the ambient air, household solid fuel use is often the largest source of local outdoor air pollution. BC emissions from household solid fuel use in India are so high that air pollution monitors observed twice daily peaks in ambient BC concentrations during morning and evening cooking times (Rehman *et al.*, 2011). Modeling results show that reducing residential biomass fuel use would significantly lower BC concentrations in this region (Ramanathan and Carmichael, 2008). Open vegetation fires are also a major cause of variability of BC and ozone emissions in parts of Asia, particularly in the southern Himalayas and northern Indo-Gangetic plains (Putero *et al.*, 2014).

BC emissions can also contribute significantly to hazy air masses known as atmospheric brown clouds (ABC). The area affected by ABCs in southern Asia covers most of the Arabian Sea, Bay of Bengal, the Northern Indian Ocean and land

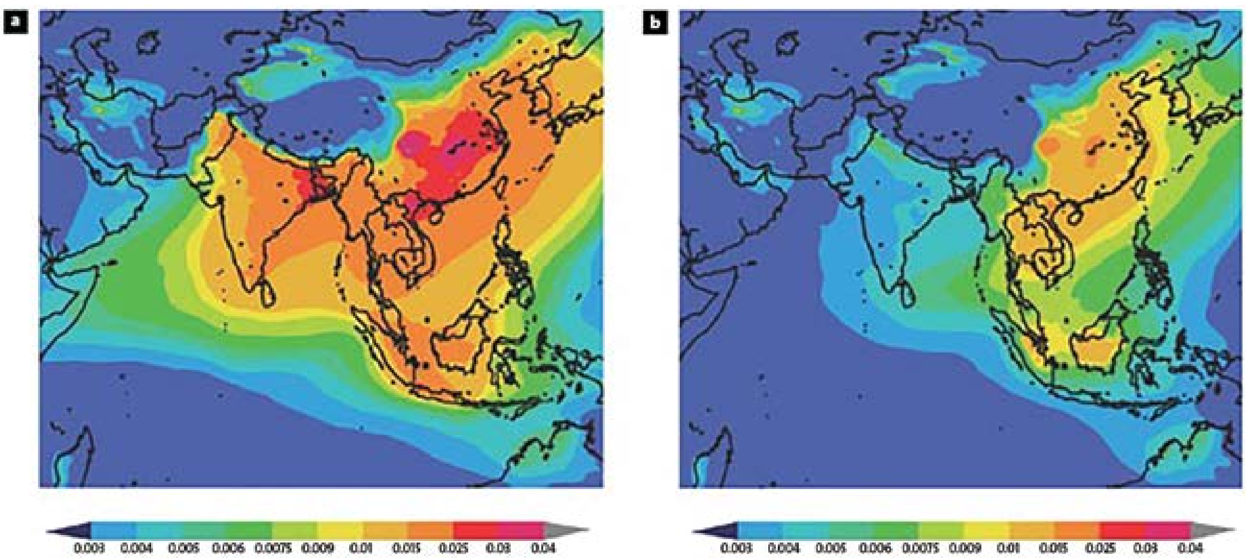
areas across the South Asian region; it lasts from about November through May (Ramanathan and Crutzen, 2003). BC and ABCs have been shown to disrupt the monsoon that millions of people depend on for agricultural productivity (Ramanathan *et al.*, 2005), and accelerate melting of the Himalayan-Tibetan glaciers and snow stores, which millions rely on for access to clean water (Armstrong, 2010; Chung *et al.*, 2012). As a result, millions of people may be at risk of water and food insecurity. BC can also reduce the surface albedo (reflectivity) by darkening the bright snow and ice cover, further contributing to solar radiation (i.e. positive radiative forcing) and thereby increasing atmospheric warming (Nair *et al.*, 2013).

The impacts of BC and co-emitted pollutants on the melting of Himalayan ice, disruption of the monsoon and severe public health impacts in this region make reducing emissions a clear priority.

East Asia and Pacific:

Every year this region contributes an estimated 1,870 kt of BC emissions (Fig 2; Bond *et al.*, 2013), due in large part to emissions from China that annually exceed any other country and even

FIGURE 6
Effect of biomass cooking on BC in Asia.



(a) Simulated annual mean optical depth (no units) of BC aerosols for 2004-05 using a regional aerosol/chemical/transport model with BC emissions included from indoor cooking using wood/dung/crop residues, fossil fuels and open field biomass burning. (b) as for (a) but without biomass used for cooking.

Source: Ramanathan and Carmichael, 2008.

some sub-continental regions (U.S. EPA, 2012). The situation with regard to emission sources and controls, however, is changing rapidly. East Asia is the only region where industrial coal combustion is a significant contributor to BC emissions due to the magnitude of the sector and lack of emission controls (Fig. 2). Residential solid fuel combustion in East Asia is also a large contributor to BC emissions, as for Africa and other parts of Asia. However, a key difference in East Asia is the use of coal in addition to biomass as fuel for indoor heating and cooking. BC emissions in East Asia are expected to grow in the future (Fig. 3).

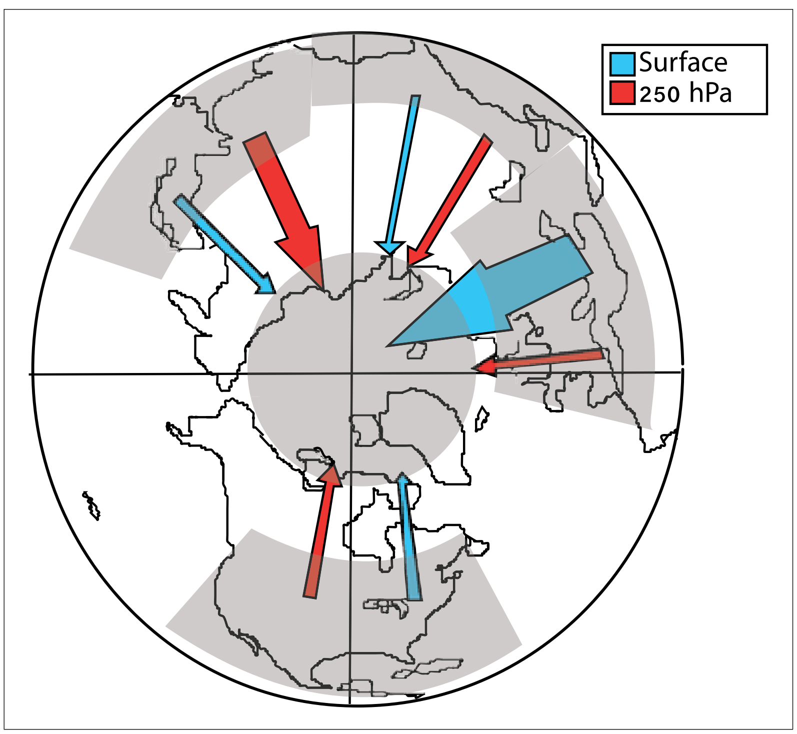
Since BC emissions from this region can travel long distances, they can have substantial impacts on the sensitive Himalayan and Arctic cryosphere regions (Fig. 7). In addition, due to large populations near to BC sources, the public health impacts are estimated to be higher than for any other region (Anenberg *et al.*, 2011). The magnitude of BC emissions from East Asia, as well as the availability of technological alternatives and emission control technologies, makes this region ideal for mitigation efforts. Studies have found that implementing BC mitigation measures in East Asia would avoid hundreds of thousands of premature deaths due to outdoor air pollution and would save millions of tonnes of crop yield from damaging ozone pollution (Anenberg *et al.*, 2012; Shindell *et al.*, 2012).

Arctic:

Because the atmosphere is drier in the Arctic and temperature inversions that inhibit atmospheric vertical mixing are frequent, BC's atmospheric

FIGURE 7

Relative importance of different regions to annual mean concentrations of BC in the Arctic at the surface and in the upper troposphere (at 250 hPa atmospheric pressure).



Note: Values are calculated from simulations of the response to 20% reduction in anthropogenic emissions of precursors from each region. Arrow width is proportional to the multi-model mean percentage contribution from each region to the total from the four source regions. *Source:* Based on Shindell *et al.*, 2008.

lifetime tends to be longer than in other world regions (U.S. EPA, 2012). In addition, BC aerosol deposition reduces surface albedo (Quinn *et al.*, 2008; Jiao *et al.*, 2014). This exerts a larger radiative forcing in the Arctic than elsewhere, leading to an increase in snowmelt rates north of 50°N latitude by as much as 19-28% (U.S. EPA, 2012). Even $PM_{2.5}$ emission sources that exert a net cooling influence on average because they are rich in reflecting components may be exerting warming in the Arctic. They are darker than the underlying ice and snow, and cloud-related cooling processes associated with OC and SO_2 are less relevant there. Similarly, brown carbon may also play an important role in the Arctic through deposition on ice and snow. More research is needed to better understand consequent climate implications (U.S. EPA, 2012).

Although BC emissions within this region are low, the Arctic is particularly sensitive to its climate effects. BC has a short atmospheric lifetime and concentrations are highest near emission sources. However, studies have shown that BC can also travel long distances and impact on more remote regions (Shindell *et al.*, 2008). Emissions from Northern Europe, North America and Asia have been shown to contribute the greatest absolute impact of BC on the Arctic (Fig. 7; Quinn *et al.*, 2008). Simulations indicate that BC contributed to abrupt recession of glaciers in the European Alps beginning in the mid-19th century when industrial BC emissions were rising in Western Europe; temperature and precipitation records suggest the glaciers should have been advancing during this period (Painter *et al.*, 2013).

Key sources of BC affecting the Arctic include forest burning and wildfires, stationary diesel engine emissions in the Arctic for electricity generation, shipping, open burning of fields and agricultural waste, off-road and on-road diesel engine emissions from Eurasia and North America, and emissions from solid fuel stoves used for residential heating, particularly within the Arctic and high latitude Northern Hemisphere regions (Arctic Council, 2013; World Bank and ICCI, 2013). Flaring of natural gas in the Arctic is now also recognized as a more important source of BC than earlier believed (Stohl *et al.*, 2013). With increased emission controls in Europe and the United States on BC-rich sources such as diesel engines, several studies have observed downward trends in Arctic BC concentrations (Gong *et al.*, 2010; Sharma *et al.*, 2013; Dutkiewicz *et al.*, 2014). Recent warming in the Arctic may be caused in part by the reduction in sulphate particles that also occurred with the reduction in BC emissions (Laing *et al.*, 2013) and the increase in over-the-pole flights that produce warming high altitude con-trails (Jacobson *et al.*, 2012). If the Northwest and Northeast Passages through the Arctic Ocean begin to be widely used to move goods from Asia to Europe, BC concentrations may rise in the Arctic in the future.

Reducing the rate of near-term climate change in the Arctic is of particular importance due to its contribution to the rapid loss of summer sea ice cover. The rate of warming over the past hundred years in the region is roughly double the global average (U.S. EPA, 2012). Reducing emissions in or near the Arctic would be particularly effective at reducing the warming effects of BC on the local climate (Arctic Council, 2013). BC emissions from Arctic nations are projected to decrease by approximately 35% over the next couple of decades due mainly to particulate matter controls on diesel engines and improved diesel fuel quality. However, BC emissions from wildfires, residential heating stoves and potentially from gas flaring may remain the same, or even

increase, with projected development (Arctic Council, 2013).

Arctic warming and consequent glacial retreat have global implications by contributing to modifications in mid-latitude weather, especially during the cold season. Additionally, loss of ice from glaciers and the Greenland Ice Sheet, contribute to global sea-level rise. Finally, increasing the thawing of permafrost and clathrates contributes to excitement of the natural carbon cycle due to the resulting release of CO_2 and methane (World Bank and ICCI, 2013). In addition to the climate and health impacts, a rapidly melting Arctic has significant implications for global security and trade given the potential for increased access to offshore oil and gas and the newly opened shipping routes through the previously non-navigable Northern Sea Route and Northwest Passage (Borgerson, 2008; Peters *et al.*, 2011; Stohl *et al.*, 2013).

Africa:

Emission sources in Africa are estimated to contribute approximately 1,690 kt of BC annually (Fig. 2; Bond *et al.*, 2013). The largest source of BC emissions in Africa is grassland fires, followed by residential solid fuel use for cooking and heating (U.S. EPA, 2012). Open-field burning of vegetation and crop and forest residues is the main BC source with a total land area burnt annually ranging from 121 to 168 Mha (Scholes *et al.*, 1996; Simon *et al.*, 2004). An estimated 465,000 premature deaths every year are associated with indoor biomass cookstove use across sub-Saharan Africa (Lim *et al.*, 2012), making it the third-worst health risk factor in that region.

Rapid population growth, high per-vehicle emissions from aged diesel vehicle fleets, lack of engine maintenance, poor fuel quality and meteorological conditions also contribute to severe atmospheric pollution in many urban areas (Kinney *et al.*, 2011; Doumbia *et al.*, 2012). Residential kerosene lighting is also emerging as a potentially important source of BC in this region (Lam *et al.*, 2012; CCAC SAP, 2014). BC in the atmosphere can reduce the planetary albedo of bright desert regions, contributing to overall warming. In addition, the snow and ice atop Mt. Kilimanjaro, Mt. Kenya and the Rwenzori mountains between Congo and the Democratic Republic of Congo are sensitive to BC emissions (World Bank and ICCI, 2013). Loss of East African glaciers may also have an economic impact since the ice attracts tourists and snowmelt run-off contributes to water supplies. African pollution emissions are expected to rise rapidly in the coming decades due to rapid growth of urban population centers (Liousse *et al.*, 2014). As a result, air pollution-related premature mortality is expected to increase.

Estimating radiative forcing impacts of BC in Africa is challenging due to complex meteorology (such as the interactions with the South Asian monsoon), errors in atmospheric model parameterization and poor understanding of emissions from this region. As a result, the weather and climate impacts of BC and benefits of reducing emissions in Africa are uncertain.

Latin America and North America:

These two regions emit on the order of 1,150 and 380 kt BC per year, respectively (Fig. 2; Bond *et al.*, 2013). Open burning, particularly of grasses and woodlands, but also forests, is by far the largest contribution to BC emissions in Latin America (Fig. 2). Residential biofuel combustion for cooking is also a significant source. Studies show that glaciers in the Andes have been

retreating over the last three decades due to climate change, which will increasingly limit water availability in the region for drinking, irrigation and hydroelectric power generation (World Bank and ICCI, 2013). Uncertainties loom larger for the Andes than for other regions due to the limited spatial resolution of atmospheric models and lack of extensive observational monitoring. However, BC likely contributes to the effects of GHG-induced climate change on glacier melt. In terms of potential mitigation measures, reducing BC emissions from residential cook-stoves and diesel-fuelled vehicles would yield significant climate benefits in this region (World Bank and ICCI, 2013).

The lower mass of BC emissions from North America compared with other regions is largely due to stringent particulate matter regulations implemented in the United States over the past several decades. However, the United States still produces over twice the BC emissions as Canada and Mexico combined (U.S. EPA, 2012), mainly from diesel-powered transport, industrial sources and residential heating stoves (U.S. EPA, 2012). The recent increase in BC emissions from more frequent forest fires and prolonged fire seasons in the western United States has been linked to increased spring and summer temperatures and an earlier spring snowmelt (Mao *et al.*, 2011). Earlier snowmelt may contribute to seasonal droughts in the region due to reduced water availability later in the spring and summer (U.S. EPA, 2012). In California, policies enacted to reduce diesel emissions, which led to a factor of 2 reduction in surface BC emissions from 1989 to 2008, have been found to be associated with climate cooling (Ramanathan *et al.*, 2013).

A brickmaker works at a kiln in Dah-e-sabz on the outskirts of Kabul.

(Photograph: James Oatway/Panos)

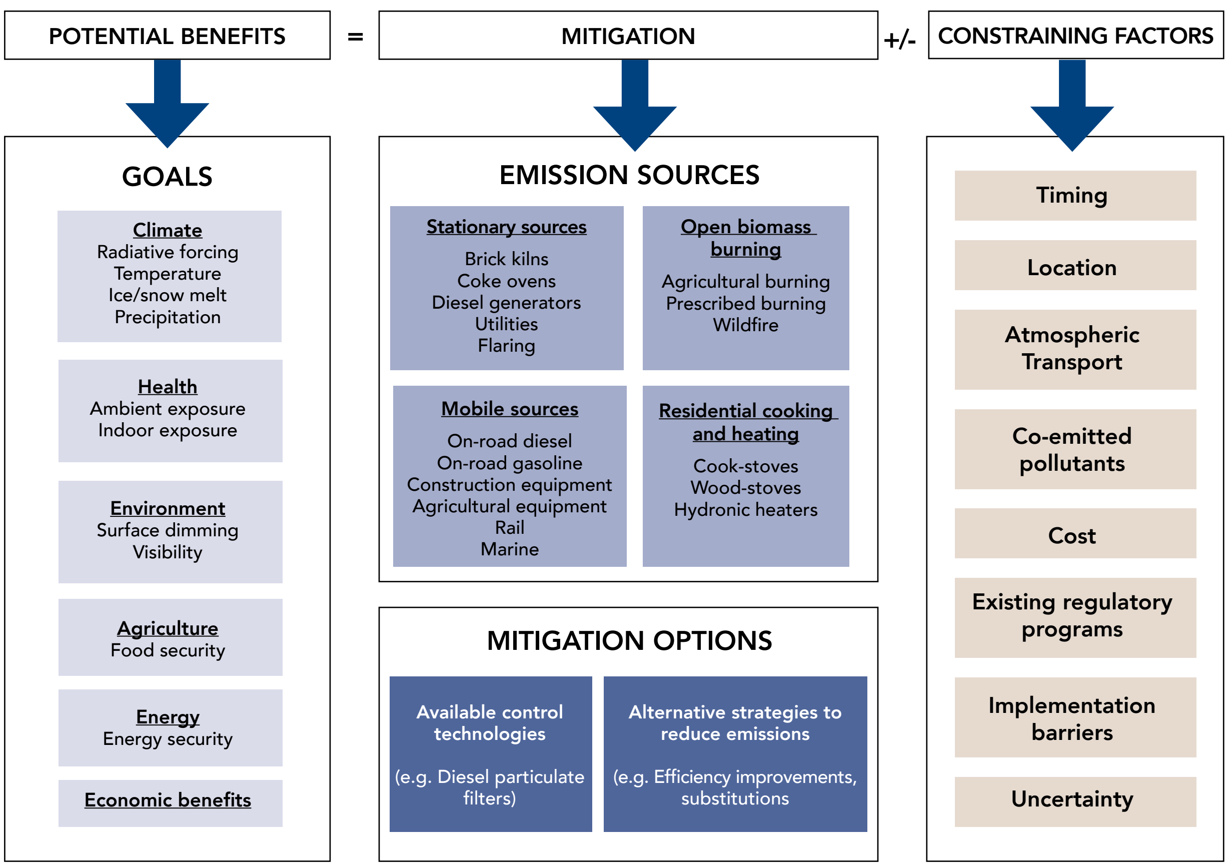
3

APPROACHES TO REDUCING BLACK CARBON EMISSIONS

Due to the nature of the approaches for reducing BC emission, successful implementation will depend mainly on the overall regulatory, economic and political context. Prioritizing mitigation options for BC is best done when based on scientific factors. These include the magnitude of emissions by sector and region and net climate forcing, as well as the enabling policy environment, including technical practicability, costs, policy design and implementation feasibility (Bond *et al.*, 2013; Fig. 8). When designing policies or projects to implement measures focusing on BC, project developers should consider whether the main goal is to mitigate climate change, reduce health impacts, minimize agricultural and ecosystem impacts, or some combination of these objectives. This step is critically important.

Not all objectives can necessarily be achieved with any one mitigation action and some actions could be beneficial for one purpose (e.g. health), but negative for another (e.g. climate). For example, an action that reduces near-term warming through lower BC emissions and also increases fuel efficiency generates a "win-win" of both air quality and climate benefits. However, if the action decreases fuel efficiency, it could improve air quality at the expense of climate change over the long term (Boucher and Reddy, 2008). Where feasible, mitigation projects should maximize ancillary co-benefits, while still achieving the same primary goal (i.e. given a choice of two alternative projects that achieve the same primary goal, the project that achieves the greatest co-benefits is the one that would most merit selection).

FIGURE 8
Policy framework for mitigation decisions to reduce BC emissions.



Source: Modified from U.S. EPA, 2012.

Typical black carbon emissions from public buses occur in many cities such as Suva, Fiji depicted in this photo.

Several studies and assessments have estimated the multiple benefits of measures to reduce BC emissions. UNEP/WMO (2011) found that fully implementing 16 specific measures to mitigate BC and methane emissions by 2030 could halve the potential increase in global temperature projected for 2050 compared to a reference scenario. The measures were also estimated to avoid 0.6 to 4.4 and 0.04 to 0.52 million annual premature deaths globally in 2030 from reduced surface concentrations of $PM_{2.5}$ and ozone, respectively (Anenberg *et al.*, 2012). Around 80% of these health benefits would occur in Asia, where large populations are co-located with high BC emissions. The BC mitigation measures alone were estimated to contribute 98% of the total deaths avoided if methane mitigation measures were also implemented. The contribution to health benefits through joint BC and methane mitigation measures is dominated by BC measures because:

- BC mitigation measures reduce both BC concentrations and total $PM_{2.5}$, as well as the ozone concentration resulting from any reductions in co-emitted ozone precursors, while methane reductions alone produce only modest reductions in the ozone concentration and associated air quality benefits; and
- $PM_{2.5}$ has a stronger association with premature mortality relative to ozone, leading to substantially greater health benefits from the BC mitigation measures.

Health benefits of the proposed BC emission reductions could be substantial enough to reverse the increasing trends of air pollution and mortality in Africa and South, West and Central Asia. This would be the case even when not accounting for the benefits of reduced indoor exposures and very high ambient exposures in some very densely populated urban areas.

While these BC control measures are generally applicable worldwide, their cost-effectiveness and mitigation potential depends on a number of factors, including location of the intervention, enabling environment and others (Fig. 8). For example, a recent study by the World Bank and ClimateWorks Foundation (2014) focused on cleaner cook-stoves in rural China and found that the deployment of 72 million cleaner stoves between the years 2014 - 33 would require a public investment of $400 million in the near term but could lead to the following benefits:

- 87,900 avoided instances of premature mortality from outdoor air pollution globally, of which 85,700 would be within China;
- reduced energy use of 450 GJ per year in 2030;
- near-term employment gains of about 22,000 jobs; and
- $10.7 billion in net present value from GDP increases between the years 2014 - 33.

Each sector has potential to reduce BC emissions with detailed information provided below, together with the relevance to GEF programs.

3.1 TRANSPORT SOURCES

Transport is typically the largest source of BC emissions in developed countries. It contributes a lower (but growing) share of total BC emissions in developing countries where per capita vehicle ownership has historically been relatively low. Globally, approximately 55% of transport-related BC emissions are from on-road diesel engines, 31% from off-road and 7% each from on-road gasoline engines and shipping (Bond *et al.*, 2013). BC emissions are projected to rise in developing countries due to growth in the transport sector (Streets *et al.*, 2004; Jacobson and Streets, 2009). Because emissions from diesel combustion contain few cooling co-pollutants, controlling emissions from diesel engines appears to offer the highest potential for reducing near-term warming of all the BC mitigation options available (Bond *et al.*, 2013). The most common vehicle emission control measures are a diesel particulate filter (DPF) in the exhaust tailpipe or diesel oxidation catalysts. DPFs are widely used in developed countries and have substantially reduced both $PM_{2.5}$ and BC emissions (although they may only modestly reduce fuel efficiency). However, the effectiveness of DPFs depends on the use of low-sulfur diesel fuel, which is generally not widely available or used in many developing countries (U.S. EPA, 2012). In addition, older vehicles with poorly-maintained engines common in developing countries limit the potential effectiveness of technical emission tailpipe control strategies.

In addition, many tailpipe and non-technical emission control measures (such as vehicle registration, inspection and maintenance, technology certification/verification programs) may be less effective in developing countries that lack the necessary infrastructure (U.S. EPA, 2012).

Non-technical measures include making vehicle inspection and maintenance programs more stringent and banning high-emitting vehicles, including public transport buses. Additionally, requiring regular maintenance and use of cleaner fuels, including some biodiesel fuels, by existing public transit fleets could significantly reduce BC emissions (U.S. EPA, 2012). One study demonstrated a reduction in BC emissions by a factor of two with the use of approximately 25% biodiesel (Magara-Gomez *et al.*, 2012). In some locations, diesel engines have been substituted by compressed natural gas (CNG) engines in vehicles, but, these vehicles are typically not equipped with any emission controls and produce large quantities of nitrogen oxides and formaldehyde, resulting in ground-level ozone. Overall, the substantial portion of BC emissions coming from transport, as well as the expected future rise in personal vehicle ownership and freight movement, makes this a critical sector worthy of support by the GEF.

The World Bank (2014) detailed BC mitigation approaches for the transport sector that included emission control technologies, new vehicle emission and fuel quality standards, emission reduction strategies for the current vehicle fleet and fiscal policies to reduce diesel emissions (see Annex 2). The CCAC is working to implement many of these approaches via a "Heavy-Duty Diesel Vehicles and Engines Initiative" that includes:

- support for regions and countries to develop vehicle emission and fuel quality standards;
- a Global Green Freight Action Plan;
- a Global Sulfur Strategy; and
- a Global Strategy for Emission Reductions from Ports and Maritime Vessels.

The GEF invested US$249 million on transport projects between 1999 and June 2010 and leveraged an additional US$2.5 billion in co-financing, resulting in an estimated direct reduction in emissions of 31.5 Mt CO_2 (GEF-STAP, 2010). Historically, the GEF has supported projects involving bus rapid transit (BRT), non-motorized transport infrastructure, travel demand management, and electric or hydrogen-fuelled vehicles or some form of hybrid (GEF-STAP, 2010). From 2010 to 2014, GEF–5 broadened activities to include land use and transport planning options that would lead to low-carbon transport systems. This shift recognized the importance of rapid urbanization as a key driver of future growth of GHG emissions in developing countries.

The current GEF–6 strategy includes a "Sustainable Transport" section, which highlights BRT and non-motorized transport infrastructure activities for their potential to reduce GHG emissions together with:

- fuel and road pricing;
- policies and strategies to improve fleet fuel efficiency;
- alternative fuels;
- advanced engine technology pilots;
- demonstrations of smart transport grids; and
- information and communication technology applications for travel demand management.

In addition, GEF–6 introduced three new Integrated Approaches, including "Sustainable Cities – Harnessing Local Action for Global Commons", which are intended to build on the GEF's urban management projects from various focal points to encompass sustainable transport (GEF, 2014). All of these project areas have the potential to simultaneously reduce BC emissions. Examples of BC-related projects are given in Boxes 1 to 6.

BOX 1
Demonstration for fuel-cell bus commercialization in China (Phases I & II).

UNDP implemented this two-phase project in China and the GEF funded part of the US$34.5 million cost. Concluding in November 2004, Phase I aimed to encourage reductions in the cost of fuel-cell buses (FCBs) for public transit applications and supported parallel demonstrations of FCBs and their fueling infrastructures in Beijing and Shanghai. It also focused on helping public transit companies purchase six FCBs each and to operate these over a combined 1.6 million km. Displacing diesel buses reduced both CO_2 and BC emissions, but the latter were not specifically assessed or monitored. The knowledge and experience gained through this project enabled the technology suppliers to identify opportunities to reduce costs, while host public transit operations gained valuable experience to adopt larger FCB fleets in the future. Phase II, completed in December 2012, reduced GHG emissions and air pollution through widespread commercial introduction of FCBs and their refueling infrastructure, but again BC reductions were not assessed.

3.2 RESIDENTIAL SOURCES

Nearly half of the world's population lack access to modern energy, relying on burning solid fuels including wood, charcoal, agricultural residues, dung and coal in open fires or rudimentary stoves for cooking and heating. These stoves are often operated indoors, where smoke pollution exposure can be extremely high without adequate ventilation. Women and children are particularly at risk since they typically spend more time indoors in close proximity to the stove. Globally, approximately 21% of BC emissions are from residential solid fuel use for cooking and heating in the developing world (Table 1; U.S. EPA, 2012). As economies develop and access to cleaner fuels expands, the proportion of people depending on traditional solid fuel combustion for cooking and heating is projected to decrease, although the overall total is likely to increase due to population growth.

Residential cooking also contributes significantly to ambient outdoor air pollution. In 2010, household cooking with solid fuels accounted for 12% of ambient $PM_{2.5}$ globally, varying from zero in five higher-income regions to 37% (2.8 µg/m3 of 6.9 µg/m3 total) in southern and sub-Saharan Africa. This resulted in an estimated loss of 370,000 lives and 9.9 million disability-adjusted life years globally in 2010 (Chafe *et al.*, 2014).

Cook-stoves emit a mixture of particulate matter (including BC), CO_2, methane and other precursors of tropospheric ozone such as carbon monoxide, thereby contributing to both near-term and long-term climate change. Biomass resources are generally regarded as "renewable" and "carbon neutral" if used sustainably, although some researchers argue that increased use of some sources of woody biomass would increase emissions, especially where land use change needs to be taken into account (Letureq, 2014). When burning traditional biomass and coal fuels (and indeed for some modern forms of biomass and bioenergy), including SLCPs in the analysis shows they are not "climate neutral"— even when the

Clean burning biogas-fuelled stove in the dwelling of a 4 cow dairy farmer in Kenya, that reduces black carbon emissions and improves health by replacing woody biomass combustion for cooking and milk pasteurization.

BC is co-emitted with organic aerosols that have a cooling effect (e.g. Anenberg *et al.*, 2013).

Since the health impacts of cook-stoves are significant and wide-ranging (Section 2.4; WHO, 2014), reducing pollutant emissions from residential solid fuel use would likely have the greatest overall health benefits of all measures currently available to reduce BC (Anenberg *et al.*, 2013). Health benefits of reducing fuel use and particulate matter emissions from cook-stoves have been estimated to outweigh the costs by 10 to 1 or more in some cases (Garcia-Frapolli *et al.*, 2010). More efficient and cleaner burning stoves would also reduce household fuel costs and fuelwood collection time, as well as avoid deforestation, forest degradation and habitat loss from fuel harvesting.

Cleaner cooking solutions are available. Stoves burning advanced fuels such as liquefied petroleum gas (LPG), ethanol and biogas are often vastly more efficient, cleaner and safer than those burning solid fuels. However, such fuels are not always accessible or affordable and often not adaptable to local cooking devices. A number of cleaner solid fuel stoves have entered the market over the last few decades, and some are now widely available. However, performance varies for individual stoves, depending on their design, fuels used and how they are operated in practice (Anenberg *et al.*, 2013). According to U.S. EPA (2012), the performance hierarchy for improved cooking solutions, in decreasing order for both cost and emissions performance is:

(1) electricity;

(2) cleaner fuels such as LPG or ethanol;

(3) advanced biomass stove designs (e.g. forced air fan or gasifier);

(4) rocket stoves; and

(5) other improved stove designs.

When solid fuel is used, processing the woody biomass or coal into pellets or briquettes with low moisture content generally results in more complete combustion and reduced BC emissions. Also, a field study confirmed earlier laboratory-based studies (MacCarty *et al.*, 2008) that using forced draft stoves can reduce BC emissions by 50–90% (Kar *et al.*, 2012). By contrast, results from natural draft stoves can be highly variable, in some cases reducing BC by 33%, but at other times increasing BC emissions (MacCarty *et al.*, 2010; Johnson *et al.*, 2011). One of the challenges of determining the impact of stoves beyond a single household involves the difficulty of measuring adoption rates. This has typically been done using standard survey methods that rely on users' recall or observations (Ruiz-Mercado *et al.*, 2015). To address this obstacle, researchers have begun using automated methods such as non-wireless and wireless stove use monitors (SUMs) and related systems to determine usage over a large number of households and for an extended period (Ruiz-Mercado *et al.*, 2015). A key consideration

for any type of monitoring and evaluation of improved stoves is the extent to which they generate local and national capacities (Smith *et al.*, 2007).

BC mitigation options for the residential sector include policy, regulatory, institutional and financial arrangements (see Annex 2; Anenberg *et al.*, 2013). In June 2012, the first interim international guidelines for evaluating cook-stove performance against specific indicators were published (ISO, 2012). They included a rating system with tiers for four performance indicators: fuel use (efficiency); total emissions (CO and $PM_{2.5}$); indoor emissions CO and $PM_{2.5}$); and safety. These guidelines provide information for governments, donors and investors as to the stove models that could achieve their intended goals, as well as drive performance benchmarks, certification procedures, and standardized fuel use and emission testing protocols (Anenberg *et al.*, 2013). Formal standards and testing protocols have been developed to address BC emissions in addition to the existing performance indicators. WHO has also recently published updated indoor air quality guidelines, which include emission targets for different kinds of domestic appliances for both carbon monoxide and $PM_{2.5}$ and advise against using coal and kerosene as home energy sources (WHO, 2014).

Many efforts, most notably the Global Alliance for Clean Cook-stoves, are already underway to create markets for clean and efficient household cooking solutions. The Alliance is working with

BOX 2
Project Surya

Project Surya is a major ongoing effort by researchers to immediately and demonstrably reduce BC, methane and ozone precursors from traditional biomass-fueled cook-stoves in India. The project aims to replace these traditional and highly polluting stoves with clean cooking technologies, such as solar-powered cook-stoves and other alternatives.

A pilot phase was launched in 2009 in the village of Khairatpur in the Sultanpur District of the Uttar Pradesh State. The pilot phase reached about 500 households, mostly living below the poverty line. The project is now in Phase 1, which is estimated to cost $US8 million to reach 8,000 households in two regions. The large size of the project will enable measurement of the climate and health impacts.

When the project is fully implemented, the resulting reduction in cook-stove BC emissions is expected to create a "black carbon hole" over the study areas within weeks of introducing the new technologies. Reduced BC concentrations will help mitigate near-term climate change, the effects of particulates on local hydrology, and the health and agricultural impacts of cooking with highly polluting traditional cook-stoves.

Under this effort, Kar *et al.* (2012) evaluated and compared commercial improved cook-stoves, revealing significant variation among different ones; force draft stoves yielded superior BC emission reductions. Consequently, forced draft stoves have significant mitigation potential.

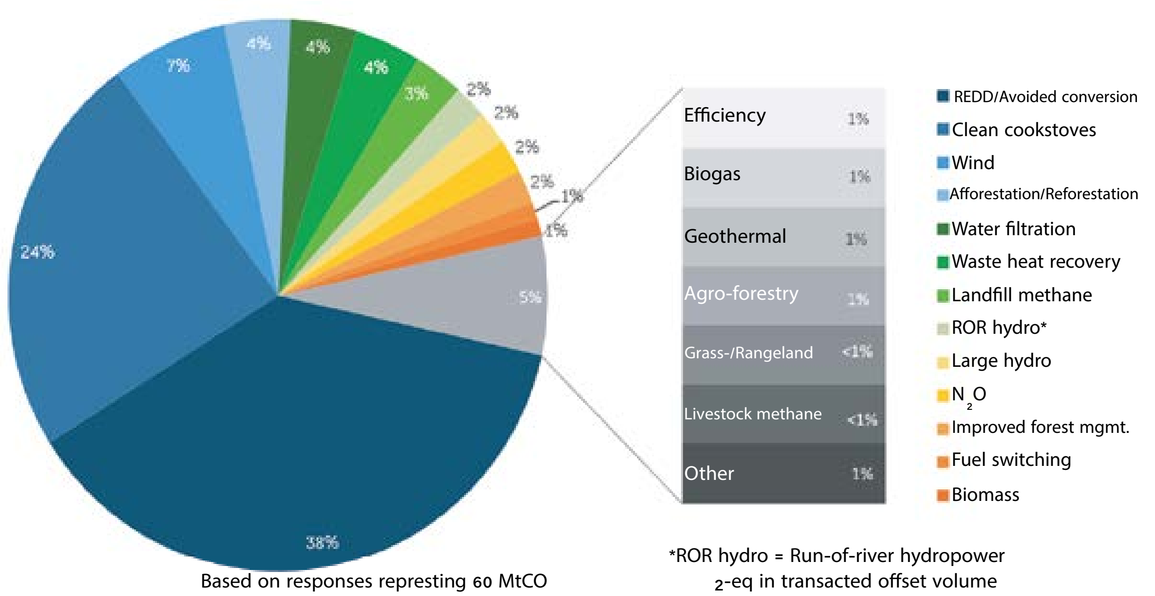
More information can be found at www.projectsurya.org.

eight focus countries (Bangladesh, China, India, Uganda, Kenya, Nigeria, Ghana and Guatemala) to build markets and address the health risks from household air pollution. China, Indonesia, Ethiopia, Nigeria, Ghana, Rwanda, Peru and Mexico have implemented national programs to increase adoption of clean cooking solutions by their rural populations. A CCAC initiative has begun to reduce BC emissions specifically from the residential solid fuel use sector. It includes several components: (1) special SLCP tranche of pre-investment grant funding under the Spark Fund of the Global Alliance for Clean Cookstoves; (2) standards and testing protocols to incorporate BC and other SLCP emissions; and (3) high-level advocacy and global education.

The importance of improving cook-stove designs from a carbon perspective is underlined by the growth in funding for these projects in voluntary carbon markets. In 2013, voluntary buyers purchased around US$80 million of offsets from projects that distribute fuel efficient, clean cook-stoves and water filtration devices (Fig. 9; Peters-Stanley and Gonzalez, 2014). Including BC in carbon financing mechanisms may bring additional funds to support clean cook-stove projects around the world. The Gold Standard Foundation has developed a methodology for quantifying the BC emission reductions from clean cook-stove projects (Section 4.2).

The GEF has supported numerous projects aimed at improving cook-stove design efficiency during its 20-year existence (for example see Box 3). These projects typically fall under the Climate

FIGURE 9
Market share of voluntary offsets in 2013 by project type (% share).



Source: Peters-Stanley and Gonzalez, 2014.
*Notes: *ROR hydro = Run-of-river hydropower. REDD = reducing emissions from deforestation and forest degradation Based on responses representing 60Mt CO_2-eq in transacted offset volume.*

Change Mitigation (CCM) or Sustainable Forest Management (SFM) portfolios. The impacts on air quality and BC are generally not included in GEF project proposals, nor are they summarized at project completion. Given the importance of using clean cook-stoves to mitigate climate change and improve local air quality, the GEF should expand its support to promoting clean cooking stoves, particularly those that further the likelihood of scaling up adoption of cleaner technologies.

Residential solid fuel use is not limited to developing countries. In parts of Europe, use of solid fuel heating stoves is rising, resulting in elevated air pollution levels during the winter months, and in some locations year-round (World Bank and ICCI, 2013). Solid fuel heating emissions from developed countries in the Northern Hemisphere can affect Arctic climate and snowmelt (World Bank and ICCI, 2013). Some countries, such as the United States, regulate heating stove emissions for air pollution purposes. As with traditional cook-stoves in developing countries, cleaner alternatives such as wood pellets, LPG, biogas, and green electricity are available.

BOX 3

Efficient biomass stoves in Kenya.

In Kenya, the government's main challenge in the biomass sector was "to reverse the current wood fuel supply-demand imbalance through provision of affordable and efficient energy services for both the rural and urban populations", as stated in its White Paper on Energy Policy (2004). The Market Transformation for Efficient Biomass Stoves for Institutions and Small & Medium-Scale Enterprises project was a $US 7 million dollar initiative, partially funded by the GEF. It sought to reduce CO_2 emissions by an accumulated total of between 0.4Mt and 0.96Mt by 2020. The project, implemented by UNDP in January 2007, was looking to remove market barriers to the adoption of sustainable biomass energy practices and technologies by institutions and small business in rural and urban areas of Kenya. The project promoted highly efficient improved stoves and installed 1,552 energy saving stoves that had a 70% energy efficiency compared to the traditionally used three-stone open fire. As of March 2011, when the project had completed implementation, it was set to meet and even exceed the targets for a reduction in CO_2 emissions for 2020. In addition, the project was able to facilitate carbon sequestration by planting over 500,000 trees, which also provide fuelwood to reduce pressures on natural forests and enhance biodiversity conservation.

Improved lighting projects also offer an important opportunity for reducing BC emissions throughout much of the developed and developing world (Jacobson *et al.*, 2013). In developing countries, kerosene lighting is widely used in households that lack reliable access to electricity and now emit around 270 kt of BC annually (Lam *et al.*, 2012). The CCAC Science Advisory Panel concluded that regarding kerosene lamps, "no other major BC source has such a combination of readily available alternatives and definitive climate forcing effects" (CCAC SAP, 2014). Household kerosene use also leads to indoor air pollution levels above WHO guidelines (WHO, 2014). Burning kerosene in lamps emits almost pure BC without a significant amount of cooling OC, making emissions from this source very efficient absorbers of solar radiation and important contributors to near-term climate change (CCAC SAP, 2014). Alternatives to simple wick-kerosene lighting appliances include either providing more efficient lamps that use less kerosene, or replacing such fuel-burning lamps with solar lamps or LED electric lighting using a renewable energy source of electricity (Jacobson *et al.*, 2013).

The GEF has supported numerous lighting projects under the Climate Change Mitigation portfolio, often with the result of replacing kerosene to reduce CO_2 emissions (Box 4). The

GEF should therefore also incorporate BC reductions into its assessments of global environmental benefits and seek to evaluate the corollary health and safety benefits of reduced reliance on kerosene (Section 5.1). This could include taking note of the economic benefits of using less kerosene. For example, in Africa, kerosene fuel costs can make up 10-25% of household monthly budgets (Lighting Africa, 2013). Where possible, opportunities for renewable energy sources of electricity, such as solar panels, to supply a household's energy demand for cooking and lighting should be considered as such configurations may yield significant reductions in emissions.

BOX 4

Lighting One Million Lives in Liberia.

Liberia has been recovering rapidly following decades of economic mismanagement and 14 years of civil war that largely destroyed the nation's existing energy infrastructure (Wesseh and Lin, 2015).

Less than 1% of Monrovia's residents have access to the electricity grid, and they pay one of the highest tariffs in the world due to heavy reliance on costly diesel fuel powered generation. The rest of the country depends on unreliable and inefficient sources of energy such as small gasoline and diesel generators, firewood, charcoal, candles, kerosene, battery-powered LED torches and lamps, and palm oil.

The GEF provided $1.5 million to leverage an additional $4.1 million in co-financing for the "Lighting One Million Lives in Liberia" project. The project, implemented by the World Bank, encourage private enterprises to market and sell solar lanterns in order to displace kerosene and other fuel-based lighting. The project will improve the capacity of the country's recently established Rural and Renewable Energy Agency.

This project seeks to replace 100,000 lanterns (at 44 litres per year of kerosene consumed per lantern), resulting in nearly 39,000 liters of CO_2 reduction. Although not explicitly described in the GEF project, the replacement of kerosene lanterns will also reduce black carbon emissions with additional benefits for the local and global climate, as well as for human health and economic and social development.

3.3
INDUSTRIAL SOURCES

The main industrial sources of BC emissions, including brick kilns, coke ovens (mainly from iron and steel production), industrial boilers, and oil and gas flaring, contribute around 20% of total BC emissions (U.S. EPA, 2012). China, the countries of the former Soviet Union, India, and Central and South America contribute most to industrial BC emissions. In developed countries, BC has declined dramatically as a result of fuel-use shifts, improved combustion processes and control technologies for direct $PM_{2.5}$ emissions.

Burning fuels in traditional, small-scale brick kilns is a significant source of air pollution in many developing countries. Of total global brick kiln production, over half is in China (54%), with India at 11%, Pakistan 8%, and Bangladesh 4% (Clean Air Task Force, 2010). Knowledge of these BC sources in many other countries is limited, such as in Bangladesh where use of small brick kilns is growing to support the booming infrastructure and construction industries generated by rapid population growth and urbanization (Guttikunda *et al.*, 2013. Depending on the type of fuel burnt, brick kilns emit BC and other particles, CO_2, CO, SO_2, volatile organic compounds (VOCs), nitrogen oxides (NOx) and heavy metals. Technology ranges from more modern and automated kilns in China to "artisanal" kilns where workers combine topsoil, manure and other raw materials with water to make a thick sludge, which is then molded into bricks that are dried in the sun before firing in the kilns (Schmidt, 2013). Mitigation options are available and have been described for different regions (UNDP, 2009; World Bank, 2011; CCAC, 2014b). While the brick kiln industry supports economic development, there are often additional negative environmental and health side effects. This is due to the fact that brick manufacturing often takes place in rural and peri-urban areas and, when fuelwood is used to provide the heat, it can lead to change of land cover, removal of nutrients and other negative environmental effects (Le and Oanh, 2010).

Options to control BC emissions fall into several categories (Annex 2). However, reducing brick kiln emissions is difficult in practice for many reasons. For example, even though technologies exist to improve efficiency and reduce pollution, artisanal kiln operators comprise an informal industry, so they rarely pay taxes or obtain operating permits. Also, brick kiln operators often lack access to the financial credit and capital needed to purchase cleaner technologies and governments may lack the ability or the will to help formalize and regulate small enterprises that are scattered throughout wide regions (Schmidt, 2013). Other barriers include lack of information and electricity (that is required for newer types of mechanized brick production) and access to roads and other infrastructure that could help in modernization of the traditional brick kiln technologies.

Nevertheless, the CCAC has invested in an initiative to reduce BC emissions from brick production, working with governments in Asia, Africa, Latin America and the Caribbean to elevate the importance of the issue.[14] The initiative aims to encourage adoption of cleaner brick production technologies through technical assistance, increasing awareness and understanding

14 http://www.unep.org/ccac/Initiatives/ImprovedBrickProduction/tabid/794080/Default.aspx, accessed 21 November 2014. Additional information is available on the CCAC website www.ccac.org.

(Photograph: Fredrik Naumann/Panos)

Gas flaring in Rivers State, Nigeria creates excessive air pollution, negatively affecting human health and the local environment.

of energy efficient technologies, conducting market analysis and training, and implementing pilot projects. The Swiss Foundation for Technical Cooperation is a key partner to implement energy-efficient brick production programs, particularly in Latin America.[15]

The GEF has supported projects aimed at reducing GHGs associated with the brick-making industry including four UNDP projects categorized under the CCM focal area[16] (Table 3).

Coke ovens for iron and steel production also contribute to industrial BC emissions globally. Modern plants typically capture coke-oven gas and burn it for heat production (RTI International, 2008), thereby minimizing emissions. In some developing regions, coke is often produced in small plants where BC emissions are not captured. China contributes approximately 60% of BC emissions from global coke production (U.S. EPA, 2012), however, efforts are underway to eliminate old and less-efficient coking technologies, promote energy-efficiency and reduce emissions (Huo *et al.*, 2012). While the best way to reduce BC emissions from coking would be to phase out smaller uncontrolled operations, some technological mitigation options may be available. These include capturing PM emissions and sending them to bag-houses or electrostatic precipitators (ESP) which typically achieve greater than 99% PM removal efficiency. However, this efficiency depends upon the design parameters of the specific unit and is generally lower for sub-micrometer-size particles such as BC. In addition, coke emissions can be reduced by controlling PM emissions during the process with good combustion, maintenance and work practices; monitoring combustion stacks to identify ovens in need of maintenance; and reducing the

15 http://www.unep.org/ccac/Partners/Non-StatePartners/tabid/130290/Default.aspx, accessed 30 January 2015.

16 PMIS is the GEF's Project Management Information System, which provides web-based access to the GEF project database, and which allows registered users to prepare and submit documentation for proposals requesting GEF funding, help Secretariat staff prepare documentation for internal review, track the status of approved proposals under preparation by the GEF Agencies and countries, and monitor implementation performance of approved projects. See http://www.thegef.org/gef/sites/thegef.org/files/publication/PMIS-guide.pdf.

TABLE 3
Examples of UNDP/GEF projects that address greenhouse gas emission reductions from the brick kiln industry.

GEF ID	Country	Agency	Focal Area	Project type	Title
1901	Bangladesh	UNDP	climate change mitigation	Full-size	Improving kiln efficiency in the brick-making industry in Bangladesh
2844	India	UNDP	climate change mitigation	Medium-size	Energy efficiency improvements in the Indian brick industry.
3091	China	UNDP	climate change mitigation	Full-size	Market transformation of energy-efficient bricks and rural buildings
4801	Vietnam	UNDP	climate change mitigation	Full-size	Promotion of non-fired brick production and utilization

amount of coal needed by recovering heat and using it to generate electricity for plant operations (U.S. EPA, 2012).

Other global industrial BC sources are small power generation sources lacking emission controls, industrial boilers and gas flaring. In some countries, small thermal power plants, industrial boilers and stationary diesel engines for power generation do not have effective controls to reduce particular matter. Diesel generators are widely used in regions of the world without reliable access to electricity, including in India, where it is estimated to account for 17% of total power generation (USAID, 2010), and in the Arctic (Quinn *et al.*, 2008). Well-established control technologies are available to reduce BC emissions from these sources.

Natural gas that is flared in the field during oil and gas extraction may have more impurities and burn less completely compared with natural gas combustion for power generation and other purposes. Therefore, flaring may lead to more BC emissions than the eventual burning of natural gas that is captured rather than flared. This generally depends on fuel composition, burning technologies and maintenance. Flaring has been estimated to contribute less than 3% of global BC emissions but dominates the estimated BC emissions in the Arctic (Stohl *et al.*, 2013). BC and co-emitted pollutant emissions from flaring are very uncertain. However, they are likely highest in countries with high rates of flaring, and can be reduced by capturing the natural gas for economic gain. This can be for direct use where a distribution pipeline is viable, for power generation in thermal power plants, or else compressed to CNG where the source is remote from demand. Alternatively, where such strategies are not attainable, other approaches should be adopted to improve burning technologies to minimize emissions.

The CCAC is investing in a project to develop and demonstrate new technology to reduce BC emissions from gas flaring.

The World Bank has also addressed flaring emissions since 2002 through its Global Gas Flaring Reduction Partnership (GGFR), a public-private partnership comprised of 30 governments and international oil companies working to increase use of the gas by increasing barriers to flaring.

In addition, the World Bank is leading the new Zero Routine Flaring by 2030 Initiative, aimed at bringing together governments, oil companies and development institutions to cooperate in eliminating routine flaring no later than 2030. Although these efforts are aimed at reducing CO_2 emissions, eliminating or substantially reducing flaring will also reduce BC emissions. The net climate benefits of reducing flaring depend on the mixture of pollutants reduced, including CO_2, BC and co-emitted pollutants that are potentially both reflecting and absorbing.

3.4
AGRICULTURAL AND OPEN BURNING SOURCES

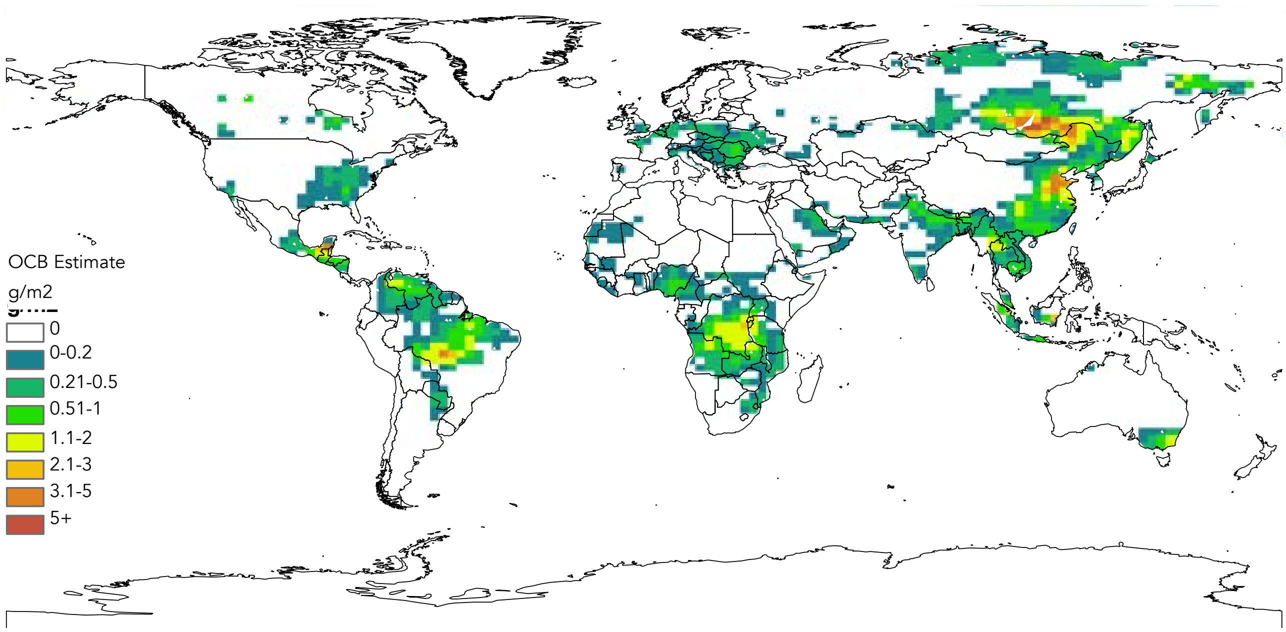
Open biomass burning contributes more to global BC emissions than any other sector, affecting nearly 340 million ha per year (U.S. EPA, 2012). The practice is widespread throughout the world and has typically been used to clear land for cultivation, convert forests to agricultural and pastoral lands, and remove dry vegetation to encourage agricultural productivity and the growth of higher yield grasses (Crutzen and Andreae, 1990). This sector also relies on use of wildfires and prescribed burns for purposes such as ecosystem, pest and disease management. Satellites have observed the extent of forest and biomass burning activity around the world, including the "arc of deforestation" in Brazil, Central America (e.g. Yucatan Peninsula), southeast Australia, southern Africa and southeast Russia (Fig. 10).

Burning is a significant source of radiatively - and chemically - active trace gases and aerosols, including BC and OC (Badarinath *et al.*, 2009). Although open burning of vegetation is the largest source of BC globally, eliminating it is the least likely to reduce climate change due to the large portion of co-emitted OC. However, mitigation could still be beneficial near snow and ice-covered regions, where the underlying surface is very bright (Bond *et al.*, 2013). As well, recent studies demonstrate that in addition to BC, a portion of OC termed brown carbon (BrC) is actually radiatively absorbing, and the BrC fraction in biomass burning can be significant (Bahadur *et al.*, 2012; Andreae and Ramanathan, 2013; Bond *et al.*, 2013; Feng *et al.*, 2013). Regardless of the net climate impacts, reducing open burning would benefit human health, with a 50% reduction in open burning estimated to avoid 190,000 premature air pollution-related deaths globally every year (World Bank and ICCI, 2013). Forest, savannah and agricultural fires in the tropics and subtropics are sources of widespread pollution that release many organic substances into air and soil, including persistent organic pollutants, i.e. polychlorinated dibenzodioxins and -furans and polycyclic aromatic hydrocarbons (Black *et al.*, 2012). Despite its

BOX 5
Less burnt for a clean Earth: Minimization of dioxin emission from open burning sources in Nigeria.

Deforestation is the largest source of GHG emissions in Nigeria. This project was implemented by UNDP (with funding from the GEF), to reduce the rate of deforestation by addressing unsustainable and growing consumption of fuelwood by households. Since its implementation in July 2010, there has been legislative strengthening and policy development, as well as a reduction of unintentional POP emissions (UPOPs) through introduction of new practices and approaches in municipal waste handling. The project aims to discover impacts from the reduction of UPOPs emissions from the open burning of crop residues in fields in preparation for planting the next crop.

FIGURE 10
Organic carbon and black carbon particulate matter emissions mass (g/m2) for 2003 (30.5 Mt) estimated through observations from MODIS and inverse transport modeling with the GOCART (Goddard Chemistry Aerosol Radiation and Transport) model.



Source: Vermote *et al.*, 2009.

high contribution to air pollution, the open burning of biomass is often overlooked in programs for improving air quality management (UNEP/WMO, 2011).

While fires have long been recognized as important in shaping ecological processes (Frost and Robertson, 1987; Pyne *et al.*, 1996; Goldammer and de Ronde, 2004), widespread and uncontrolled anthropogenic burning is affected by increased global land degradation. This complex interplay between fire and land degradation may be further enhanced under climate and land-use change scenarios (Bajocco *et al.*, 2010). In addition, agricultural crop wastes generated during harvesting are often burned in fields to assist subsequent soil cultivation. This practice has strong regional and crop-specific differences, as well as seasonal variations (Bond *et al.*, 2013). For example, in Asia, burning tends to occur during the dry season (pre- and post-monsoon in India). During these times, the air tends to be stagnant, causing high levels of air pollution locally and in adjacent urban areas (Oanh *et al.*, 2011).

While most open fires are caused by humans, either purposefully or involuntarily (Bond *et al.*, 2013), here we focus on strategies for controlling and reducing emissions from open burning of agricultural and municipal waste, which are purposeful and avoidable. Approaches used to control $PM_{2.5}$ emissions from open burning may in some cases be effective at specifically reducing BC. However,

the mixture of $PM_{2.5}$ emissions from fires varies according to the location, vegetation type and burning conditions. Little information is available to understand how different mitigation approaches would affect the whole mixture of $PM_{2.5}$. Therefore, the net climate impact of each approach is generally highly uncertain. Mitigation options include developing economic alternatives to slash-and-burn agriculture, enhancing basic fire management infrastructure, strengthening enforcement of fire policies, and educating and training workers on fire management techniques (U.S. EPA, 2012). Prospective mitigation approaches are summarized in Annex 2.

Given the widespread nature of burning and the ancillary benefits to human health of minimizing this practice, many organizations including the CCAC are actively supporting efforts to mitigate emissions from open burning of agricultural wastes.

The GEF has previously supported activities to minimize burning of municipal and agricultural wastes — mainly with the goal of reducing persistent organic pollutants (POPs) as part of the Chemicals and Waste focal area (Box 5). However, these projects did not include BC emission reductions as a global environmental benefit or their near-term impacts.

Farmers burn a field in preparation for planting crops.

4

MONITORING AND MEASURING BLACK CARBON

The GEF could address the multiple impacts of BC on climate, health, agriculture and ecosystems in prioritizing, selecting and evaluating projects. To do this, however, it needs methods and tools to quantify the potential reductions in direct emissions, atmospheric concentrations, and/or health and environmental impacts that result from each project.

There are several challenges associated with quantifying BC emissions, resulting ambient concentrations and downstream impacts. This section discusses the potential for equating reductions in BC with CO_2 and other greenhouse gases; outlines issues related to the most commonly proposed metrics; and provides an overview of how BC emissions and concentrations are measured, including challenges related to scientific uncertainty and practical shortcomings.

4.1
MEASURING BC EMISSIONS AND CONCENTRATIONS

BC can be measured in various ways to produce estimates of how a policy, technology or other action can reduce emissions and to gain evidence of how effective a mitigation investment has been. A range of metrics can be used with differing requirements for technology instruments and expertise, each with varying levels of uncertainty. BC is often measured optically, and while a common approach, it is not a direct measure of carbon. It is a measure of light absorption assumed to be based on carbon and quantified through an assumed mass absorption coefficient. Alternatively, thermo-optical methods measure elemental carbon (EC), but not light absorption. Thus, it is important to understand the range of methods and how they compare to one another (Salako *et al.*, 2012).

- **BC emissions can be measured at the source (for example, the tailpipe of a vehicle or chimney stack of a thermal power plant) using specialized air monitoring equipment.** It can also be calculated using estimated emission factors per unit of activity from the emission source. Direct emissions measurement will usually have the greatest ability to accurately determine the impact of a specific mitigation project on BC emissions. However, the chemical and physical nature of carbon particles may change in the near environment as they disperse away from the source. The full health impacts or benefits of emission reductions from a source will depend not only on BC emissions, but also on associated co-pollutants.

- **Atmospheric concentrations of BC and associated co-pollutants can be measured using in situ ground-based monitoring or observations from satellites or aircraft.** However, in contrast to measuring emissions from a specific project, BC concentrations in the atmosphere result from a variety of sources. The impact of concentration changes due to a specific emission-reducing project will only be observed, if at all, with measurements taken close to the emission source.

- **The impacts of changing BC and associated co-pollutant concentrations can be measured directly.** It is possible, for example, to monitor human health outcomes for individuals whose exposure has changed as a result of an emission-reducing project. However, monitoring impacts directly is quite expensive and time-consuming, and thus may not be practical or feasible for proposed GEF projects.

- **Impacts can also be simulated using atmospheric and impact models.** Modeling a change in impacts from reducing BC emissions is possible, particularly as new rapid assessment tools are being developed for non-technical users,[17] but modeling introduces many assumptions and uncertainties into the impact estimates.

Measuring and monitoring the performance of mitigation measures for BC can be done at various points along the "impact chain" (emissions ➡ concentrations ➡ exposure ➡ impacts). Approaches for measuring BC emissions at the project level, the atmospheric concentrations of BC (typically in a nearby geographic area as air quality monitors are relatively sparsely located) and resulting impacts at various spatial scales are described below.

Measuring emissions from a point source such as a thermal power plant flue or a ship's exhaust is a technically challenging task that can only be properly carried out with specially designed equipment. It is usually conducted in a laboratory

17 For example, the BenMAP-CE tool facilitates computation of health impacts/benefits of alternative air pollution scenarios (http://www2.epa.gov/benmap).

setting, although initial estimates of emission changes under various project assumptions can also be obtained using simple equations based on "bottom-up" emission inventories (adapted from Bond *et al.*, 2013).

Mitigation of emissions can therefore be achieved by:

- reducing the activity level (e.g. through improved energy efficiency);
- reducing the emission factor (e.g. more efficient combustion, use of cleaner fuels);
- increasing the efficiency with which emissions are controlled (e.g. diesel engine particle traps).

Equation (1) offers a general approach for estimating emissions based on data and/or assumptions on source activity and emission factors. Variations on this common approach are necessary for each sector.

(EQUATION 1)

where:
A = level of activity of a particular source (e.g. litres of fuel consumption, tonnes of commodity production).

EF = emission factor (g BC per activity).

eff = the removal efficiency of any BC emission control equipment that is used.

Transport sector

PM emission factors from transport vehicles can be measured quantitatively using standardized laboratory testing methods. These monitor tailpipe emissions while operating a vehicle under pre-set driving conditions in a laboratory (U.S. EPA, 2012). Such measurements require expensive and technically advanced equipment. Typically, they will not be practical or feasible for most individual emission reduction projects. This type of approach can be useful, however, in defining generic emissions factors for particular engine types, as well as fuel combinations that may be relevant for individual projects. Most currently available emission factors for motor vehicles pertain to technologies deployed mainly in developed countries. An important goal, therefore, could be to generate such data for vehicle technologies more prevalent in developing-country settings.

Once emission factors are obtained, either via laboratory testing or from published tables, project-level emission estimates can be calculated from Equation 1. Project-related goals are used such as reductions in vehicle distance traveled, improved engine and/or fuel types or tailpipe emission controls. The Transportation Emissions Evaluation Model for Projects (TEEMP), developed for the Scientific and Technical Advisory Panel of the GEF, includes PM_{10}[18] estimates for different categories of transport projects (GEF-STAP, 2011). In most cases, proposed new technologies will only be effective in practice when other conditions are met. One condition, for example, is the availability of low-sulfur fuel and assurance of proper maintenance of vehicles. This implies the need to harmonize policies with the development of institutions and control capacity.

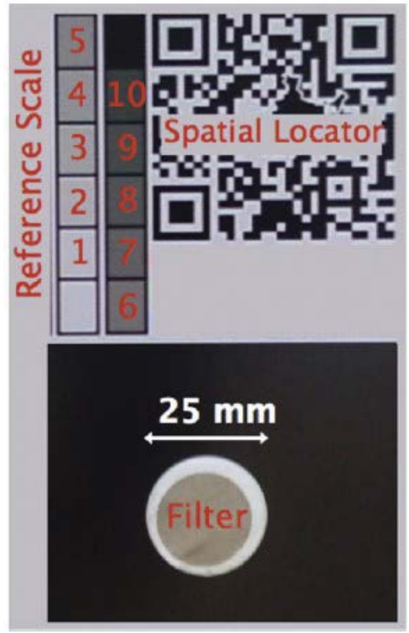
Residential sector

Residential BC emission measurements require similar considerations to those for transport. Protocols for direct monitoring of emissions from individual cooking events in field settings have

18 PM_{10} is defined as particulate matter with diameter of no more than 10 microns.

been developed (Johnson *et al*., 2009). They can be used in conjunction with project-level data compiled on the type of intervention and number of households to estimate changes in project-wide BC emissions, as well as associated co-pollutants. Field measurements of BC emissions from widely distributed cook-stoves are very difficult and expensive. Consequently, researchers from Project Surya (Box 2) developed a monitoring system that uses a cellphone to capture images of BC collected on filters. It sends the images to a laboratory, where the filter coloration is analyzed to estimate BC concentrations (Fig. 11; Ramanathan *et al*., 2011). New stoves can also be equipped with stove-use monitors (SUMS) that track and record the extent to which the stoves are actually used.

FIGURE 11
Cell phone-based BC monitoring approach used for cook-stove showing reference scale, spatial locator and photographic image of a sample filter.



Source: Ramanathan *et al*., 2011.

Industrial sector

Process-specific emissions of total PM emissions from industrial operations can be monitored and samples collected that can then be analyzed for content and other PM components. Mitigation projects that replace specific industrial processes with alternatives that promise lower BC emissions can be used in conjunction with established monitoring methods to document resulting emission changes. Where new monitoring is not feasible due to financial or technical constraints, published process-related emission factors can be used to estimate emission changes that could be achieved by changing an industrial process. However, such data are generally lacking for industrial sources in developing countries (e.g. brick kilns in South Asia). Where they are available, it may be difficult to extrapolate to other regions due to different technologies and fuels. This highlights the critical need for project-specific emission monitoring.

Open biomass burning

Emissions from open burning of biomass can be estimated from the following equation (adapted from Bond *et al.*, 2013).

(EQUATION 2)

where:
BA = the burned area (km^2)

FL = the available fuel load (kg dry matter per km^2)

CC = the combustion completeness fraction

EF = the emission factor (g compound emitted per kg dry matter).

Estimates for each input variable can be obtained by field measurements, published data or laboratory measurements.

Measuring atmospheric BC concentrations is complicated since there is no universally accepted definition of BC. It can be defined operationally on the way in which it is measured, of which there are two broad categories.

- The "thermal-optical" method defines elemental carbon (EC) based on its thermal properties. Here EC represents the amount of material that can be burned off at very high temperature from a filter sample after volatilization has first removed all the organic carbon (OC). Though relatively expensive, this method has the advantages of providing EC measurements in units of mass (µg/m3) and of providing a measure of OC.
- **The "optical" method** measures BC using directly observed optical properties of filters (i.e. blackness of the filter sample compared with a clean filter). BC is measured as the "absorption coefficient." Though relatively inexpensive and quick, no measure of OC is obtained, and the BC measurement does not provide a direct measure of mass. However, the conversion of absorption coefficient data to mass units can be done in various empirical ways.

Each of these two broad categories has many variations, adding additional complexity (U.S. EPA, 2012).

Extensive inter-comparison studies indicate general agreement between methods within a factor of around 2, though at times the differences are much larger (e.g. Bond *et al.*, 2004). In the future, there would be value in standardizing methods. The large air monitoring networks in the United States, for example, have transitioned to a well-documented thermal-optical method of measuring elemental carbon, referred to as "IMPROVE TOR" (Chow *et al.*, 2007).

In nearly all cases, measurement of atmospheric BC involves drawing air through a filter paper at a known rate over a set period, often 24 hours. The sample filter is then measured for EC or BC at a laboratory. Thus, regardless of collection method, precise equipment and technical expertise are needed to make and analyze these measurements. A new instrument for measuring air quality has recently been released by UNEP (2015) which, at a cost of around USD 1500 per unit, can enable wide spread monitoring. The device can measure the concentration of particulate matter ranging from 1 to 10 microns in diameter including $PM_{2.5}$.

Measurements of BC in snow, ice or sediment deposits can be made, directly and possibly via remote sensing from space or ground-based sensors. While important for scientific studies, these methods have little relevance for assessing health and environmental benefits of specific mitigation projects.

In Europe, BC monitoring is part of several urban national air quality monitoring networks. These are mostly continuations of optical "black smoke" or "soot" monitoring put in place by national regulations many decades ago. For example, Germany, Switzerland and the United Kingdom

(Photograph: Abbie Trayler-Smith/Panos)

Thanks to the Orissa Tribal Empowerment and Livelihoods Programme funded by DFID, six year old Timo and her friends can now study after dark and do not have to use dangerous kerosene lamps, which also emit black carbon.

have long-standing and continuous urban, optical-based, BC monitoring networks. There are also monitoring stations in Finland (two), Germany (eight), Ireland (two) and one each in Malta, the Netherlands and Poland. In the United States, the largest networks of BC monitoring sites are the Chemical Speciation Network (CSN) and Interagency Monitoring of Protected Visual Environments (IMPROVE) (Table 4). In Europe, measurements of BC concentrations are taken from regional background monitoring sites of the European Monitoring and Evaluation Programme (EMEP), and from sites run in cooperation with the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO). Altogether, BC-related mass concentration data are available from 21 stations in 13 European countries gathered over 2010-12, as well as absorption coefficient data from 22 European stations.

Simulating impacts

Atmospheric modeling has been crucial for estimating the climate, health and agricultural impacts of sectoral mitigation approaches (UNEP/WMO, 2011; Anenberg *et al.*, 2012; Shindell *et al.*, 2012; World Bank and ICCI, 2013). Models can operate at different spatial scales over different geographic domains, from the local to the global. It is important to use a model appropriate to the problem at hand. Many GEF projects involve local implementation of specific development projects that result in comparatively small BC emission reductions and more localized impacts. Consequently, it will be increasingly important for models to operate at fine geographic scales.

There is a need to develop robust automated and quality-assured models for estimating benefits from local-scale BC emission reductions that typically result from a GEF project. In addition, current emissions testing, monitoring and modeling approaches often require advanced technical expertise. Modifying methods and tools into a reduced form could possibly reduce the present barrier to entry for Implementing Agencies to estimate the benefits of proposed BC projects. However, it may introduce more uncertainty into the estimates than would further development and application of full-form modeling approaches.

TABLE 4
Worldwide air monitoring networks for BC.

Network	Country/ agency	Years of data	Black Carbon-indicator	Number of sites	Measurement method	Location of information and / or data
ESRL/GMD Aerosol Network	United States / National Oceanic and Atmospheric Administration	1957-present	BC	22 rural	Aethalometers, Particle soot/ absorption photometers	http://www.esrl.noaa.gov/gmd/aero/index.html
World Data Centre for Aerosols	Global Atmospheric Watch	1974-present	BC	~16 rural	Light absorption	http://www.gaw-wdca.org/
Nepal Climate Observatory-Pyramid	Nepal	2006-08	BC	1 rural	Multi-angle absorption photometer	http://www.atmos-chem-phys-discuss.net/10/8379/2010/acpd-10-8379-2010.pdf
CSN/Speciation Trends Network —PM2.5	United States/ EPA	1999-present	ECa	~200 urban	Thermal optical transmittance	http://www.epa.gov/ttnamti1/specgen.html
IMPROVE	United States/ NPS	1988-present	EC	110 rural (plus ~67 protocol sites)	Thermal optical reflectance	http://vista.cira.colostate.edu/IMPROVE/
Aerosol Research Inhalation Epidemiology Study / South Eastern Aerosol Research and Characterization Study (ARIES / SEARCH)	United States / EPRI / SC	1992-present	EC	5 urban 3 rural	Thermal optical reflectance	http://www.atmospheric-research.com/studies/SEARCH/index.html
National Air Pollution Surveillance Network (NAPS)	Canada	2003-present	EC	4 rural 13 urban	R&P Partisol-Plus 2025. R&P Partisol Model 2300	http://www.ec.gc.ca/rnspa-naps/Default.asp?lang=En&n=5C-0D33CF-1
Canadian Air and Precipitation Monitoring Network (CAPMoN)	Canada	2002-present	EC	29 rural	R&P Partisol Model 2300 PM2.5 Speciation Sampler	https://www.ec.gc.ca/rs-mn/default.asp?lang=En&n=752CE271-1
European Monitoring and Evaluation Program (EMEP)	Norwegian Institute for Air Research	2002-03	EC	2 urban 12 rural	Thermal optical transmittance – Sunset Lab	http://www.atmos-chem-phys.net/7/5711/2007/acp-7-5711-2007.pdf
European Supersites for Atmospheric Aerosol Research (EUSAAR)	European Union	2006-present	BC & EC	20 rural	Aethalometer / Sunset Lab	http://www.eusaar.net/
China Atmosphere Watch Network (CAWNET)	Chinese Meteorological Administration	1999-present	EC	6 urban 12 rural	Thermal optical reflectance	http://www.agu.org/journals/jd/jd0814/2007JD009525/2007JD009525.pdf
Multiple Independent Sites	Multiple agencies	Various periods 1976-2002	BC & EC	11 rural 7 rural	Various	http://www.atmos-chem-phys.net/10/2595/2010/acp-10-2595-2010.html

[a] EC =elemental carbon, measured using thermal optical methods. http://www.epa.gov/blackcarbon/2012report/Appendix1.pdf
Source: adapted from U.S. EPA, 2012, Appendix 1.

Several efforts are underway to provide reduced-form tools for policy makers or project implementers who may not have the technical expertise or resources to run full-form modeling. The most broadly applicable tool is the Benefits Calculator being developed jointly by the Stockholm Environment Institute (SEI), U.S. Environmental Protection Agency, Research Triangle International and the University of Colorado under the Climate and Clean Air Coalition Supporting National Action Planning initiative. The tool has been developed and already applied on a test basis in CCAC National Action Plans for Bangladesh, Colombia, Ghana and Mexico. It is a reduced-form tool that relies on previous global chemical transport modeling to estimate the radiative forcing, premature mortality and agricultural impacts of air pollution emission reductions (including BC). The tool is linked to SEI's Long-range Energy Alternatives Planning (LEAP) tool, which allows users to develop mitigation scenarios and estimate the projected magnitude of emission reductions for each pollutant and pollutant precursor species (e.g. BC, OC, NOx, SO_2). The tool then estimates the national-level benefits that would result from such emission reductions. The Benefits Calculator is expected to be developed for all countries globally in the coming years; non-technical users should be able to apply it quickly to estimate potential benefits of any particular project in any location. At present, the spatial scale remains coarse, and thus there is a need for further developments to enable assessing local-scale impacts of individual projects.

Concerns about local air pollution and the need for robust estimates of benefits to inform national policies go back many decades. In response, tools to assess beneficial health impacts of BC and $PM_{2.5}$ emissions have been developed. The many tools available vary with geographical scope, spatial resolution, pollutants addressed and other factors. Several were recently surveyed and compared by Anenberg *et al.*, (in press). The availability of these tools may enable the GEF to consider the air pollution-related health benefits from the BC emission reductions expected by proposed projects. However, care must be taken in selecting the most appropriate tool for a given project as they differ in technical and operational characteristics.

International standards for cook-stoves are currently under development using official International Standards Organization (ISO) practices. These standards should establish performance indicators and benchmarks, certification procedures and standardized fuel use and emission testing protocols. As a result, standardized information regarding emission reductions for each cook-stove model should be available. The standards are expected to address $PM_{2.5}$ emissions, and may include BC emissions specifically. WHO recently published updated indoor air quality guidelines that include emission targets for different kinds of domestic appliances for both CO and $PM_{2.5}$ and advise against using coal and kerosene as home energy sources (WHO, 2014).

For cook-stoves in particular, several initiatives will soon assist project proposers and developers to quantify potential multiple benefits from BC mitigation approaches. The Household Air Pollution Intervention Tool (HAPIT), under development, is a reduced-form tool that quickly estimates the health benefits of alternative, low emission, cook-stove intervention approaches in individual countries.

The user inputs an estimate of the exposure change expected as a result of the intervention, though the tool provides default values if such

data are unknown. In addition, the Gold Standard Foundation, a certification standard for carbon mitigation projects, in partnership with Project Surya, The Energy and Research Institute (TERI), the Global Alliance for Clean Cookstoves, Nexleaf Analytics and the University of California at San Diego, has developed a new method for estimating the near-term climate benefits of reducing BC and co-emitted species by replacing inefficient stoves with efficient cook-stoves.

The method uses global or regional GWPs for a 20-year time frame to convert other short-lived pollutants (OC, NMVOC, CO, NOx and sulphates) to BC-equivalents. While challenging, the approach allows for consideration of co-emitted atmospheric coolers; it avoids issues associated with using GWPs to compare short-lived pollutants with long-lived greenhouse gases.

New methods and tools under development to help quantify the near-term climate benefits of reducing BC emissions, as well as assessing any health and agricultural productivity benefits, may allow the GEF to formally consider near-term climate change actions as a focal area for selecting BC emission reduction projects in the future. Such tools and methods should be considered during the development of GEF–7 programming.

4.2 UNCERTAINTIES IN MEASURING BC AND ITS IMPACTS

Despite the advance in understanding of BC emissions on climate, local environment and health over recent years, many uncertainties remain. These preclude any useful estimation, with a high degree of confidence, of how projects could reduce BC and related impacts. Uncertainties affect the entire "impact chain" from emissions to concentrations to impacts. More research is needed in these areas, including on potential "leakage" if mitigation actions in one area lead to increases in other areas.

BC emissions are highly uncertain at the global, national and project scales due to uncertainties related to sources, activity levels and emission factors. Most countries lack a national BC emissions inventory, although some are creating BC inventories through the Arctic Council and other initiatives such as the Convention on Long-Range Trans-boundary Air Pollution (CLRTAP; see Annex 3). At the project level, direct emission measurements are rare because the main focus of many mitigation projects has been on total particulate matter or long-lived greenhouse gases rather than on BC. As a result, measurements of BC from individual sources are relatively limited. For example, cook-stoves have been tested for total PM emissions in both the laboratory and the field for years, but there are few measurements of BC emissions reported from laboratory tests, and only a couple from in the field. Uncertainties in emissions are a constraint not just for assessing total BC emissions, but also for evaluating the ratio of BC emissions to any co-emitted pollutants that act as coolers.

Ambient BC concentrations are also not adequately documented in many parts of the world. Although monitoring networks are extensive in the United States and Europe (Table 4), many commercial monitors measure total particulate matter rather than BC, they are sparse or even non-existent in other parts of the world. Among BC monitors, there is a lack of standardization in measurement methods and protocols, and many

methods give a bias due to the presence of other chemical components (Bond *et al.*, 2013).

There is no general consensus as to the most appropriate climate metric to use for BC and other aerosols. Typical metrics used for GHGs are not easily applied. The Science Advisory Panel of the CCAC recommended avoidance of metrics to compare BC with CO_2 since they influence climate on different time and spatial scales, and through different physical mechanisms. Rather, reducing near-term and long-term climate change pollutants should be considered as separate issues; different mitigation approaches are complementary, but not interchangeable. (See Annex 4 for more information on different climate metrics).

Overall, the impacts of BC on the climate system are uncertain. Estimates of the radiative forcing impacts of BC have much larger uncertainty bounds compared with those of carbon dioxide and methane. Some mechanisms by which BC influences the climate, such as the direct effects of BC radiation absorption, are better understood than others. For example, interactions of BC with clouds are poorly understood and hence are a major contributor to the uncertainty in estimates of BC climate impacts. In addition, although models are increasingly run with finer spatial resolution, the impacts of BC on local climate and weather remain very uncertain. This makes it difficult to project how changing BC emissions will affect important factors such as rainfall or storm frequency and intensity in specific areas. Nevertheless, even with the uncertainties, reducing BC and related pollutants is always beneficial for public health and ecosystem protection.

The Arctic region is sensitive to atmospheric warming effects, as well as to the effects of BC deposition on snow and ice.

(Photograph: UN Photo/Mark Garten)

5

OPERATIONAL GUIDANCE TO THE GEF ON BLACK CARBON MITIGATION

The GEF has an opportunity to help slow near-term climate change by considering BC in its funding decisions, as suggested by UNEP (2011) following the publication of the Integrated Assessment of Black Carbon and Tropospheric Ozone (UNEP/WMO, 2011). Consideration of BC emission levels in GEF project selection and tracking would complement the work of the CCAC and other multinational efforts working towards large-scale BC emission reductions around the world (see Annex 3).

The World Bank, in partnership with the CCAC, convened a series of meetings with experts to analyze financing options for BC projects (World Bank, 2015). The end result was a report which highlighted strategies to directly increase investment in near-term interventions, particularly for the residential cooking and diesel use sectors. The aim was to mobilize finance to support BC abatement activities and obtain the various co-benefits. Building capacity to finance BC mitigation on a broad scale is an essential component of the coordinated and complementary efforts needed to deliver on the opportunities.

Existing public and private financial flows with mandates for developing clean energy, and achieving more sustainable cities, can be used to finance a range of interventions and policies. These, in turn, can reduce BC emissions and adopt performance measurements. While several projects funded by the GEF are already reducing BC emissions, they are not usually acknowledged or counted. Given the GEF's goal of supporting transformational change and achieving global environmental benefits at scale, the organization is in a position to catalyze investment, share information, and build capacity to reduce BC emissions and help promote environmentally sustainable development.

The following section discusses potential entry points to incorporate BC abatement into GEF projects and programs. Specifically, STAP recommends four main categories of action, which combined, could make a meaningful impact in mitigating global climate change.

5.1 MAINSTREAM BLACK CARBON INTO THE EXISTING GEF CLIMATE CHANGE MITIGATION PORTFOLIO AND THE INTEGRATED APPROACH PILOTS

Although the GEF is increasing the number of multi-focal/cross-sectoral projects and initiatives, much of the programming continues to be organized by focal area.

Each project mainly pertains to a single global environmental issue, the most directly relevant focal area for BC mitigation being climate change mitigation (CCM). The GEF–6 Climate Change Mitigation Strategy supports integrated approaches that combine policies, technologies and management practices with significant climate change mitigation potential. With regards to SLCPs, the Strategy states that:

> *"... reducing the concentration of SLCFs, such as hydrofluorocarbons (HFCs), black carbon, tropospheric ozone and methane (CH_4), has the potential to slow the rate of global warming over the next two to four decades, as they tend to have much stronger global warming potentials compared to CO_2."*

Therefore GEF–6 support for BC mitigation may include:

> *"...reducing emissions from sources such as vehicles, brick-kilns, cook-stoves and open-field burning through measures including energy efficiency improvements, alternative technologies and appliances with lower emissions, as well as mitigating methane emissions through upgrading wastewater treatment works."*

Of the SLCPs, GEF projects have to date mainly focused on the mitigation of methane emissions

BOX 6.
Integrated responses to short-lived climate forcers promoting clean energy and energy efficiency.

Reducing short-lived climate forcers (SLCFs) in Mexico offers a realistic opportunity to significantly reduce the rate of global warming over the next two to four decades. The Integrated Responses to Short-Lived Climate Forcers Promoting Clean Energy and Energy Efficiency project, partially funded by the GEF, will contribute to development and implementation of a comprehensive and sustainable Low Emissions Development Strategy (LEDS) for Mexico by promoting clean energy and energy efficiency through an integrated assessment of SLCFs and the development and demonstration of targeted SLCF mitigation procedures. Once completed, this project will be a vital contribution to the development of effective strategies to achieve a low emission, energy-efficient future for Mexico. In its independent, nationally determined contribution (INDC), Mexico has included reducing its present BC emissions by 51% by 2030, largely as a result of improving the quality of the transport diesel fuel.

from landfills and coal bed methane. The GEF has not focused on controlling tropospheric ozone, only protecting the stratospheric ozone layer in line with objectives outlined in the Montreal Protocol. No GEF projects have specifically focused on BC, although one GEF project relating to SLCPs sought to characterize methane, BC and co-pollutants from various sources in Mexico and then integrate mitigation technologies into the country's low-emissions development strategies (LEDS) (Box 6).

The GEF–6 Climate Change Mitigation (CCM) strategy supports actions that directly reduce anthropogenic emissions or enhance carbon sinks and reservoirs (Table 5). From the examples discussed in Section 3, many technologies and practices clearly help mitigate BC in the transport, residential, industrial and agricultural sectors that could be actively supported with GEF financing.

Reducing BC can have impacts on other focal areas. For example, reducing the volumes of dung or wood gathered for fuel can mitigate deforestation, forest and land degradation, and loss of habitat and biodiversity. The use of improved cook-stoves simultaneously mitigates BC emissions and reduces the amount of dung or fuelwood consumed when cooking a meal (Brooks *et al.*, 2002).

In addition to the focal areas, GEF–6 includes three Integrated Approach Pilots that seek to tackle drivers of environmental change to achieve sustainable development goals:

1. Sustainable Cities – Harnessing Local Action for Global Commons
2. Fostering Sustainability and Resilience for Food Security in Sub-Saharan Africa
3. Taking Deforestation out of Commodity Supply Chain

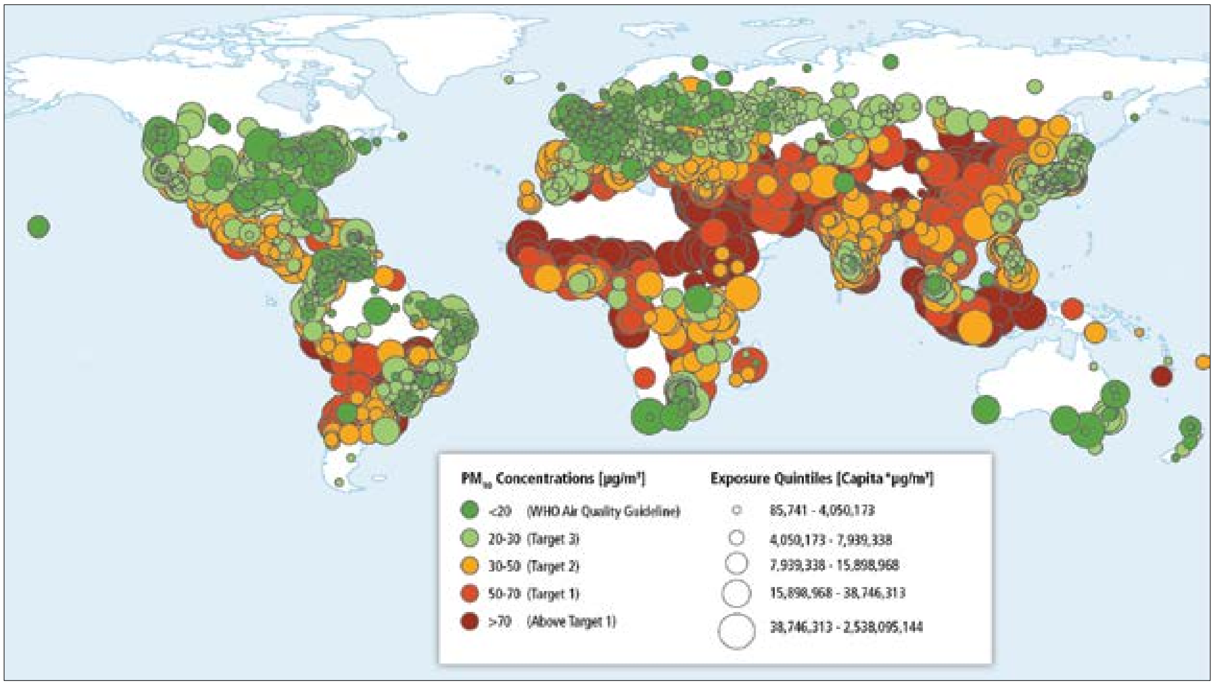
The Sustainable Cities IAP includes transport issues and informal settlements, hence could have BC implications, as could the Food Security IAP due to reduced crop productivity from BC emissions. In urban areas, BC is already a major issue due to its negative impact on human health. Air quality co-benefits can be achieved through mitigation actions in the urban context, especially in developing country megacities where outdoor air pollution tends to be higher than in urban centers in industrialized countries (Fig. 12; Molina and Molina, 2004).

One practical means to mainstream BC-related projects in future is through the GEF Project

TABLE 5
Options to reduce black carbon emissions as elements of the GEF Climate Change Mitigation Program.

	Programs under the CCM Strategy for GEF–6	Relevance to black carbon mitigation
1	Promote timely development, demonstration and financing of low-carbon technologies and mitigation options.	Directly finance technologies that mitigate BC such as: - diesel retrofit technologies for the transport sector; - electric and processed clean fuel cook-stoves; - more efficient lamps that use less kerosene, or replacing kerosene-burning lamps with solar lamps or electric lighting using a renewable energy source of electricity; - household clean energy solutions for lighting and cooking; and - improved efficiency and design of rice cookers.
2	Develop and demonstrate innovative policy packages and market initiatives to foster new range of mitigation actions.	Support policies designed to prevent or reduce activities that result in the emission of BC such as: - modal shifts away from diesel vehicles; - quality assurance testing, standards and protocols for cook-stove designs that reduce BC emissions and removal of subsidies for kerosene; - industry-led best practices for gas flaring reduction; and - alternative uses of crop wastes to avoid open burning.
3	Promote integrated low-carbon urban systems.	Incorporate measures designed to provide near-term climate benefits by reducing BC into the GEF Sustainable Cities Integrated Approach Pilot (IAP), particularly with regards to the transport sector.
4	Promote conservation and enhancement of carbon stocks in forest and other land use, and support climate-smart agriculture.	Support policies and programs designed to: - reduce household reliance on biomass fuels for cooking and heating; - promote prescribed burn-offs to minimize climate impact, with restrictions according to season and weather; - encourage tractor and harvester engine maintenance to reduce emissions; and - add particulate filters to diesel trucks and agricultural vehicles.
5	Integrate findings of UNFCCC obligations and enabling activities into national planning processes and mitigation targets.	Coordinate efforts to reduce BC emissions with activities under the UNFCCC through the CCAC and other related efforts.

FIGURE 12
Human risk exposure to PM_{10} pollution in 3,200 cities worldwide.



Sources: IPCC, 2014 based on Doll, 2009; Doll and Pachauri, 2010; Grubler *et al.*, 2012.

Identification Form (PIF) — a short description of a project concept used by the GEF to determine whether the project meets basic criteria.[21] If a proposed project is anticipated to also reduce BC emissions, this should be made explicit in relevant sections of the PIF and in any other relevant project documents.

5.2 MEASURE AND ACCOUNT FOR THE AMOUNT OF BLACK CARBON AVOIDED AS A RESULT OF GEF- FUNDED PROJECTS

Tracking tools are used to collect information on key indicators from individual GEF projects and aggregate them across all projects to track overall portfolio performance in each of the GEF focal areas.[20] Each focal area has unique indicators and thus a separate tracking tool is needed for projects within each category.[21] For example, the tracking tool for the Climate Change Mitigation (CCM) focal area objective on renewable energy, collects data from each project on installed capacity and lifetime heat or electricity generation for the various technologies (wind, biomass, geothermal,

19 See http://www.thegef.org/gef/sites/thegef.org/files/gefcs/docs/922.pdf.

20 http://www.thegef.org/gef/tracking_tools, accessed 24 November 2014.

21 The recent trend towards more multi-focal area projects has brought new challenges in monitoring and evaluation.

hydro, photovoltaic), as well as lifetime GHG emissions avoided. Similarly, for the CCM objective on transport and urban systems, the tracking tool collects information on whether the project targets various efficient transport approaches (e.g. bus rapid transit, mass transit, freight logistics, transport efficiency, non-motorized transit), as well as assesses the lifetime GHG emissions avoided.

BC could be incorporated into the GEF tracking tools as a separate category in addition to GHGs. As previously discussed, there is no consensus as to the most technically sound, effective and feasible means of quantifying near-term climate impacts on a project-level basis. Organizations such as the CCAC and the Gold Standard Foundation, are engaging experts from the relevant fields to develop indicators that can be used for this purpose. This includes, for example, demonstrating the impacts of activities under the CCAC, developing financial mechanisms for incentivizing BC mitigation, and quantifying and valuing the near-term climate benefits of clean cook-stove projects.

Until such indicators are developed and available, at a minimum, a tracking tool could be amended to include a query asking whether the project will reduce BC emissions and, if so, by how much. This will need careful consideration to ensure any additional reporting requirements are warranted given the lack of a robust BC reduction methodology at present. Nearly every project that has an impact upon fossil fuel or biomass combustion will impact upon BC emissions. However, such a simple approach will not produce the information needed to understand the net climate impact of the reduction in BC. A project that also reduces OC emissions to a greater extent than BC emissions would be categorized under this framework as reducing BC emissions. Conversely, the overall net climate impact of the project would be warming due to reducing the cooling offsets of the OC emissions.

Ideally, the GEF would collect information on not just BC, but on all the climate-active pollutants co-emitted with BC and also affected by BC mitigation approaches. However, this ideal needs to be balanced with the burden on project developers to provide this information. At a minimum, it would be more informative for the tracking tool to seek inputs on the amounts of both BC and OC emissions likely to be reduced. Since existing GEF tools already track methane and carbon dioxide emissions, this information can be used in concert with the BC and OC emissions to estimate total long-term and near-term climate impacts. Considering also information about CO and NMVOC emissions would help the GEF further elucidate the net climate impact of any particular project. The net near-term climate impact of the short-lived species — BC, OC, CO and NMVOCs — could be determined by converting each species to a near-term climate equivalence metric, such as BC equivalence using the ratios of GWPs between each species and that of BC. This technique avoids issues associated with converting short-lived species to CO_2 equivalence, and allows for a near-term climate impact metric to be reported in addition to a long-term climate metric. This project-level information could then be aggregated at the portfolio level.

Project developers, however, would need to estimate the impact of the project on the various short-lived pollutant emissions, which may be difficult and require technical expertise. Even so, obtaining such information could lead to additional information about how different types of projects and technologies affect these emissions. This, in turn, would incentivize projects that

reduce BC emissions and ultimately enhance the knowledge base among the GEF Partnership. Since total $PM_{2.5}$ exposure drives health impacts, one option would be to add inputs to the tracking tool requesting the amounts of BC and total $PM_{2.5}$ emissions reduced, as well as the percentage of total $PM_{2.5}$ that is the BC component. Projects that reduce both BC and overall $PM_{2.5}$ may therefore have co-benefits of improved climate and reduced health impacts (although the climate impacts could be a dis-benefit when OC reductions are greater than BC reductions). Therefore, the BC percentage of total $PM_{2.5}$ must be lower (i.e. in addition to reduced total $PM_{2.5}$, the absorbing portion of $PM_{2.5}$ is also reduced leaving a more reflective $PM_{2.5}$ mixture) after implementation than before. Including information about $PM_{2.5}$ would also enable the GEF to compile information from funded projects about $PM_{2.5}$-related health benefits. However, as for collecting information on OC emissions, estimating the impact of the project on both BC and total $PM_{2.5}$ may be impractical in some cases.

Once information on BC, OC and $PM_{2.5}$ emissions is collected from project developers, the GEF may consider not just the magnitude of the emission reduction, but the location and proximity to climate-sensitive regions such as the Arctic and Himalayas. Projects that reduce BC emissions in these locations are likely to have a greater climate benefit than in less sensitive regions.

5.3 ENGAGE WITH STAKEHOLDERS INVOLVED IN NATIONAL, REGIONAL AND INTERNATIONAL EFFORTS TO ADDRESS VARIOUS ASPECTS RELATED TO BLACK CARBON MITIGATION

There are many ways in which the GEF can engage with the international community to show support for mitigating black carbon. The CCAC and the Global Alliance for Clean Cookstoves are organizations and initiatives focused on improving the global climate and human health by advancing research and projects to mitigate black carbon across sectors throughout the world. Given the GEF's longstanding experience financing projects in the field, it could provide useful "lessons learned" and other expertise to help advance the goals of these and other like-minded institutions. This could include, for example, the Convention on Long-Range Trans-boundary Air Pollution (CLRTAP), which recently became the first international treaty organization to address BC specifically (see Annex 3). In addition, as outlined in Section 4, modeling methods and tools are in development, such as the Benefits Calculator and the HAPIT tool. These will enable non-technical users to quickly estimate the benefits of policies and mitigation measures to reduce emissions from BC-rich emission sources in specific locations. Such new methods and tools may allow the GEF to consider not just the potential amount of BC emissions reductions by a project, but the climate impacts. These are highly spatially dependent so should be considered during the development of GEF–7 programming.

Other activities underway may also inform how the GEF considers BC in the future. The CCAC and the World Bank recently convened a BC Finance Study Group (BCFSG) to recommend how financial mechanisms can be used to invest in BC mitigation projects, similar to methane finance

mechanisms. With support from the CCAC, the Gold Standard, the Global Alliance for Clean Cookstoves and several other partners have developed a methodology to quantify climate benefits from BC emission reductions from cook-stove projects. Therefore, enhanced engagement by the GEF could include direct support for the CCAC and others to develop methodologies and tools for project-level BC accounting. The GEF could also potentially support BC monitoring efforts of recipient (key developing) countries as a part of this project/program.

Woman carrying fuelwood from the countryside into Addis Ababa, Ethiopia.

5.4
DIRECTLY ENCOURAGE PROJECTS THAT REDUCE BLACK CARBON

Several GEF Implementing Agencies are already prioritizing SLCP mitigation in their activities. In addition to UNEP hosting the Secretariat of the CCAC, GEF Implementing Agencies that are partners of the CCAC include the World Bank, UNDP, UNIDO and FAO. Table 6 summarizes some key actions by GEF Implementing Agencies towards mitigating SLCPs, including BC.

The existing interest in SLCP mitigation among Implementing Agencies means that some project developers may already have experience in considering the impacts of different types of projects on BC emissions. The expertise, knowledge and actions currently underway among several of the GEF Implementing Agencies, including UNEP, the World Bank and UNIDO, could be harnessed. BC could be incorporated into GEF project selection and tracking as discussed above, for example.

This would augment the efforts of individual Implementing Agencies to reduce SLCPs, possibly with a regional (such as Asia) or sectoral (such as agriculture) focus. In so doing, it could potentially expedite the scaled-up BC reductions needed worldwide to avoid dangerous climate change.

Some of the output of ash from the coal burnt in the Guru Hargobind Thermal Power Plant in Bathinda, India escapes into the air and has been linked to health problems in the area, as well as affecting crops.

(Photograph: Chris Stowers/Panos)

TABLE 6
Activities undertaken by selected GEF Implementing Agencies and other international organizations towards mitigating SLCPs, including BC.

GEF Implementing Agency	Activity
World Bank	• CCAC partner. • Assessed how SLCPs can be integrated into WB activities (World Bank, 2013). • Assessed potential BC mitigation approaches to reduce impacts on cryosphere regions (World Bank and ICCI, 2013). • Engaged in reducing BC emissions from the brick sector in South Asia (e.g. World Bank, 2011). • Examined technical and policy options for addressing BC emissions from diesel vehicles and quantified resulting climate and health benefits (World Bank, 2014). • Evaluated any multiple benefits from simultaneously addressing GHG and SLCP reductions (World Bank and ClimateWorks Foundation, 2014). • Evaluated approaches to address BC in local air pollution planning and World Bank activities (World Bank, 2015). • Lead partner of CCAC Finance Initiative (leads Black Carbon Finance Study Group). • Lead partner of the CCAC Agriculture Initiative. • Partner of CCAC Bricks Initiative, Municipal Solid Waste Initiative, Supporting National Planning for Action on SLCPs Initiative. • Partner of the Global Alliance for Clean Cook-stoves.
United Nations Environment Programme (UNEP)	• CCAC partner and hosts CCAC Secretariat. • Co-sponsored Integrated Assessment of Black Carbon and Tropospheric Ozone (UNEP/WMO, 2011). • Highlighted cost-effective actions for controlling short-lived climate forcers (UNEP, 2011). • Lead partner of CCAC Finance Initiative, Supporting National Action Planning Initiative, Regional Assessments Initiative, Urban Health Initiative, Heavy Duty Diesel Initiative, and Municipal Solid Waste Initiative. • Partner of CCAC Oil & Gas Initiative and Agriculture Initiative. • Partner of the Global Alliance for Clean Cookstoves • Hosts the Partnership for Clean Fuels and Vehicles. • Facilitates the Atmospheric Brown Cloud program.
United Nations Development Programme (UNDP)	• CCAC partner. • Partner of the Global Alliance for Clean Cook-stoves.
United Nations Industrial Development Organization (UNIDO)	• CCAC partner. • Partner of the Global Alliance for Clean Cook-stoves.
Food and Agriculture Organization of the United Nations (FAO)	• CCAC partner. • Lead partner of the CCAC Agriculture Initiative.

6

CONCLUSIONS AND RECOMMENDATIONS

Mitigating BC emissions can have multiple benefits on global and regional climate change, public health and the environment. Because BC is relatively short-lived in the atmosphere, these benefits are expected to accrue within months following implementation of mitigation measures, thereby slowing the rate of climate change in the near term. This is particularly significant given recent trajectories that show the world is not yet on a pathway to limit warming to below 2°C and that ecological and socio-economic systems will need more time to adapt. The majority of the benefits would be felt locally and regionally by the communities near to where the mitigation measures were implemented. These relatively immediate and local benefits contrast to the long-term global benefits of reducing long-lived GHG emissions, which is why mitigating long-lived GHGs remains essential if dangerous climate change is to be avoided.

Mitigation approaches are available for reducing BC from the transport, residential, industrial and agricultural sectors and from open burning sources. International efforts are underway to expedite further implementation of these mitigation measures. The GEF is already funding climate change mitigation projects that simultaneously reduce BC. It should therefore incorporate BC into its programming as an additional basis for selecting projects for funding. As noted throughout this report, black carbon can also negatively impact on ecosystems, food security and human health, thereby interacting across sectors across several GEF focal areas and cross-cutting themes. Therefore, when assessing mitigation opportunities in this domain, the GEF should look well beyond its climate change mitigation portfolio, particularly to sectors addressing land use, to implement innovative measures and seek out new partnerships that will have positive impacts across multiple sectors.

Measurement and monitoring methods are available to quantify BC emissions and atmospheric concentrations. However, such methods cannot evaluate relatively small changes in concentrations resulting from individual development projects. While measuring tools are further developed, the GEF could incorporate BC mitigation into its programming by:

- mainstreaming BC into project selection;
- tracking reductions in BC and co-emitted pollutants from specific projects to begin to measure impact;
- engaging with organizations actively seeking to advance BC mitigation through activities such as developing project-level tools and methods for calculating benefits; and
- building demand for, and sharing of, knowledge among Implementing Agencies and the wider GEF partnership through targeted funding.

Successfully constraining the rise of mean annual global temperature to below 2°C will depend not only on reducing GHG emissions, but also on reducing SLCP emissions. Doing so will also position mitigation efforts within the context of sustainable development by positively contributing to enhanced human health and security.

A family in Tarialan, Uvs Province, Mongolia, uses a solar panel to generate power for their ger, a traditional Mongolian tent.

(Photograph: UN Photo/Eskinder Debebe)

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ANNEX 1

DESCRIPTION OF OTHER CLIMATE WARMERS

Carbon dioxide (CO_2) is the primary anthropogenic greenhouse gas contributing to global climate change, with radiative forcing estimated as 1.68 Wm-2 (Myrhe *et al.*, 2013). CO_2 increased by an estimated 40% from 1750 to 2011, mainly due to fossil fuel burning and emissions arising from land-use change (IPCC, 2013). CO_2 is also emitted naturally, and concentrations cycle in the atmosphere due to the global carbon cycle: CO_2 is taken up by carbon reservoirs (e.g. the ocean, land vegetation and soil) and released back into the atmosphere over time (e.g. via ocean-atmosphere exchange, plant and animal respiration, soil respiration and decomposition, and volcanic eruptions). In 2013, the Intergovernmental Panel on Climate Change Fifth Assessment Report concluded that "it is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in greenhouse gas concentrations and other anthropogenic forcings together" (IPCC, 2013).

Methane (CH_4) is the second-largest contributor to forcing resulting from anthropogenic GHG emissions, with radiative forcing estimated as 0.97 W m-2. It is emitted by natural sources such as wetlands. In addition, approximately 60% of total CH_4 emissions are directly caused by human activity, including from leakage from the production and transport of fossil fuels, rice cultivation, bacterial breakdown of organic wastes and the enteric digestive systems of ruminant livestock (Zaelke *et al.*, 2013; IPCC, 2014). Natural processes in the soil and chemical reactions help remove CH_4 from the atmosphere (U.S. EPA, 2010). The typical lifetime of a methane molecule in the atmosphere is approximately 12 years, but this can vary depending on changes in the atmosphere's chemical state, which depends on the concentrations of species and the temperature and other variables. On an equivalent mass basis, emission of a kg of methane is much more efficient at trapping infrared radiation than emission of a kg of CO_2 over the lifetime of the methane molecules. But given the CO_2 perturbation lasts for a much longer time, the ratio goes down over time. In addition, because there are of order 200 times as many molecules of CO_2 in the atmosphere as methane, the roles of both species must be considered. For example, over a hundred-year period[1], the comparative warming influence of emission of a mole of CH_4 molecules is between 20 and 30 times greater than emission of a mole of CO_2 (U.S. EPA, 2010). CH_4 is also a precursor gas of tropospheric ozone (O_3) (see below), itself an important greenhouse gas, and globally, methane emissions are responsible for half of its observed rise (Zaelke *et al.*, 2013).

Another important anthropogenic GHG is nitrous oxide (N_2O), which is produced as a result of agricultural and industrial activities, as well as during combustion and human waste disposal (IPCC, 2014). N_2O is also the most important anthropogenic contributor to the destruction of stratospheric ozone (Ravishankara *et al.*, 2009). N_2O "leaks" from the nitrogen cycling process have increased over time as agricultural productivity has been increased to feed an increasing number of people. Meeting the nutritional needs

1 Hence, the global warming potential on a per tonne-equivalent basis over a hundred-year period compared with 1t CO_2 is around 23 times, whereas on a 20-year basis the ratio is 4-5 times as much.

Modern charcoal production in Kenya emitting black carbon during the carbonization process.

of a growing human population will likely create even greater demand for the use of synthetic nitrogenous fertilizers and therefore escalate the risk of increasing N_2O emissions (Davidson, 2012).

Other GHGs are fluorinated gases (known as "F-gases"), which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6). These are emitted through a variety of industrial processes such as aluminum and semiconductor manufacturing and manufacture of refrigerants. F-gases have a very high global warming potential (GWP) relative to other GHGs; small atmospheric concentrations can have relatively large effects on global temperatures. Their lifetimes in the atmosphere range from one to several hundred years, with an average of 15 years (Blackstock and Allen, 2012). For example, a number of HFCs, used primarily in refrigeration and insulating foams, have a warming effect that, on a per tonne-equivalent basis, is hundreds to thousands of times more forceful than CO_2 (Zaelke *et al.*, 2013). HFCs largely replaced chlorofluorocarbons (CFCs) as refrigerants under the Montreal Protocol and an increase in the emission of HFC use in developing countries has resulted, mainly from the increased demand for refrigeration and air conditioning. According to one estimate, HFCs could contribute the equivalent of 5.5 to 8.8 Gt of carbon dioxide per year, accounting for 9-19% of global GHG emissions by mid-century (Velders *et al.,* 2009).

Tropospheric ozone (O_3), another important greenhouse gas, is the main component of "smog". It is not emitted directly, but forms when precursor gases such as CO, NOx, NMVOCs[2] and CH_4 react in the presence of sunlight (Zaelke *et al.*, 2013). O_3 remains in the atmosphere from hours to days (Blackstock and Allen, 2012) and results in significant negative health impacts — even premature death — and is particularly dangerous when inhaled by children, older adults and people with compromised health. Ground-level ozone also has a negative impact on plant growth by reducing the ability to absorb CO_2 during photosynthesis resulting in lower crop yields and the ability to sequester carbon (Zaelke *et al.*, 2013).

2 Non-methane volatile organic compounds.

ANNEX 2

SUMMARY OF MITIGATION OPTIONS BY SECTOR

TRANSPORT SECTOR

Summary of mitigation objectives, examples of mitigation options, and potential policy/regulatory/institutional/financial arrangements to promote the option for BC emissions mitigation.

Miti-gation objective	Examples of mitigation options	Policy/regulator/institutional/financial arrangements to promote the options	Regions / countries with high mitigation potential	Mitigation costs	Non-climate benefits	Comments/ additional considerations
Reduce tailpipe emissions	Electrification or use of cleaner fuels such as ultra-low sulfur diesel, compressed natural gas, liquefied natural gas, and hydrogen.	Electric vehicle and clean fuel infrastructure development; large-scale investment in fuel refining upgrades; government mandates, targets and incentives; removal of fossil-fuel subsidies and increased fuel and carbon taxes. Consumer education on alternative technologies and their availability. Market-specific measures to address range anxiety.	Asia, Africa, Latin America	High cost. Estimated US$80-$2,000/t CO_2eq break-even carbon price. US$36,000-815,000/t BC though health benefits are very substantial if social benefits can be internalized (UNEP, 2011). Social cost can be diminished where fossil-fuel subsidy reduction or fuel taxes will create revenue or reduce expenditure.	Avoided health impacts related to air pollution exposure. Improved environmental benefits, including crop productivity, ecosystem health (reduced acid rain), urban livability, real estate values, etc.	High mitigation potential: 0.3 Mt BC for heavy duty vehicle Euro VI/6 standards; 0.1 Mt BC for Euro VI/6 light-duty vehicle standards; 0.3Mt BC for Euro VI/6 standards for off-road vehicles (UNEP, 2011). Key global programs: CCAC Heavy-Duty Diesel Vehicles Initiative; UNEP's Partnership for Clean Fuels and Vehicles; the International Council on Clean Transportation (ICCT).
	Increased use of diesel retrofit technologies such as diesel particulate filters, diesel oxidation catalysts, closed crank-case ventilation systems, selective catalytic reduction systems.	Emission regulations; incentives to private and fleet-owning vehicle purchasers and manufacturers; R&D to lower costs; subsidies and cheap credit for high-efficiency engine purchase.				
	Cleaner engines through engine repower, in-cylinder PM controls and engine upgrade.	New engine requirements for lower emissions.				
		Fuel sulfur content standards				
		Retrofit programs				
	Better vehicle maintenance.	More stringent vehicle inspections and maintenance programs. Educational initiatives for fleet owners. Subsidies & tax benefits for vehicle maintenance.				
	Idle reduction through automatic engine shut-off devices or other technologies.	Technology certification/verification programs. Corporate pledges & fleet conversions to no-idle (e.g. WalMart). Municipal regulations against idling. Hybrid electric charging stations for long-haul trucks. Other engine idle reduction programs.				

Encourage modal shifts	Bus rapid transit and light rail through new infrastructure.	Provision of appropriate infrastructure and facilities for alternatives (e.g. road structures accommodating two-wheelers, interconnectedness of modes); dedicated bus lanes and stops	Asia, Africa, Latin America	Variable range of costs. In developing countries where infrastructure build-out is in the initial stages and freight and road bottlenecks are often worst, benefit-cost and financial & social return calculations are best. Public-private partnerships and climate finance mechanisms can overcome barriers to finance.	Avoided health impacts related to air pollution exposure.	Public transit and freight infrastructure already receive large-scale public and private investment. Concessional terms and subsidies can expand the size and scope of investments already considered viable, or make marginal investments viable on cost/benefit terms. Key players include CCAC, ICCT and the Smart Freight Centre. New global Green Freight Action Plan.
	Urban passenger commuting public transit using non-motorized transport.	Road access and parking restrictions; bicycle lanes and paths; build-out of public transit infrastructure; toll roads & subsidized transit fares.		Public-private partnerships and climate finance mechanisms can overcome barriers to finance.	Less traffic; fewer traffic accidents and injuries; reduced commuting times; reduced fuel use; more personal travel options.	
	Clean and efficient two-wheelers and public transport.	Usage proportional road fees; dedicated bus lanes & stops.			Reduced reliance and economic cost of personal vehicle ownership.	
	Freight moved from road to rail and coastal shipping.	Green freight programs; build-out of rail, shipping, intermodal hubs (including ports), and other freight infrastructure.			Increased efficiency of shipping, lower fuel imports, lower cost of goods.	
Removal of high-emitting vehicles	Accelerated fleet turnover practices.	Fleet turnover rates (vehicle taxes proportional to vehicle vintage, e.g. Japan) and scrappage programs.		Difficult to quantify. Societal cost is low (though monitoring & enforcement can be costly). Private cost to replace vehicles can be high.	Avoided health impacts related to air pollution exposure.	High mitigation potential: 0.4 Mt BC (UNEP, 2011). Implementation requires strong sub-national commitments to enforcement.
	Banning high-emitting vehicles (“smokers”).	Regulatory mandates; more stringent vehicle inspections and maintenance programs.				
	Better vehicle maintenance.					

Summary of mitigation objectives, examples of mitigation options, and potential policy/regulatory/institutional/financial arrangements to promote the option for BC emissions mitigation.

Mitigation objective	Examples of mitigation options	Policy/regulator/ institutional/financial arrangements to promote the options	Regions /countries with high mitigation potential	Mitigation costs	Non-climate benefits	Comments / additional considerations
Increase access to clean fuels in developing countries	Household electrification	Power sector reform; public-private partnerships; deployment of large-scale renewable energy; distributed micro-grid promotion through subsidies.	Wide applicability and potential in sub-Saharan Africa, South and Central Asia, East Asia, Southeast Asia, Latin America & Caribbean. Concentrations of energy-poor households highest in South Asia (India, Bangladesh and Pakistan especially) and in sub-Saharan Africa. Major rural electrification and energy access programs underway in India, Bangladesh and sub-Saharan African countries.	Variable. Often very high in rural and remote areas, while potentially viable in peri-urban and urban areas.	Energy access; health benefits, especially for women and children; cheaper energy costs; ability to use electricity for the full range of energy services.	Best long-term option, but often cost-prohibitive and dependent on strong institutions and investment climate. In many developing countries, grid access provides only intermittent and unreliable power.
	Substitution of fuel-wood and coal with liquefied petroleum gas (LPG), ethanol, or biogas	Government investment in fuel refining and distribution infrastructure; support for small business & supply chain development.		Low cost (negligible to US$14/t CO_2 eq carbon price). Often financially viable if capital constraints can be overcome. Very strong social cost-benefit calculation.	Health benefits, especially for women and children; improved cook-stove performance and reliability; less time devoted to wood collection; improved safety in the home. Climate benefits may be marginal depending on emissions profile and fuel source of new fuel and fuels replaced. Crop productivity protected with improved air quality.	Combined with adoption of clean-burning stoves, 1.8 Mt BC reduction potential (UNEP, 2011), the largest global mitigation source. Key players include the Global Alliance for Clean Cookstoves and the CCAC.
	Substitution of lump coal with coal briquettes l			Approximately zero cost.		Large 0.4 Mt BC mitigation potential (UNEP, 2011).
	Substitution of wood biomass with wood pellets			Variable, dependent on supply chain dynamics.		Climate benefits depend upon sourcing of wood for pellets.
Increase adoption of clean stove and fuel technologies in developing countries	Adoption of electric and processed fuel-powered cook-stoves	BC-reducing quality assurance testing, standards and protocols for cook-stoves; government support for advance cook-stove market infrastructure; marketing campaigns; carbon finance schemes.		Low cost (negligible to US$14/t CO_2 eq carbon price). Often financially viable if capital constraints can be overcome. Very strong social cost-benefit calculation.		Combined with adoption of clean fuels, 1.8 Mt BC reduction potential (UNEP, 2011), the largest global mitigation source. Mitigation options are listed in descending order from high to low impact, and from long-term to short-term time frame. Key global player is the Global Alliance for Clean Cookstoves.
	Adoption of forced draft cook-stoves					

Increase adoption of clean stove and fuel technologies in developing countries	Improved cook-stove design (e.g. rocket stoves)	*continued from above*	Wide applicability and potential in sub-Saharan Africa, South and Central Asia, East Asia, Southeast Asia, Latin America & Caribbean. Concentrations of energy-poor households highest in South Asia (India, Bangladesh and Pakistan especially) and in sub-Saharan Africa. Major rural electrification and energy access programs underway in India, Bangladesh and sub-Saharan African countries.	*continued from above*	*continued from above*	Combined with adoption of clean fuels, 1.8 Mt BC reduction potential (UNEP, 2011), the largest global mitigation source. Mitigation options are listed in descending order from high to low impact, and from long-term to short-term time frame. Key global player is the Global Alliance for Clean Cookstoves.
	Better consumer operation of traditional cook-stoves	Public service announcement campaigns on proper methods and fuel conditions for stove operation.		Low.	Improved stove efficiency, less smoke, improved health outcomes.	
Increase adoption of clean lighting technologies in developing countries	Deployment of LED solar lanterns Deployment of solar home systems Rural & peri-urban electrification Deployment of mini-grids powered by cleaner fuels	Quality assurance testing and standards to prevent market spoilage; removal of subsidies for kerosene; government bulk purchasing to prime the market and lower costs; business support services to accelerate market deployment and supply chain development; access to finance for consumers and businesses of clean lighting & power; consumer awareness and marketing campaigns.		Unquantified, but potentially very low. Often financially viable if capital constraints can be overcome. Household savings can be substantial if initial capital cost barrier can be removed. Very strong social cost-benefit calculation.	Improved home safety (from burns and fires); improved productivity and education outcomes; improved lighting; lower household energy costs; more consumer product options and payment plans (pay-as-you-go, fixed price, purchase & lease options).	250 to 500 million households (1/3 to 1/5th of the world population) rely on kerosene or other liquid fuels for lighting, consuming 5 to 65 million tons (Mt) of kerosene per year, producing an estimated 40 to 500 Mt of CO_2, as well as black carbon (BC) and other pollutants. As indicated by the range above, there is nearly a factor of 13 discrepancy between recent studies on the consumption of kerosene." (CCAC SAP, 2014). Key programs are Lighting Africa, Lighting Asia and Lighting Global (World Bank and IFC) and Global LEAP (Clean Energy Ministerial).

INDUSTRIAL SECTOR

Summary of mitigation objectives, examples of mitigation options, and potential policy/regulatory/institutional/financial arrangements to promote the option for BC emissions mitigation.

Mitigation objective	Examples of mitigation options	Policy/regulator/institutional/financial arrangements to promote the options	Regions /countries with high mitigation potential	Mitigation costs	Non-climate benefits	Comments / additional considerations
Upgrade to cleaner, more efficient brick kilns	Convert to vertical shaft brick kiln (VSBK) or zig-zag designs.	Regulate production processes and emissions of brick kilns; improve land tenure to encourage investment; improve availability of affordable credit to businesses; introduction of standards and labeling for high-quality production.	Brick production is highly concentrated in China (54%), India (11%), Pakistan (8%), and Bangladesh (4%), giving about 75% of global production (Clean Air Task Force, 2010). Low-efficiency brick production also prevalent in Latin America and sub-Saharan Africa.	Low cost. Negative marginal carbon price can stimulate action. Very attractive social cost/benefit ratio: -US$5,500 cost per ton of BC (UNEP, 2011).	Improved quality of bricks, health protection, energy efficiency, improved air quality (crop productivity, environmental benefits).	0.04 Mt BC annual mitigation potential in 2030 (UNEP, 2011). CCAC brick kilns initiative; targeted programs to assist government and small-scale manufacturers may yield significant, quick wins. Numerous World Bank and UNDP projects. SwissContact is a major donor supporting efficiency improvements in the brick kilns space.
	Government regulation to ban certain kiln types, shift construction away from traditional bricks and set emission standards.					
Apply appropriate air pollution control technologies to brick kilns	Add gravity-settling chambers to Bull Trench Kiln fixed chimney design.			Moderate cost.		
Use cleaner fuels for brick kilns	Switch Hoffmann kilns from using waste oil to natural gas.	Targeted incentives and regulation to encourage fuel switching.				
Process changes for brick kilns	Produce hollow bricks.	Outreach & training of brick manufacturers; incentives & regulation. phase out smaller uncontrolled operations.				
	Use fly ash in the brick material.					
Shift brick industry market	Reduce the use of solid bricks (e.g. China).		China, other regions.	Moderate to high cost.	More cost-effective production, energy efficiency, improved air quality.	

Improved emissions profile and efficiency of coke ovens	Replace traditional coke ovens with modern recovery ovens.	*continued from above* Introduction of emissions controls in existing industrial facilities with regulation and low-cost capital.	China contributes approximately 60% of global coke production BC emissions (U.S. EPA, 2012).	Moderate cost, ~US$1 ton/$CO_2$ eq, US$140-$500 social cost per ton BC.		0.2 Mt BC global emissions reduction potential (annually in 2030; UNEP 2011)
Reduced use of diesel generators.	Improve efficiency and emissions controls from diesel generators.	Regulation, testing and standards for emissions of diesel generators. Subsidies for technology upgrades to efficient, lower-emissions generator sets.	Diesel generators are widely used in regions of the world without reliable access to electricity, but with rapidly growing power demand, including in India and Nigeria.	Potentially high cost for new generators; lower net cost but high capital cost for old and inefficient unit replacement.	Improved local air quality; reduced melting of glaciers; protection of meltwater sources.	Estimated 0.10-0.17 Mt BC annual global emissions from non-biomass residential BC, primarily diesel, in 2000 (Bond et al 2013), and growing rapidly. Falling cost of distributed solar and hybrid systems makes alternatives viable.
	Improve grid & distributed electricity production.	See residential sector actions. Also target improved on-site and grid-connected power supply for commercial and industrial enterprises.		Potentially low to moderate, depending on fuel costs and availability of alternatives. Potentially high capital costs.	Improved local air quality; reduced fuel costs and imports; lower electricity bills; improved electricity reliability; reduced operations and maintenance costs.	
Reduce oil and gas flaring	Eliminate flaring in sensitive (cryosphere) regions.	Regulation of oil & gas production and flaring bans in sensitive regions. Mandatory measurement and reporting of flaring emissions. Integrate flaring avoidance and reduction plans into permitting for new wells. Charge high fees for flaring emissions and/or volume of gas flared.	Arctic, cryosphere areas (alpine areas - Himalayas, Andes, Pacific rim).	Moderate to high cost in areas remote from gas pipelines and industrial infrastructure.	Air quality-related health and environmental benefits; reduced melting of glaciers; protection of meltwater sources; increased supply of gas for sale (for companies) and to tax for royalties (governments).	Ideally paired with measures to reduce vented and leaked methane from oil & gas production. Key global program is the World Bank-managed Global Gas Flaring Reduction Initiative (GGFR), including Zero Routine Flaring by 2030 Initiative. CCAC Oil & Gas Methane Partnership is an important partner. Also yields significant CO_2 reduction benefits: Approx. 360 million tonnes of carbon dioxide into the atmosphere each year (GGFR, 2013).
	Limit flaring at existing wells	Regulation of oil & gas production. Mandatory measurement and reporting of flaring emissions. Mandate flaring avoidance for new wells and flaring reduction plans into permitting for existing wells. Charge high fees for flaring emissions and/or volume of gas flared.	All areas of extensive oil & gas production, largest flarers: Middle East, West Africa, Russian Federation; also North & Latin America and others.	Variable cost. Nearly 4 million t CO_2eq/year can be reduced at no cost. >20 million t CO_2eq/year can be reduced at a carbon price of $US40 t/$CO_2$eq or more (GGFR, 2013).	Air quality-related health and environmental benefits; reduced melting of glaciers; protection of meltwater sources increased supply of gas for sale (for companies) and to tax for royalties (governments).	
	Eliminate flaring at new wells					
	Establish industry-led best practices for flaring reduction					

AGRICULTURAL SECTOR

Summary of mitigation objectives, examples of mitigation options, and potential policy/regulatory/institutional / financial arrangements to promote the option for BC emissions mitigation.

Mitigation objective	Examples of mitigation options	Policy/regulator/institutional/financial arrangements to promote the options	Regions /countries with high mitigation potential	Mitigation costs	Non-climate benefits	Comments / additional considerations
Eliminate field burning of agricultural waste	Blanket bans on crop burning.	Regulation; local education and training of farmers, agricultural extension services, and forest rangers; low-cost loans & leasing and business support services for farmers pursuing no/low till agriculture and crop waste repurposing businesses.	Cryosphere regions have highest mitigation potential: Andes, Himalayas and E. Europe/ Central Asia. Field burning is ubiquitous globally.	Costs difficult to quantify (UNEP, 2011). Costs may depend on viability and cost of alternative non-burn policies for farmers.	Increased soil quality and crop productivity. Improved air quality, health, visibility, reduced wildfire risk.	CCAC Agriculture Initiative Component on Open Agricultural Burning, focusing on Andes and Himalayas. ICCI, ICIMOD, USDA, and EC are lead players.
	Highly managed burns to minimize climate impact, with restrictions according to season and weather.					
	Promote alternative uses of crop wastes, including as biomass fuel stock, biochar as soil emolument, and building material.			Costs high in areas studied, such as Russian Federation. Not well understood in most areas.		
Improve efficiency of rice parboiling.	Improve efficiency and design of rice parboiling furnaces.	Regulation; local education and training of farmers, agricultural extension services; low-cost loans & leasing and business support services.	Bangladesh, India, other South and Southeast Asia.	Potentially low if capital barriers can be overcome.	Improved air quality/health benefits; fuel efficiency gains; operational efficiencies.	Proposed project by Bangladesh in the CCAC. Collaboration with GIZ in Bangladesh.
Reduced burning of dung cakes for residential fuel.	Introduction of improved cooking fuels.	See residential section for household fuel use improvements, particularly on fuel substitution and provision of improved cook-stoves.	South Asia, some regions of sub-Saharan Africa, SE Asia and Latin American highlands	Dependent on relative cost of alternatives. Low, but potentially prohibitive for bottom-of-pyramid consumers.	Improved air quality - health benefits; fuel efficiency gains.	Not yet well studied.
	Introduction of improved practices for using dung for biogas and fertilizer.	Promotion of household, farm and community biogas digesters; farmer education and market development for fertilizer to improve soil fertility.		Likely to be high for infrastructure, training and market development.	Improved air quality - health benefits; fuel efficiency gains; improved soil quality; new revenue streams for farmers.	Not yet well studied.
Reduced burning of garbage and other waste	Introduction of solid waste collection systems.	Comprehensive municipal solid waste management planning; investment in landfills, recycling and collection systems.	Global; particularly South Asia and sub-Saharan Africa.	High	Improved air quality and public health; improved sanitation and waste disposal; jobs for waste disposal.	Reduced garbage burning is part of the CCAC Municipal Solid Waste Initiative.
	Education and training on alternatives to waste burning.			Moderate to high		
	Banning waste burning.	Regulatory action and enforcement.		Low		

ANNEX 3

EXISTING INTERNATIONAL EFFORTS TO REDUCE BLACK CARBON

Compared with programs designed to mitigate long-term climate forcers such as CO_2, efforts to address black carbon internationally are relatively new and less widespread. However, several important efforts are underway that can be useful sources of information. Some of the proponents could become potential GEF partners in this area.

One of the first efforts to demonstrate the importance of BC emissions for global and regional climate impacts was the UNEP Atmospheric Brown Cloud (ABC) project, commissioned by UNEP in 2002 (Ramanathan *et al.*, 2008). The ABC project has laid the scientific foundation that led to subsequent comprehensive assessments (Arctic Council, 2011; UNEP/WMO, 2011; U.S. EPA, 2012; Bond *et al.*, 2013; Arctic Council, 2013). It focuses on improving understanding of ABCs and their impacts through measurements and impact assessments, demonstrating mitigation solutions, and creating awareness of the issue in policy forums.[3] In addition to the initial Regional Assessment Report (Ramanathan *et al.*, 2008), the ABC project recently produced an emission inventory manual that describes the methodology for compiling the emissions of major pollutants from various sectors (Shrestha *et al.*, 2012). The project works through three sub-programs: (1) Observatory and capacity building program; (2) Impact assessment program; and (3) Mitigation and awareness program.[4] The project has now commissioned Project Surya to demonstrate options for mitigating ABCs from biofuels through technological advancement and awareness raising.[5]

3 http://www.rrcap.ait.asia/abc/Pages/default.aspx.

4 http://www.rrcap.ait.asia/abc/Pages/default.aspx, accessed 22 November 2014.

5 www.projectsurya.org, accessed 22 November 2014.

The Arctic Council is an intergovernmental forum that addresses issues facing Arctic nations and indigenous people. Member states are Canada, Denmark, Finland, Iceland, Norway, Russian Federation, Sweden and the United States. The Arctic Monitoring and Assessment Programme (AMAP) of the Arctic Council, established in 1991, monitors and assesses pollution and climate issues in the Arctic region, document pollution levels and effects, and produces science-based policy-relevant assessments to inform decision makers.[6] AMAP maintains a short-lived climate forcer expert group and produced a report on the impacts of BC on the Arctic in 2011 (AMAP, 2011). The Arctic Council Ministerial Tromsø Declaration from April 2009 created the Arctic Council Task Force on Short-Lived Climate Forcers in 2009, charging it to identify existing and new measures to reduce emissions from SLCPs and recommend immediate actions to reduce them (Arctic Council, 2011). The Task Force has now produced a progress report and recommendations for ministers on SLCPs (Arctic Council, 2011). Subsequently, the Task Force for Action on Black Carbon and Methane made a series of policy-relevant recommendations to reduce BC and methane emissions to slow Arctic climate change (Arctic Council, 2013). The Task Force continues to meet and is expected to produce a final report to the Arctic Council Ministerial meeting in 2015. As the United States assumes the leadership of the Arctic Council in 2015, SLCPs are expected to be a prominent issue area over the next few years.

In 2009, the United States initiated a new project to reduce BC emissions in the Arctic, particularly

6 http://www.amap.no/about, accessed 22 November 2014.

focusing on emissions from the Russian Federation. Within the framework of the Copenhagen Climate Summit in December 2009, Nancy Sutley, Chair of the White House Council on Environmental Quality, announced the administration's intention to commit US$5 million towards international cooperation to quantify emissions and impacts of BC from fossil fuel and biomass burning, and to reduce BC emissions and the associated warming effects in and around the Arctic through the launch of the Arctic Black Carbon Initiative. With support from the U.S. Department of State, several U.S. agencies are cooperating to reduce BC emissions in the Russian Federation that are contributing to Arctic BC concentrations. The U.S. EPA is focusing on reducing BC emissions from mobile and stationary diesel engines. The U.S. Department of Energy is developing collaborative programs on combined heat and power. The U.S. Forest Service is working on reducing BC from forest fires and agricultural burning in the Russian Federation. This work also complements ongoing policy and technical work in the Arctic Council and the EPA's programs in the Russian Federation. These efforts were redoubled in President Obama's Climate Action Plan, issued in June 2013, which commits to international efforts to reduce SLCPs, including black carbon.[7]

In 2012, the governments of six countries (Bangladesh, Canada, Ghana, Mexico, Sweden and the United States), along with UNEP, established the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC). The CCAC, administered by UNEP, is the first intergovernmental initiative focused solely on the mitigation of SLCPs. It aims to catalyze scaled- up actions to mitigate BC, methane and hydrofluorocarbon (HFC) emissions globally to mitigate near-term climate change, recognizing that controlling both SLCP and long-lived greenhouse gas emissions such as through the United Nations Framework Convention on Climate Change are needed to avoid dangerous climate change. Since its inception, the CCAC partnership program has grown to over 40 national governments, many non-governmental organizations and several key intergovernmental organizations, including the World Bank, World Health Organization (WHO), World Meteorological Organization (WMO), United Nations Development Programme (UNDP), United Nations Industrial Development Organization (UNIDO), and the InterAmerican Development Bank (IADB). The CCAC has now invested in eight sectoral and three cross-sectoral initiatives to spark scaled-up emission reductions (Table 7). Initiatives include reducing emissions from diesel vehicles, brick kilns, residential solid fuel combustion, oil and gas operations, agriculture and municipal solid waste. Each of these initiatives creates an opportunity for developers and GEF Implementing Agencies to communicate and potentially partner with the CCAC initiative to exchange technical information, expand networks of contacts in governments and Implementing Agencies, among other benefits.

Other international efforts are addressing BC emissions through the CCAC or within their broader work. For example, the Global Alliance for Clean Cook-stoves[8], established in 2011, has a goal of 100 million clean cook-stoves adopted around the world by 2020. While the Alliance has a broader focus including health, long-term climate, environmental and social impacts of traditional residential solid fuel use, some cleaner stoves reduce BC along with these other impacts. To bolster its

7 https://www.whitehouse.gov/climate-change.

8 www.cleancookstoves.org, accessed 22 November 2014.

activities to reduce SLCPs specifically, the Alliance joined the CCAC and is co-leading the CCAC initiative on Residential Solid Fuel Use for Cooking and Heating with Nigeria. Similarly, the Partnership for Clean Fuels and Vehicles[9], established in 2002, focuses more broadly on achieving cleaner air and lowering greenhouse gas emissions. However, its programs, particularly those that reduce diesel emissions, would also reduce BC.

The World Bank has demonstrated a significant commitment to reducing black carbon across its operations, as well as in programs it manages. Having commissioned a study in 2013 on integration of short-lived climate pollutants, including black carbon, into World Bank operations (Akbar *et al*., 2013),[10] World Bank representatives have also voiced a desire to increase its lending support for SLCP reduction projects.[11] The World Bank has also targeted black carbon from oil and gas flaring in its Global Gas Flaring Reduction initiative (GGFR)[12], as well as in the Zero Routine Flaring by 2030 initiative.[13] The United Nations-sponsored Sustainable Energy for All (SE4ALL) has also highlighted gas-flaring reduction as a high-impact opportunity (HIO) for international focus.[14]

The Convention on Long-Range Trans-boundary Air Pollution (CLRTAP), which applies to the countries of the UN Economic Commission for Europe (UNECE) that have ratified it, has a protocol adopted in 1999 known as the Gothenburg Protocol to Abate Acidification, Eutrophication, Ground-Level Ozone.[15] CLRTAP has recently become the first international treaty organization to address black carbon, having recognized black carbon specifically in 2012 by adopting amendments to the Gothenburg Protocol on control of particulate matter emissions. The newly adopted amendments have not yet entered into force and measures related to black carbon are voluntary. Specifically, in implementing their national targets for particulate matter, Parties commit to give priority to those measures that also significantly reduce black carbon. Parties are urged to also apply best available techniques to reduce black carbon emissions from certain sources in accordance with guidance adopted by the Executive Body. The amendments also include provisions related to the (voluntary) development of emissions inventories, based on guidance adopted by the Executive Body, as well as provisions related to research, reporting and the exchange of information. The development of emission inventories, and the guidance for such inventories, is a significant development; other bodies, such as the Arctic Council, are considering how to rely on the guidance and inventories being developed under CLRTAP. The technical body that develops the guidance met earlier this year and the steering body overseeing the technical work is reviewing this guidance. In addition, in December 2012, the Executive Body adopted a guidance document on control techniques for emissions of particulate matter and black carbon from certain stationary sources.[16]

9 http://www.unep.org/transport/new/pcfv/, accessed 22 November 2014.

10 http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2013/08/19/000333037_20130819113818/Rendered/PDF/804810WP0G80Re00Box0379805B00OUO090.pdf.

11 http://www.worldbank.org/en/news/feature/2013/09/03/cutting-short-lived-climate-pollutants-win-win-health-climate, accessed 30 January 2015.

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14 http://www.se4all.org/hio/phase-out-of-gas-flaring-from-oil-production/, accessed 30 January 2015.

15 http://www.unece.org/env/lrtap/multi_h1.html, accessed 30 January 2015.

16 http://www.unece.org/environmental-policy/conventions/air/guidance-documents-and-other-methodological-materials/gothenburg-protocol.html, accessed 30 January 2015.

TABLE 7
International programs focusing on reducing black carbon or short-lived climate pollutant emissions and impacts.

Program / Partnership	Agency / Organization	Primary Focus or Signature Initiatives	Potential Role of the GEF
Arctic Council's Arctic Monitoring and Assessment Program (AMAP)	The Arctic Monitoring and Assessment Programme is one of six Working Groups of the Arctic Council.	AMAP is mandated to: 1. monitor and assess the status of the Arctic region with respect to pollution and climate change issues 2. document levels and trends, pathways and processes, and effects on ecosystems and humans, and propose actions to reduce associated threats for consideration by governments; and 3. produce sound science-based, policy-relevant assessments and public outreach products to inform policy and decision-making processes.	Track progress and outcomes, and incorporate findings and recommendations into GEF programs as appropriate.
Arctic Council's Short-lived Climate Forcer Task Force	The Arctic Council Ministerial Tromsø Declaration from April 2009 created the Task Force.	The Task Force was charged to identify existing and new measures to reduce emissions of these (short-lived climate) forcers and recommend further immediate actions, and to report on progress at the next Ministerial meeting. Final report: https://oaarchive.arctic-council.org/handle/11374/78	The work of the Task Force is complete and is now superseded by the Arctic Council's Task Force on Black Carbon and Methane.
Arctic Council's Task Force on Black Carbon and Methane	The Arctic Council Ministerial Nuuk Declaration from April 2013 created the new Task Force. https://oaarchive.arctic-council.org/handle/11374/78	The Arctic Council, an intergovernmental association of the eight countries with territory in the Arctic, has also taken action on black carbon, having commissioned a Task Force on Short-Lived Climate Forcers in 2008, tasked primarily with producing reports on mitigation options for black carbon and methane, and a follow-up task force in 2012 to explore the promotion of those mitigation options within and among the members and observers of the Council. This latest task force will deliver its recommendations to the ministers of the Arctic Council in April 2015.	Track progress and outcomes, and incorporate findings and recommendations into GEF programs as appropriate.
Climate and Clean Air Coalition (CCAC) http://www.unep.org/ccac/	The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) is the first global effort to treat short-lived climate pollutants (SLCPs) as a collective challenge.	The Coalition's initial focus is on methane, black carbon and HFCs. At the same time, Partners recognize that action on SLCPs must complement and supplement, not replace, global action to reduce carbon dioxide, particularly efforts under the UNFCCC. The Coalition's objectives are to address short-lived climate pollutants by: -Raising awareness of SLCP impacts and mitigation strategies -Enhancing and developing new national and regional actions, including by identifying and overcoming barriers, enhancing capacity and mobilizing support -Promoting best practices and showcasing successful efforts -Improving scientific understanding of SLCP impacts and mitigation strategies.	The GEF could become a partner of the CCAC, engage in CCAC Initiatives, and explore whether opportunities exist to complement the CCAC's focus on leveraging high-level political will to scale up SLCP mitigation with the GEF's focus on funding individual projects that achieve global environmental benefits. In particular, the GEF could engage in the CCAC Finance

		The CCAC aims to catalyze scaled-up actions to reduce SLCPs through 11 focused Initiatives: -Reducing BC emissions from heavy duty diesel vehicles and engines -Mitigating BC and other pollutants from brick production -Mitigating SLCPs from the municipal solid waste sector -Promoting HFC alternative technology and standards -Accelerating methane and BC reductions from oil and natural gas production -Addressing SLCPs from agriculture -Reducing SLCPs from household cooking and domestic heating -Financing of SLCP mitigation -Supporting National Planning for action on SLCPs -Regional Assessments of SLCPs -Urban Health Initiative.	Initiative, Supporting National Action Planning Initiative, and individual sectoral initiatives such as the Heavy Duty Diesel Initiative and the Residential Cooking and Heating Initiative.
UNEP Atmospheric Brown Cloud Project http://www.rrcap.ait.asia/abc/	Regional Resource Centre for Asia and the Pacific. At the Asian Institute of Technology. A UNEP Collaborating Centre. The ABC appears to focus primarily on better understanding the impacts of the brown cloud, which includes BC.	Atmospheric brown clouds (ABC), observed as widespread layers of brownish haze, are regional scale plumes of air pollutants, consisting of mainly aerosol particles, such as black carbon (BC) and precursor gases that produce aerosols and ozone. ABCs and their interaction with build-up of greenhouse gases (GHGs) significantly affect the regional climate, hydrological cycle, glacial melting, agriculture and human health. The effect of ABCs on climate, hydrological cycle, glacier melting, agriculture and human health is an outstanding problem that prevents a complete understanding of climate change and its impacts, and needs to be more fully explored.	Track progress and outcomes, and incorporate findings and recommendations into GEF programs as appropriate.
U.S. Arctic Black Carbon Initiative (ABCI)	With support from the U.S. Department of State, several U.S. agencies are cooperating to reduce BC emissions in the Russian Arctic. U.S. EPA is focusing on reducing BC emissions from mobile and stationary diesel engines. The U.S. Department of Energy is developing collaborative programs on combined heat and power. The U.S. Forest Service is working on reducing BC from forest fires and agricultural burning in the Russian Arctic. This work also complements ongoing policy and technical work going on in the Arctic Council and the U.S. EPA's programs in the Russian Federation.	Within the framework of the Copenhagen Climate Summit in December 2009, Nancy Sutley, Chair of the White House Council on Environmental Quality, announced the Administration's intention to commit $US5 million towards international cooperation to quantify emissions and impacts of BC from fossil fuel and biomass burning and to reduce black carbon emissions and the associated warming effects in and around the Arctic through the launch of the ABCI.	Track progress and outcomes, which will improve understanding of BC mitigation approaches in the Russian Arctic, and incorporate lessons learned into GEF programming and project selection, as appropriate.

Convention on Long-Range Transboundary Air Pollution, 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol) http://www.unece.org/env/lrtap/multi_h1.html	This protocol to the LRTAP Convention was completed in 1999. In May 2012, Parties adopted amendments to the Gothenburg Protocol under the Convention on Long-Range Transboundary Air Pollution. The amendments updated targets to further reduce emissions of harmful air pollutants and added measures to address particulate matter, including BC. The amended Gothenburg Protocol will be the first international treaty to address BC. The amendments also include provisions for flexible transitional arrangements to encourage the participation of the Russian Federation and other former East Bloc countries.	Guidance document for black carbon: http://www.unece.org/environmental-policy/conventions/air/guidance-documents-and-other-methodological-materials/gothenburg-protocol.html The newly adopted amendments have not yet entered into force and measures related to BC are voluntary. Specifically, in implementing their national targets for particulate matter, the amendments advise that Parties should give priority to those measures that also significantly reduce black carbon and should apply best available techniques to reduce BC emissions from certain sources in accordance with guidance adopted by the Executive Body. The amendments also include provisions related to the (voluntary) development of emissions inventories, based on guidance adopted by the Executive Body, as well as provisions related to research, reporting and the exchange of information. The development of emission inventories, and the guidance for such inventories, is a significant development; other bodies, such as the Arctic Council, are considering how to rely on the guidance and inventories being developed under LRTAP. The technical body that develops the guidance met earlier this year and the guidance is being reviewed by the steering body overseeing the technical work. In addition, in December 2012, the Executive Body adopted a guidance document on control techniques for emissions of particulate matter and BC from certain stationary sources.	
Sustainable Energy for All (SE4ALL) http://www.se4all.org/about-us/	In September 2011, UN Secretary-General Ban Ki-moon shared his vision for making sustainable energy for all a reality by 2030. He launched Sustainable Energy for All as a global initiative that would mobilize action from all sectors of society in support of three interlinked objectives: (1) providing universal access to modern energy services; (2) doubling the global rate of improvement in energy efficiency; and (3) doubling the share of renewable energy in the global energy mix. Sustainable Energy for All has generated significant momentum since its launch. Both developed countries and more than 85 developing countries have partnered with SE4ALL to advance the three objectives on the country level. Over 50 High Impact Opportunities (HIOs) have been identified, with a wide range of stakeholders undertaking actions that will have significant potential to advance Sustainable Energy for All. Governments, the private sector and multilateral institutions alike are mobilizing resources in support of the initiative's three objectives.	High Impact Opportunity identified to phase out gas flaring from oil production. Multi-stakeholder cooperation along the value chain of gas is needed to reduce risk and to establish incentives for investment in pipelines, technology, production facilities, infrastructure, customers and finance frameworks, as well as stable and transparent regulatory frameworks. The Phase-out of Gas Flaring from Oil Production HIO will build on the work of the World Bank's Global Gas Flaring Reduction Initiative and further promote multi-stakeholder cooperation. http://www.se4all.org/hio/phase-out-of-gas-flaring-from-oil-production/	

UNEP's Partnership for Clean Fuels and Vehicles (PCFV) http://www.unep.org/transport/new/pcfv/	In 2012, at Rio de Janeiro, the PCFV redoubled its commitment to its global lead and sulfur campaigns, the latter of which directly leads to black carbon reduction.	The PCFV is the leading global public-private initiative promoting cleaner fuels and vehicles in developing and transition countries. Established at the World Summit on Sustainable Development in September 2002 in Johannesburg, the PCFV brings together 72 organizations representing developed and developing countries, the fuel and vehicle industries, civil society and leading world experts on cleaner fuels and vehicles. Our partners combine their resources and efforts to achieve cleaner air and lower greenhouse gas emissions from road transport by applying fuel quality improvements and proven vehicle technologies in use in leading global auto markets. The PCFV provides a range of technical, financial and networking support for governments and other stakeholders to reduce vehicle emissions, namely fine particulate matter, carbon monoxide, black carbon and nitrogen oxides and improve fuel economy.	
Global Gas Flaring Reduction Initiative	World Bank	The World Bank's GGFR public-private partnership was launched at the World Summit on Sustainable Development in Johannesburg in 2002. GGFR supports the efforts of oil-producing countries and companies to increase the use of associated natural gas and thus reduce flaring and venting, which wastes valuable resources and damages the environment. The GGFR partnership is a catalyst for reducing wasteful and undesirable practices of gas flaring and venting through policy change, stakeholder facilitation and project implementation. GGFR partners have established a collaborative Global Standard for gas flaring reduction. This Global Standard provides a framework for governments, companies and other key stakeholders to consult with each other, take collaborative actions, expand project boundaries and reduce barriers to associated gas use.	
Zero Routine Flaring by 2030	World Bank	The "Zero Routine Flaring by 2030" initiative, introduced by the World Bank, brings together governments, oil companies and development institutions that recognize the flaring situation described above is unsustainable from a resource management and environmental perspective. They agree to cooperate to eliminate routine flaring no later than 2030. The Initiative pertains to routine flaring and not to flaring for safety reasons or non-routine flaring, which nevertheless should be minimized. Routine flaring of gas occurs during normal oil production operations in the absence of sufficient facilities or amenable geology to re-inject the produced gas, use it on-site or dispatch it to a market. Venting is not an acceptable substitute for flaring.	

Low-Carbon Low-Emission Clean Energy Technology Transfer (LCET) Programme	UNIDO and the Ministry of Economy Trade and Industry (METI), Japan	Accelerate deployment and dissemination of low- carbon, low-emission clean energy technologies, services and products (LCETs) to replace conventional energy sources in remote areas. This is achieved through the implementation of demonstration projects, capacity building and knowledge management activities, and the identification of suitable business models for replication. In its first phase, the LCET programme, has implemented two pilot projects focusing on ultra-low head micro hydro power (ULH-MHP) technology systems; these contribute to the displacement of conventional fuels in remote regions, thereby reducing BC emissions.	Track progress and outcomes, and incorporate findings and recommendations into GEF programs as appropriate.
Sustainable Transport Strategy	UNIDO	With this strategy, UNIDO aims to promote low-emission transport that supports the sustainable industrialization and urbanization goals of its member states. The specific interventions will focus on: fostering enabling policy frameworks, strengthening local capacities, and enhancing knowledge and innovation in the thematic areas of vehicle technologies, transport support facilities and alternative fuels. Under the "Alternate Fuels" thematic area the project will support 1) Biofuels Production 2) Fuel switching (Petrol/Diesel to LPG/CNG) 3) Standardized methodologies for the life cycle analysis of carbon emissions of biofuel products, which will reduce BC emissions from combustion of conventional fossil fuels such as diesel.	Track progress and outcomes, and incorporate findings and recommendations into GEF programs as appropriate.

ANNEX 4

COMMONLY USED CLIMATE METRICS

Several GHG metrics have been considered in terms of their applicability to BC, including global warming potential (GWP), global temperature potential (GTP), specific forcing pulse (SFP) and surface temperature response per unit of continuous emissions (STRUCE) (U.S. EPA, 2012; Bond *et al.*, 2013). GWP is the most common metric in use for GHGs defined as:

> *An index, based on radiative properties of greenhouse gases, measuring the radiative forcing following a pulse emission of a unit mass of a given greenhouse gas in the present-day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in causing radiative forcing. The Kyoto Protocol is based on GWPs from pulse emissions over a 100-year time frame.* (IPCC, 2013)

The GWP of CO_2 is defined as 1 since it is the GWP reference point. The time frame for the GWP calculation has most often been chosen as 100 years (GWP100), reflecting the interest in limiting peak warming over the centuries. The commitment to a global temperature increase is on a path to exceed the ~2°C value agreed upon as the upper limit by international leaders by near mid-century. Consequently, increasing attention is being paid to near-term actions that can slow the pace of warming over the next few decades. In setting those priorities (without pulling back from the first commitment to lower long-term warming), it is more appropriate to calculate relative warming contributions over a 20-year time frame. Thus, GWP20 can characterize the relative effectiveness of aerosols, including BC, given their shorter lifetime and hence greater influence on climate in the near-term. The most recent IPCC Assessment report (IPCC, 2013) estimated that GWP100 and GWP20 for BC are respectfully 659 (i.e. emission of 1 t BC would have the same integrated radiative effect over 100 years as emission of 659 t CO_2) and 2,421 (same radiative effect over 20 years as emission of 2,421 t CO_2) (Fig. 13). While GWP does treat the effect of different substances having different lifetimes, GWP does not account for the different physical mechanisms by which BC affects climate, nor does it account for the strong regional heterogeneity of BC in its climate effects.

Like the GWP, the GTP is also a physical metric. It compares the globally averaged temperature change at a given point in future time resulting from the emission of two climate forcers of equal mass (Shine *et al.*, 2005). In contrast to GWP, which characterizes radiative forcing, GTP goes one step further to address the temperature change resulting from that radiative forcing. GTP can be calculated using a variety of timescales, including 100 years and 20 years, but has some advantages over GWP for application to BC: it can be used formulate a rate of change goal and not just an absolute temperature target. However, a major disadvantage is that the GTP requires the use of computer models to estimate temperature impacts, and the GTP of BC for a given time period can vary by a factor of three depending on assumptions made and the model used (U.S. EPA, 2012). Myhre *et al.*, (2013)

FIGURE 13
Global anthropogenic emissions weighted by GWP and GTP for chosen time horizons (aerosol-cloud interactions are not included).

Species	GWP_{10}	GWP_{20}	GWP_{50}	GWP_{100}	GTP_{10}	GTP_{20}	GTP_{50}	GTP_{100}
CO_2	1	1	1	1	1	1	1	1
CH_4	104.2	83.9	48.4	28.5	99.9	67.5	14.1	4.3
N_2O	246.6	263.7	275.6	264.8	253.5	276.9	281.8	234.2
BC	4349.2	2421.1	1139.3	658.6	2398.2	702.8	110.0	90.7
OC	−438.5	−244.1	−114.9	−66.4	−241.8	−70.9	−11.1	−9.1
SO_2	−253.5	−141.1	−66.4	−38.4	−139.6	−40.9	−6.4	−5.3
NOx	134.2	16.7	−15.6	−10.8	2.8	−86.3	−27.4	−2.8
CO	8.6	5.9	3.2	1.9	6.8	3.7	0.7	0.3

Source: Myrhe *et al.*, 2013.

estimated that the GTP100 and GTP20 for BC are 90.7 and 702.8, respectively (Fig. 13).

Because the radiative forcing caused by BC emissions are spatially dependent, unlike CO_2, several studies have calculated regional GWP and GTP values for BC, as well as for OC (Reddy *et al.*, 2007; Rypdal *et al.*, 2009; IPCC, 2013; Streets *et al.*, 2013). The studies have found these values can vary by ± 30% between regions (Bond *et al.*, 2013). Because of this, regionally based metrics that account for the differential climate impacts of BC and OC, and are more representative of the actual impacts in each region, may well be more appropriate to use (than global GWP or GTP values that mask regional differences in forcing and response). Regional metrics could be applied in place of global metrics to estimate the climate benefits of a particular BC emission-reducing project in a particular region, accounting for any greater benefits in areas that are more sensitive such as the Arctic. There is currently no common agreement, however, as to whether regional GWP or GTP estimates are the most appropriate metric to use.

The SFP and STRUCE are relatively new metrics. The SFP, which quantifies climate warming or cooling effects from short-lived climate pollutants, is based on the amount of energy added to the Earth's system by emission of a given mass of the pollutant (Bond *et al.*, 2011). The STRUCE is similar to a sustained version of the GTP since it assumes any emission reduction persists over time rather than decays from a pulse of emissions (Jacobson, 2010).

The IPCC has not endorsed a particular metric or time horizon for BC. Similarly, a comprehensive report specifically on BC emissions and impacts urged caution in using any particular metric as BC has differential regional impacts and different climate forcing mechanisms compared with GHGs (Bond *et al.*, 2013). Using metrics to calculate "equivalence" between given amounts of SLCPs and CO_2 mitigation could create perverse incentives to reduce SLCPs instead of CO_2 emissions, rather than being in addition to, as they could be perceived and treated as if they were fungible (Blackstock and Allen, 2012).

Woman in India using traditional cooking methods to prepare food.