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RESEARCH BACKGROUNDER

Mitigating poverty and climate change

How reducing short-lived climate pollutants can support pro-poor, sustainable development

Ryan Hottle and Thomas Damassa

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CONTENTS

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ACRONYMS AND ABBREVIATIONS

AWD	Alternate wetting and drying (in rice production systems)
BC	Black carbon
°C	degrees Celsius
CCAC	Climate and Clean Air Coalition
CFCs	Chlorofluorocarbons
CH_4	Methane
CO_2	Carbon dioxide
DALYs	Disability-adjusted life years
GDP	Gross domestic product
GWP	Global warming potential
HFCs	Hydrofluorocarbons
kWh	kilowatt-hours
LPG	Liquid petroleum gas
SDGs	Sustainable development goals
SLCPs	Short-lived climate pollutants
SRI	System of rice intensification
$T\text{-}O_3$	Tropospheric ozone

EXECUTIVE SUMMARY

Reducing poverty, improving health and livelihoods, and enhancing the resiliency of vulnerable communities are moral imperatives of our times. Indeed, they are central goals of governments, development agencies and banks, and national and international organizations around the world. However, achieving these goals in the 21st century will be exceedingly difficult, if not impossible, if the world fails to address climate change adequately. Although reducing long-lived pollutants such as carbon dioxide is essential for stabilizing the climate system, policies and measures that mitigate black carbon, methane, hydrofluorocarbons, and other so-called short-lived climate pollutants (SLCPs), or “super pollutants,” are gaining prominence as a complementary means of significantly reducing the rate of global warming in the near-term and achieving poverty alleviation and development priorities.

Using peer-reviewed and “gray” literature, this paper aims to provide an initial review of linkages between SLCP mitigation and development outcomes necessary for reducing poverty. These outcomes include, among others, enhanced food and water security; improved health and productivity; greater livelihood resiliency, particularly in rural communities; creating socio-economic opportunities for women; and access to cleaner sources of energy. This review also examines several specific SLCP-mitigation strategies that are likely relevant for development and aid-oriented organizations and institutions. These measures include: introducing improved cookstoves; intermittent aeration strategies for lower-emissions rice production; conservation agriculture, agroforestry, and other alternatives to crop residue open burning and slash-and-burn agriculture; and strategies that complement efforts to reduce emissions of hydrofluorocarbons (which are used as refrigerants) such as “cool” roofs and more-energy-efficient housing. For each mitigation measure, we assess the potential impacts in a broader development context, highlighting benefits for relevant poverty alleviation objectives, as well as potential barriers and constraints to implementation. Findings for each measure assessed include the following:

Clean cookstoves can reduce household air pollution, including black carbon, thereby providing large benefits to human health, particularly of women and children. However, not all “clean” or “improved” cookstoves necessarily reduce black carbon emissions, and therefore stove design and construction needs to be carefully considered if climate benefits are to be realized alongside development ones. Transitioning from more efficient biomass cookstoves to other options, such as liquid petroleum gas (LPG) or electrified cooking, would nearly eliminate household air pollution from cooking and reduce drudgery associated with fuelwood gathering, but challenges to the adoption of “modern” fuels remain. These include sufficiently considering the cultural and culinary needs of the target group, as many cookstove projects are expensive and have experienced poor uptake or lack of sustained use because the stoves are not appropriately designed. Where LPG and electrified cooking are not possible, practitioners may focus on the production of woody biomass for cooking and heating, and the cultivation of rapidly growing energy crops that can be sustainably and repeatedly harvested.

Intermittent aeration practices used in rice production, such as the System of Rice Intensification (SRI) or alternate wetting and drying (AWD) methods, can conserve water use substantially and reduce methane emissions while yielding comparable amounts of grain. Intermittent aeration may also be critically important in water-stressed areas and those more likely to face drought conditions. Intermittent aeration practices are likely to be adopted in regions where there is a limited supply of water or a price on water high enough to encourage conservation practices. However, SRI and AWD are knowledge-intensive practices, and farmers require significant institutional and capacity-building support to learn and adopt new techniques. This support for education and training is essential, since poor management, timing, and other factors can lead to decreases in crop yields. Practitioners that can invest in understanding local barriers to adoption may be particularly well suited to working with farmers and partners to promote the uptake of intermittent aeration practices and other strategies that can in turn reduce methane emissions in rice.

Reducing the use of fire in agriculture can help increase the sustainability of farming systems while reducing black carbon and methane emissions. Practices such as agroforestry (the cultivation of trees on farms for food, fodder, timber, and biomass for energy) and conservation agriculture (the retention [*i.e.,* not burning] of crop residues on the soil surface, minimum tillage, and proper crop rotation) offer more sustainable alternatives to burning. Although it is not always clear how substantial the benefits will be for income generation or agricultural yields, and in some cases there may be tradeoffs, there are likely to be farmer health and livelihood benefits, in addition to environmental and climate ones from promoting increased access to inputs, agroforestry, conservation agriculture, and composting. However, innate challenges exist in expanding adoption of such practices as fire is an inexpensive tool for farmers—especially low-input farmers. Enabling them to switch to other methods of production will likely require a combination of incentives and policies to discourage burning. For example, increased access to affordable farm inputs such as fertilizer and lime, which can add nutrients and neutralize soil acidity, can also reduce the need to burn, although there may be environmental trade-offs.

Climate-smart cooling practices can help reduce the need for and improve the efficiency of air conditioning, thus lowering emissions of hydrofluorocarbons (HFCs). These practices include cool roofs and reflective pavements, better-insulated and safer housing infrastructure, and proper urban planning to reduce urban heat islands. At the household level, there is a huge opportunity to provide an integrated, systematic approach to upgrading the housing infrastructure of both urban and rural poor, including, where appropriate, the installation of high-quality reflective cool roofs with built-in insulation, rainwater catchment for household use, proper sanitation facilities, outdoor or screened kitchens with good ventilation and a flue or chimney to remove air pollutants from the house, running water, solar installations, and other design components that could be packaged together to provide multiple human health and climate benefits. The cost of such systems is likely to be substantial, however, and would likely require financing schemes.

These and other findings suggest that organizations and institutions with development and poverty-alleviation mandates should consider incorporating SLCP mitigation into their strategies and missions. This can be done directly through service delivery programming or through targeted advocacy to support policy changes and/or deliver financing that facilitates both poverty alleviation and climate change mitigation. Practitioners can start pursuing potential poverty and climate mitigation win-wins by focusing on several key issue areas for strategic alignment and improved integration of existing practices, including:

- **Finding a common language.** Development practitioners should work with climate change practitioners to find a common language that can speak appropriately to beneficiary communities but can also engage multiple stakeholders around shared goals.

- **Capacity building and empowerment.** Development practitioners should invest in growing and maintaining targeted stakeholders' technical and social capacities. Areas for focus could include, among others: operational structures; data and information collection; sharing of best practices and challenges across disciplines; and enhancing the institutional and governance systems that enable beneficiaries to have power and a voice in the design and deployment of initiatives at the nexus of development and climate change mitigation.

- **Ensuring effective financing.** Development practitioners should identify the financial costs to ensure that SLCPs are considered (monitored and/or reduced) as part of a particular development intervention and advocate for funders and donors and support win-wins for poverty and climate change.

INTRODUCTION

In the past two decades, more than 1 billion people worldwide have been lifted out of poverty, achieving greater access to healthcare, education, and economic opportunity.[1] Yet the progress has been unequal, and inequality continues to rise. New data show that the number of people who are hungry or malnourished in some regions is still increasing (IFPRI, 2017). Moreover, global emissions of carbon dioxide, methane, and other greenhouse gases and pollutants that contribute to climate change continue to increase (IPCC, 2013). The impacts of a changing climate are already threatening development gains, particularly in vulnerable and poor communities and within the agricultural sector, which underpins the economies of many lower-income countries and provides income generation to the majority of poorer households. Research by the World Bank suggests that "without rapid, inclusive and climate-smart development, together with emissions-reductions efforts that protect the poor, there could be more than 100 million additional people in poverty by 2030, particularly in Africa and South Asia" (Hallegatte, et al., 2015).

In 2015, nearly all countries adopted the Paris Agreement on climate change[2] and a new development agenda for 2030—the Sustainable Development Goals (SDGs)[3]. Both frameworks explicitly acknowledge the relationships between climate change and poverty, recognizing that a stable climate system and human well-being are inextricably linked. They also implicitly suggest that governments, businesses, financial institutions, and international organizations design and implement policies and actions that address both climate change and sustainable development.

To date, the focus for many development-oriented organizations and institutions seeking to link their agendas with actions to address climate change has been on implementing measures that support climate change resilience and adaptation.[4] Enhancing resilience and adopting adaptation strategies is essential in the world's poorest countries and communities, since these regions are more vulnerable to the impacts of climate change, including extreme heat, droughts, floods, and other extreme weather events (see, for example, Lobell et al., 2008;

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1. Oxfam recognizes poverty as a human-made condition that is multidimensional in nature. Although common poverty metrics include economic indicators, such as the number of people in a country living on less than $2 per day, Oxfam considers several aspects of poverty in its work and research, including standard of living, health and well-being, diversity and gender inclusion, stability and security, and empowerment. This analysis similarly considers development and poverty impacts of SLCP mitigation beyond a monetary output.
2. http://unfccc.int/paris_agreement/items/9485.php
3. http://www.un.org/sustainabledevelopment/sustainable-development-goals/
4. For example, disaster relief efforts are preparing not for yesterday's weather but for what climate modelers suggest tomorrow's weather may be (Carty, 2012), with the knowledge that extreme weather events are likely to increase in severity and frequency (Mann et al., 2017). Efforts are underway to create "sponge cities"—urban locations that can slow and absorb rainfall as a way to reduce flooding and water damage (Liu, 2016). In addition, public health efforts to reduce disease are increasingly informed by climate science and models that help predict future zones of infection and transmission (Altizer et al., 2013).

Adger et al., 2003; and IPCC, 2014). Such countries and communities are less likely to have the financial and technological means to fully adapt to a changing climate (IPCC, 2014). However, climate change mitigation strategies—even in poor countries—can also be a means to directly address hunger, disease burdens, and a lack of economic opportunity (Ürge-Vorsatz et al., 2012), so long as the mitigation does not become a burden or counterproductive to development goals.

One such set of proposed mitigation solutions is reducing emissions of short-lived climate pollutants (SLCPs), such as methane, black carbon, tropospheric ozone,[5] and HFCs (see Box 1). Although these pollutants are released in smaller quantities and have shorter atmospheric lifetimes than does carbon dioxide (CO_2; the main contributor to global warming), SLCPs have a significant effect on the climate (Hansen et al., 2000).[6] SLCPs are produced by sources as diverse as livestock, natural gas and oil systems, biomass burning, diesel engines, and refrigerants, among others (see Table 1 and Box 1). The diverse nature of SLCP emissions sources and their effects can present a challenge in terms of effectively targeting emissions. However, the diversity of sources and pollutants also means that addressing SLCPs can provide a range of benefits across multiple sectors, scales, and locations.

Globally, the benefits of reducing SLCPs are estimated as avoiding up to 4.7 million annual premature deaths, mainly from decreasing air pollution, and avoiding annual crop losses by as much as 135 million metric tons per year (UNEP WMO, 2011; Shindell et al., 2012).[7] Additional analysis done at a regional, national, and sector level similarly demonstrates that although the benefits of SLCP mitigation will vary depending on the specific geographic context,[8] there are significant and net positive benefits across development-relevant metrics, including air quality, human health, and crop yields, as well as energy and emissions savings, employment, and fuel costs (Shindell et al., 2012; Kuylenstierna et al., 2011). These results suggest that SLCP mitigation can, in many cases, support attainment of the SDGs, in addition to climate mitigation (Shindell et al., 2017; Haines et al., 2017)[9] (Figure 1).

5. As Box 1 shows, tropospheric ozone cannot be mitigated directly. Rather, it occurs through reductions in precursor gases, including methane.

6. Emissions from carbon dioxide have been and will likely continue to be the major source of warming from anthropogenic activity. From the last Intergovernmental Panel on Climate Change report (IPCC, 2013), the amount of warming from carbon dioxide, measured in watts per square meter, was 1.82 W m-2 of the total 2.83 W m-2, constituting around 64 percent of observed warming. Lowering emissions from SLCPs can reduce warming extremely quickly but that is not sufficient to substantially reduce warming over the long-term.

7. These figures come from studies that looked specifically at associated benefits from reductions of methane and black carbon.

8. See, for example, Figure 4 in Shindell et al. (2012).

9. See also http://ccacoalition.org/en/content/contribution-short-lived-climate-pollutants-sustainable-development-goals.

Table 1. Comparing CO_2 and SLCPs

Species	Symbol	Type	GWP-20	GWP-100	Atmospheric residence time	Major anthropogenic sources
Carbon dioxide	CO_2	Gas	1	1	5-200 years	Fossil fuel consumption, land use change, cement
Black carbon	BC	Aerosol	2,530	840-1,280	days-weeks	Biomass burning, residential biomass energy use, fossil fuel production and consumption
Hydrofluorocarbon	HFC-134a	Gas	3,830	1,430	14 years	Industrially produced refrigerant
Methane	CH_4	Gas	86	34	12 years	Fossil fuel production, livestock, rice production, biomass burning, dams
Tropospheric ozone	T-O_3	Gas	*	*	hours-days	Forms from methane and nitrous oxide emissions in the presence of sunlight

*Because a significant portion of tropospheric ozone in the atmosphere is produced during the degradation of methane (a process called "photolysis"), the radiative forcing and resulting global warming potential (GWP) is calculated in the methane GWP figures presented here.

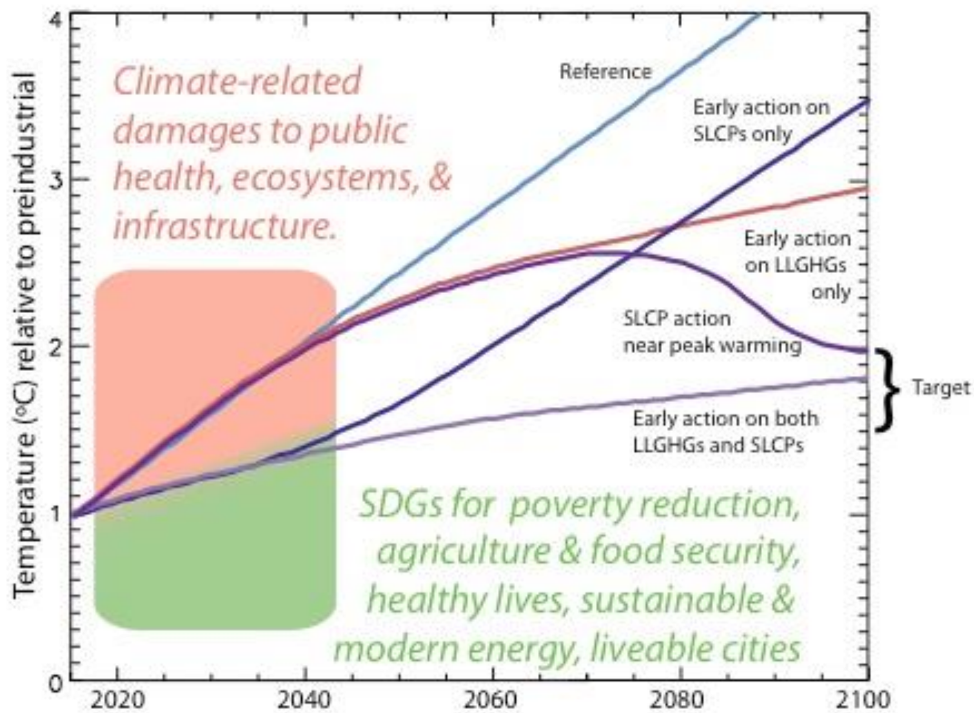
Sources: IPCC (2013) for all pollutants, except black carbon, from Jacobson, 2007. Notes: GWP-20 means global warming potential calculated over a 20-year time horizon; GPW-100 means global warming potential calculated over a 100-year time horizon.

With respect to climate change, there is a short window of time, probably less than 10 to 20 years, to reduce emissions of climate pollutants substantially in order to stabilize the Earth's climate in line with the Paris Agreement, which seeks to limit the increase in global average temperatures to "well below 2°C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5°C above preindustrial levels"[10] (IPCC, 2013; Hansen et al., 2016; Rogelj, et al., 2016). If temperatures are allowed to continue to rise, climate risks will increase, and adaptation will likely become more difficult, if not impossible, for

10. A full description of the Paris Climate Agreement can be found here: http://unfccc.int/paris_agreement/items/9485.php.

large swathes of the world's people[11] (Hansen, 2016). With increased warming, there is also an increased likelihood of crossing dangerous thresholds, or "tipping points," in the Earth's climate system that could essentially make the problem unmanageable and drive the planet into extreme warming that hasn't been experienced in millions of years (Lenton et al., 2008). As with adaptation, mitigation is therefore also critical from a humanitarian perspective. Aggressive mitigation of SLCP emissions could slow the rate of global warming in the near-term and reduce total warming by about 0.5°C over the coming century (Shindell et al., 2012; Shindell et al., 2017). SLCP mitigation alongside rapid reductions in carbon dioxide emissions (Rockström et al., 2017) is therefore critical to the achievement of the Paris Agreement and, in the near-term, would help reduce climate-related risks to poor and vulnerable communities.

Figure 1. Global temperature scenarios with and without SLCP mitigation



Source: CCAC (2017). Notes: In Figure 1, "Reference" refers to business as usual emissions scenarios with different mitigation pathways using early or late action on mitigation of LLGHGs (long-lived greenhouse gases, e.g., carbon dioxide and nitrous oxide) and SLCPs (short-lived climate pollutants, e.g., methane, black carbon, HFCs, and tropospheric ozone). Note that the only scenarios which keep warming less than 2°C, the safe upper limit of warming, are those in which both LLGHGs and SLCPs are reduced. However, the climate-related damage to public health, ecosystems, infrastructure, agriculture and other sectors—impacts likely to hit the poor harder—are likely to be greater if SLCPs are not reduced in near term. This figure implies that early action on both LLGHG and SLCP is the most intelligent path forward to reduce climate risks especially for poor people.

11. This is especially true for communities close to the equator and to coastlines, in arid and semi-arid locations more prone to drought, places dependent on monsoonal rains, such as the Indian subcontinent, and those in the path of hurricanes and cyclones.

Despite this analytical evidence and the availability of cost-effective technologies to address SLCPs (UNEP WMO, 2011), financing and policies that support low-SLCP-emissions development are still limited in both number and scale (Victor et al., 2015). Entities such as the Climate and Clean Air Coalition (CCAC)[12] provide a catalyst for national policy, finance, and communications strategies related to SLCPs, but actions to reduce SLCPs will arguably need to be taken up in a more purposeful way by those outside the climate and clean air sectors, and mainstreamed into a variety of development interventions to realize the ambitions of the Paris Agreement and the SDGs.

This research backgrounder aims to highlight opportunities to scale and support development investments and policies while mitigating SLCP emissions and addressing climate change. Although we identify several possible areas of intervention, our goal is not to promote any single policy or measure but rather to open the discussion about what may be achievable within the frameworks and priorities of development practitioners. Thus, we also examine some of the costs and tradeoffs associated with various policies and measures.

The next section provides a brief, high-level overview of major development- and poverty-relevant linkages related to SLCP mitigation. The paper then provides a deeper assessment of several specific actions that can reduce SLCPs and their prospects for supporting pro-poor outcomes that contribute to the achievement of poverty-alleviation goals. Finally, in the discussion section, we put some initial considerations for development practitioners, organizations, and institutions—even those without an existing strong focus on climate change—to design development strategies and programs that consider SLCPs.

12. http://www.ccacoalition.org/

Box 1. Short-Lived Climate Pollutant Overview

Black carbon

Black carbon (BC) soot is an aerosol and air pollutant (not a greenhouse gas) created from the incomplete combustion of fossil fuels or biomass that is small enough to stay aloft in an air mass, causing warming while in the air and when deposited on ice and snow. (For a good overview of black carbon, see Ramanathan and Carmichael, 2008.) Globally, 35 percent of anthropogenic, or human-caused, black carbon emissions are the result of fossil fuel combustion, and 65 percent come from biomass burning, with the majority of biomass burning occurring in the tropics (Bond et al., 2004; Bond et al., 2007). Bond (2007) estimated that the sources of anthropogenic black carbon emissions are 42 percent from open biomass burning (*e.g.,* slash-and-burn agriculture and combustion of crop residues), 18 percent from traditional household biofuel use, 14 percent from diesel for transport, 10 percent from diesel for industry, 6 percent from residential coal use, and a smaller proportion from other sources.

Black carbon is an extremely short-lived pollutant, staying in the atmosphere for days to weeks only, and has a large but uncertain impact on Earth's climate system, contributing an estimated 10–20 percent to total observed warming globally. For this reason, targeting black carbon can be a fast-action strategy for mitigating climate change, with an often greater "co-benefit" of reducing associated carbon dioxide and other air pollutant emissions. (See, for instance, Jacobson, 2002; Bond and Sun, 2005; Ramanathan and Carmichael, 2008; Ramanathan and Xu, 2010.)

In addition, black carbon—along with its co-pollutants, such as carbon monoxide, nitrogen oxides, polycyclic aromatics, and dioxins—is known to have significant negative impacts on human health (Cohen et al., 2017) and is the leading environmental cause of premature death. Prolonged exposure to black carbon can contribute to an increased risk of cardiovascular and respiratory diseases. In addition, deposition of black carbon has a disproportionately large impact on warming in the Arctic and Himalayan regions, where it decreases the reflectivity or albedo of snow and ice, warming the surface, and thereby accelerating melting.

At present, national inventories of black carbon are limited, which is an impediment to incorporating black carbon emissions reductions into global climate agreements. To help rectify the black carbon data gap, some governments and non-governmental organizations are using satellites to monitor open burning and fires around the world (see, for example, work by the International Cryosphere Climate Initiative - http://iccinet.org/open-burning; and World Resources Institute - http://fires.globalforestwatch.org/home/).

Hydrofluorocarbons

Some hydrofluorocarbons (HFCs) are short-lived climate pollutants. They are commonly used as refrigerants, propellants, solvents, foam-blowing agents, and fire-protection agents, and are also powerful greenhouse gases. HFCs are human-made compounds, originally introduced to replace chlorofluorocarbons (CFCs) and other stratospheric ozone-depleting substances as part of the 1987 Montreal Protocol, which phased out production and emissions of CFC-11, CFC-12, CFC-113, and methyl chloroform compounds. However, HFCs have a global-warming impact that can be hundreds to thousands times greater than that of CO_2. Therefore, targeting these species can significantly reduce radiative forcing on Earth's climate system. To that end, in October 2016, countries agreed to an update of the Montreal Protocol called the Kigali Amendment, which provides a timetable for the phase-down of HFCs and could prevent an estimated 0.5^{o}C of warming by 2100 (UNEP, 2016).

Methane

Methane (CH_4) is a greenhouse gas that is 86 times more powerful than carbon dioxide over a 20-year time horizon and 34 times more potent over a 100-year time horizon (IPCC, 2013), contributing around 25 percent of warming since 1750 (Nisbett et al., 2014). Methane lasts for approximately a decade in the atmosphere (IPCC, 2013). Methane is also a precursor gas in the formation of tropospheric ozone.

There are many sources—both natural and anthropogenic—of atmospheric methane. More than two-thirds (~71 percent) of methane emissions are of anthropogenic origin: coal and oil mining and natural gas (19 percent); enteric fermentation from livestock production (16 percent); the flooding of fields during rice cultivation (12 percent); biomass burning (8 percent); landfills (6 percent); sewage treatment (5 percent); and animal waste (5 percent) (Augenbraun et al., 1997). The remaining 29 percent come from natural sources: wetlands (22 percent); termites (4 percent); and methane hydrates and oceans (3 percent). Annual emissions are 230 to 300 megatons of methane emissions: 33–45 percent from agriculture and livestock, 30 percent from energy production, and 25 percent from waste treatment and disposal (Ramanathan and Xu, 2010). Recent literature has also identified large-scale dam projects to be a major source of methane emissions (see, for example, Deemer et al., 2016 and Fearnside, 2015).

Over the past century, methane concentrations in the atmosphere have grown, however, in the mid 1990s, the rate of growth slowed, and the amount of methane in the atmosphere remained nearly constant until 2007 (Nisbett, 2014; Dlugokencky, 2018). Shortly thereafter, the rate of methane emissions began to increase relatively rapidly, although there is still debate within the scientific community about the source of the rapid increase in emissions, with the most recent theory suggesting that a large portion derives from increased emissions related to oil and gas production (Worden et al., 2017).

Tropospheric ozone

Ground-level or tropospheric ozone (T-O_3) is a potent greenhouse gas that negatively affects human health (Bell et al., 2004). In fact, tropospheric ozone is thought to be responsible for around 150,000 premature deaths each year globally (CCAC, 2018). In addition, it negatively affects infrastructure, crop yields, and natural ecosystems (Tubiello et al., 2007; Wittig et al., 2009; Ray et al., 2015). In particular, tropospheric ozone causes damage that can impede photosynthesis, increase susceptibility of crops to disease, stunt growth, inhibit reproduction, increase senescence, alter gene expression, and reduce crop yields (Avnery et al., 2011, Mauzerall and Wang, 2001). A large-scale US study found that around one-third of crops in the US were reduced by 10 percent or more from tropospheric ozone (Heagle, 1989), with similar findings in India (Ghude et al., 2014), China (Wang et al., 2007), South Africa (Van Tienhoven and Scholes, 2003), and elsewhere. The adverse impact on agricultural productivity harms farmers' income generation and hinders regional food security.

Additionally, ozone poses a high risk to individuals who suffer from asthma, particularly children and the elderly (Zhang et al., 2017). Ozone can exacerbate the symptoms of asthma; worsen lung diseases like bronchitis, pneumonia, and emphysema; and can cause chronic obstructive pulmonary disease among other ailments (Zhang et al., 2017). Higher tropospheric ozone levels in urbanized and industrial areas are superimposed on higher ozone levels regionally and globally, often leading to greater health risks for those living in urban, peri-urban, and industrial areas.

Unlike other SLCPs, the formation of anthropogenic tropospheric ozone is caused primarily through emissions of other pollutants (principally from methane and nitrogen oxides) and not through direct emissions. Thus, targeting leading precursor gases is considered the most effective means of reducing atmospheric tropospheric ozone levels. Nitrogen oxides such as nitric oxide and nitrogen dioxide are responsible for the majority of tropospheric ozone in polluted areas, but methane may have more impact globally (West and Fiore, 2005).

POVERTY ALLEVIATION PRIORITIES AND SHORT-LIVED CLIMATE POLLUTANTS

As we have already noted, certain development benefits from SLCP reductions have been quantified at a global level, including premature deaths and crop yield losses avoided (UNEP WMO, 2011). Other linkages between development and SLCP mitigation are less readily quantified, however, and are often contingent on the specifics of the intervention, including location, sector, target population, and desired outcomes. Nevertheless, SLCPs and SLCP mitigation strategies are clearly relevant to priority issue areas and sectors for organizations aiming to reduce poverty and promote development. Some examples follow.

FOOD SECURITY AND RURAL LIVELIHOODS

The food and agriculture sector is both a major source of emissions that drive climate change, including SLCPs, and highly vulnerable to climate change impacts. Agriculture is the second-largest contributor to SLCP emissions, particularly through the emissions of methane from livestock production and rice, and black carbon from agricultural residue burning and slash-and-burn agriculture. Agriculture also provides livelihoods to 40–80 percent of the population in many developing countries, most of whom are small-scale producers that produce relatively few emissions yet whose livelihoods are critical to ensuring national and regional food security in many parts of the world.

In general, climate change is projected to decrease global crop productivity 2–15 percent for every 1°C warming, with large differences among regions and crops (Challinor et al., 2014), and has the potential to cause dramatic non-linear changes whereby productivity and yields can drop sharply with increasing temperature (Schlenker and Roberts, 2009; Burke et al., 2015). The agriculture sector is particularly vulnerable to changes in weather and climate in places such as the tropics, semi-arid regions, and locations that depend on monsoonal rainfall patterns for productivity. Models predict, for instance, that without adaptation, maize yields in Africa could decrease by 22 percent by 2050 (Schlenker and Lobell, 2010). In addition, the production of methane in the presence of other precursor pollutants can form tropospheric ozone, which negatively affects plant health and thus decreases crop productivity.

For these reasons, enhancing resilience to climate change is critical in the agricultural sector, particularly among poor rural communities and small-scale producers. Drought-proofing, flood-proofing, and pest-proofing the world's crop and pasture lands will likely become an increasingly central organizing concept in the agricultural sector. Addressing SLCPs can support these efforts. For example, reducing methane emissions, which contribute to the formation of tropospheric ozone, can lead to an estimated 1.3 to 3.2 percent increase in crop productivity globally, with an estimated economic value of $4-33 billion (UNEP WMO, 2011).

WATER SECURITY

Agriculture uses an estimated 56 percent of the world's fresh water reserves (Alcamo, et al., 2000), which are coming under increasing pressure—from climate change, but also from urbanization, industrialization and population growth. Some of the practices and technologies used to control methane emissions may also be relevant for regions where water supply is limited or uncertain, and can help sustain food production during times of water scarcity. Examples include increasing the efficiency of irrigation water through intermittent aeration in rice paddies and the use of drip irrigation in place of flood irrigation. In addition, reducing black carbon emissions in countries such as India, Pakistan, Bhutan, China, Myanmar, and Nepal may be critical to regional water (and food) security in the decades ahead, since much of these countries' water supply flows from glaciers. For example, although black carbon contributes an estimated 10 to 20 percent of global warming around the world, it is responsible for around 30 percent of warming in the Hindu-Kush-Himalayan region where the soot darkens snow and ice, which in turn leads to greater heat uptake and therefore enhanced melting (Ramanathan et al., 2007). The meltwater from the Hindu-Kush-Himalayan region directly supplies water to some 500 million people and is used for irrigating rice that feeds as many as 1.4 billion people (Rasul, 2014).

HEALTH AND PRODUCTIVITY

Air pollution, including emissions of SLCPs, is responsible for 16 percent of all deaths globally—a figure that is approximately three times greater than the number of deaths from HIV-AIDS, tuberculosis, and malaria combined (Landrigan et al., 2017). Reduced exposure to air pollution can help prevent 5.3 to 37.4 million premature deaths, with a monetized value of $5 trillion (UNEP WMO, 2011). These benefits will also largely accrue to the developing world, particularly Bangladesh, Nepal, Pakistan, China, India, Uganda, and other parts of Africa and Asia (UNEP WMO, 2011). Reducing SLCPs and other air pollutants has been described by the World Health Organization as "an opportunity not only to reduce climate change and its consequences, but to promote actions that can yield large and immediate health benefits, and reduce costs to health systems and communities."[13] Other strategies both to aid health outcomes and reduce emissions of SLCPs include increasing access to more modern and hygienic sanitation facilities that prevent surface and groundwater contamination, water-borne disease, and reduce methane emissions (El-Fadel and Massoud, 2001).

The impact that SLCP reductions can have on reducing the rate of global warming is also relevant for economic development. For example, rising temperatures from climate change are going to lead to both acute and chronic heat stress, particularly in places with already high temperatures (Sherwood and Huber, 2010). Worker productivity is likely to be affected, especially in environments with very hot seasons in low- and middle-income tropical countries, where exposure to and risk from excessive heat exposure is greatest (Kjellstrom et al., 2009). Countries such as Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates are at substantial risk, as are many countries in sub-Saharan Africa, Asia, and Central and South America (Kjellstrom et al., 2009). Urban areas are particularly prone to heat-related risks due to the ability of pavement, buildings, and other human-made

13. http://www.who.int/phe/news/oct2015/en/

structures to absorb and hold onto heat. As rapid urbanization continues[14] and the climate continues to warm, a greater number people will be at risk from high heat events.

ELECTRICITY ACCESS

Nearly 1.6 billion people (22 percent of the world) lack access to electricity (IEA, 2017). Increasing access to electricity is widely viewed as fundamental to reducing poverty, enhancing sustainable development, and increasing quality of life. Electrification can shift households from reliance on traditional biomass such as wood, charcoal, and coal to electricity from clean energy sources such as solar, wind, and water. This can help reduce energy poverty and provide additional development benefits while reducing emissions of SLCPs. For example, electricity can support both clean cooking and lighting. The benefits of clean cooking include improved health, particularly for women and children, which we discuss below, although to date there is limited use of electricity for cooking in poor, rural areas (Morrissey, 2017), and access to electrified lighting can provide for increased productivity outside of daylight hours, as well as increased safety and the prevention of violence. In addition, electrification can help support education and small-scale entrepreneurship by increasing lighting and power to enable critical activities.

GENDER EQUALITY AND WOMEN'S EMPOWERMENT

Gender norms are often deeply entrenched, and women in particular may have unequal access to resources and/or opportunity, including unequal access to political, institutional, and legal rights. Although systems-based solutions are necessary to overcoming many of these barriers and providing employment, tenure, and other empowerment opportunities for women, SLCP mitigation measures can help support these broader gender-based development initiatives.

For example, air pollution, including black carbon, is the result of inefficient biomass and fossil fuel burning, with a large proportion from cookstoves. Because women often do the cooking, they and the young children they look after are often the ones subjected to the highest levels of pollutants,[15] which in

14. As of 2008, 50 percent of the world's population lived in urban areas and by 2050, it is estimated that 70 percent, nearly 7 billion people, will be living in cities (UNPD, 2017).

15. Including black carbon, carbon monoxide, nitrogen oxides, polycyclic aromatics, and dioxins.

turn have been linked to a variety of pulmonary-cardiovascular diseases[16] (Burnett et al., 2014). Indoor air pollution results in an estimated 370,000 to 4.3 million deaths per year[17] (Chafe et al., 2014) and around 108 million lost disability-adjusted life years (DALYs) per year in medium- and low-income countries (Pillarisetti et al., 2016). The vast majority of morbidity and mortalities occur in developing countries, with disproportionately large impacts to women and children (Miller et al., 2007). By 2050, the number of deaths per year is expected to rise to 3.6 million (UNEP WMO, 2011). Thus, reducing black carbon emissions from traditional biomass burning through the adoption of clean burning cookstoves, liquid petroleum or natural gas stoves, anaerobic digestion with combustion, or electricity[18] is likely to have health benefits that accrue primarily to women and girls in poor communities.

In addition, fuelwood collection, often carried out by young girls, further exposes them to possible violence. Access to lower-emissions cooking and heating sources can therefore reduce the time and transport burden on women and young girls, in particular, to collect fuelwood, which in turn increases opportunities for women to pursue education or trades that may be income-generating activities, or spend more time with children and relaxing (Anenberg et al., 2013). Ultimately, however, addressing the issue of unpaid work will be necessary before women can gain opportunities outside the household.

A woman in Guatemala making tortillas on a traditional three-stone fire. The tortillas are being cooked over a “plancha.” Notice the thick black streak of black carbon soot residue on the back of the wall. Inhalation of black carbon soot and other products of incomplete combustion lead to the death of 1.8 million people annually and more than 900,000 children under the age of five. (Photo credit: Ryan Hottle.)

16. Including lung cancer, myocardial infarctions, eye infections, stroke, acute lower respiratory infection in children, and chronic obstructive pulmonary disease.

17. Among the deaths from cooking with traditional biomass, 12 percent are due to pneumonia, 34 percent from stroke, 26 percent from ischemic heart disease, 22 percent from chronic obstructive pulmonary disease, and 6 percent from lung cancer, according to the World Health Organization (see http://www.who.int/mediacentre/factsheets/fs292/en/).

18. Although access to electricity will benefit everyone, it benefits women in particular, often providing them the ability to earn additional income, because they are tied to the home (gender norms may limit women’s physical mobility, so being at home and having access to electricity—rather than biomass fuel—can mean that women have an opportunity to engage in some type of paid house work after daylight and do not have to spend time collecting fuelwood).

SHORT-LIVED CLIMATE-POLLUTANT MITIGATION, POVERTY, AND DEVELOPMENT

A list of 16 priority measures for black carbon and methane mitigation were identified in UNEP WMO (2011) (Table 2). The initial identification criterion used in the UNEP WMO (2011) study required that measures provide air quality, health, climate, and local environmental benefits. From an analysis that initially included approximately 2,000 different measures,[19] the study found that "a relatively small set of [16] measures … provide about 90 percent of the climate benefit compared to the implementation of all 2,000 measures." This paper examines a cross-sectoral selection of the priority SLCP mitigation measures that are frequently linked to development and aid agendas and evaluates the diversity of opportunities and challenges associated with these measures. We also consider an additional measure related to HFCs (which were not assessed in the original UNEP WMO study), since refrigerant use is expected to increase significantly in developing countries, particularly where incomes are rising and the effects of global warming are pronounced.

The measures assessed here (and highlighted, in green, in Table 2) include:

1. Cleaner cooking and heating;
2. Lower-emissions rice production;
3. Alternatives to crop residue open burning, including conservation agriculture and agroforestry; and
4. Reducing HFCs through complementary climate-smart cooling such as cool roofs.

For each of the measures we review, we briefly synthesize key development-relevant aspects of the intervention and attempt to answer questions such as: How can the SLCP mitigation measure support development and poverty alleviation? What community benefits can be directly or indirectly attributed to the SLCP reduction action? What barriers exist to wider adoption of the measure? Have trade-offs between mitigation and development been identified?

19. This study used the GAINS model (Greenhouse Gas—Air Pollution Interactions and Synergies) developed by the International Institute for Applied Systems Analysis. The GAINS model aids researchers to examine the cost-benefit relationship of emission control strategies, including both impacts to local air quality and greenhouse gases. The tool allows simulation of costs, health, and ecosystems benefits of air pollution control measures using user-defined policy targets. Available online at: http://gains.iiasa.ac.at/models/.

Table 2. Priority SLCP Mitigation Measures

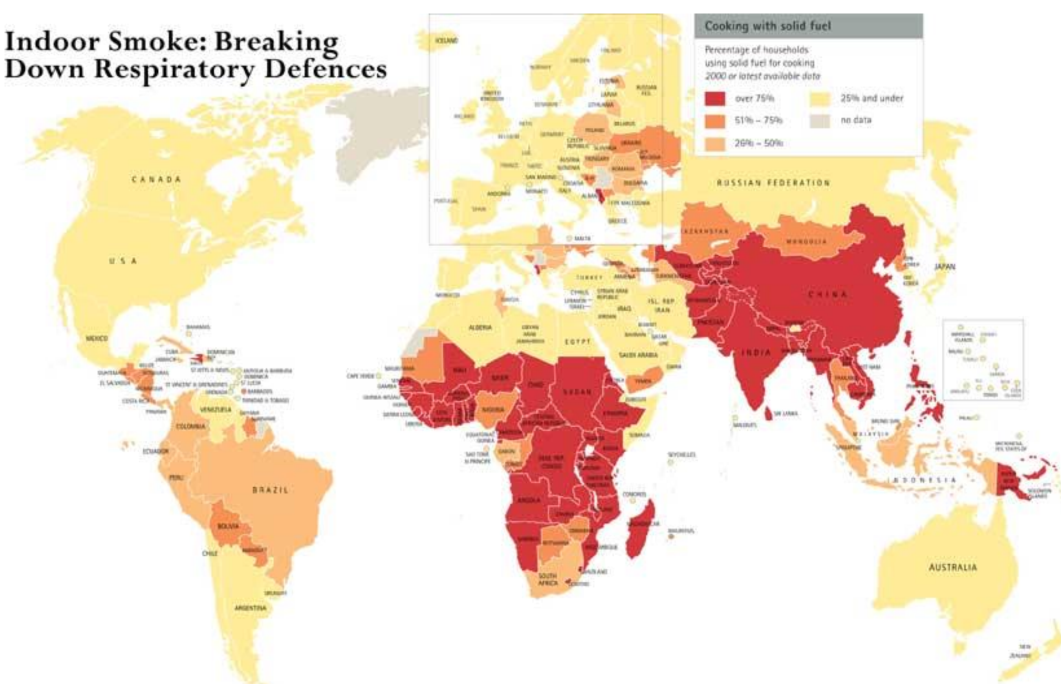
Black carbon abatement measures	**Sector**
Standards for the reduction of pollutants from vehicles (including diesel particle filters), equivalent to those included in Euro-6/VI standards, for road and off-road vehicles	Transport
Elimination of high-emitting vehicles in road and off-road transport	
Replacing lump coal by coal briquettes in cooking and heating stoves	Residential
Pellet stoves and boilers, using fuel made from recycled wood waste or sawdust, to replace current wood burning technologies in the residential sector in industrialized countries	
Introduction of clean-burning (fan-assisted) biomass stoves for cooking and heating in developing countries	
Substitution of traditional biomass cookstoves with stoves using clean-burning fuels (liquefied petroleum gas (LPG) or biogas)	
Replacing traditional brick kilns with vertical shaft brick kilns	Industry
Replacing traditional coke ovens with modern recovery ovens	
Ban on open burning of agricultural waste	Agriculture
Methane abatement measures	Sector
Extended pre-mine degasification and recovery and oxidation of methane from ventilation air from coal mines	Fossil fuel production and transport
Extended recovery and utilization, rather than venting, of associated gas and improved control of unintended fugitive emissions from the production of oil and natural gas	
Reduced gas leakage from long-distance transmission pipelines	
Separation and treatment of biodegradable municipal waste through recycling, composting and anaerobic digestion as well as landfill gas collection with combustion/utilization	Waste management
Upgrading primary wastewater treatment to secondary/tertiary treatment with gas recovery and overflow control	
Control of methane emissions from livestock, mainly through farm-scale anaerobic digestion of manure from cattle and pigs	Agriculture
Intermittent aeration of continuously flooded rice paddies	

Source: Adapted from UNEP WMO (2011). Notes: Those measures highlighted in green are assessed in this paper.

CLEANER COOKING AND HEATING

More than 2.7 billion people (38 percent of the global population) rely upon "traditional biomass" sources for cooking and heating, including fuelwood, charcoal, dung, and coal (IEA, 2016). Cooking with traditional biomass has long been associated with negative impacts on health and livelihoods, as well as on the local environment (Smith et al., 2014; Bailis et al., 2015). Globally, residential biomass burning for cooking and heating is responsible for approximately 18 percent of anthropogenic black carbon emissions (Bond et al., 2007). Yet the use of traditional biomass for cooking and heating is particularly widespread among households in South Asia and sub-Saharan Africa, where use is greater than 90 percent of the rural population (IEA, 2016; see Figure 2). As a result, people from these geographical areas and demographics are exposed to extremely high levels of household air pollutants, which include black carbon, as well as accompanying emissions of carbon monoxide, nitrogen oxides, polycyclic aromatics, and dioxins. One estimate suggests that air pollution from household cooking and heating accounts for around 108 million lost disability-adjusted life years (DALYs) annually in medium- and low-income countries (Pillarisetti et al., 2016).

Figure 2. Percentage of people relying on "solid" or "traditional" fuels (wood, coal, and dung) for heating sources.



Source: Torres-Duque et al. (2008).

An additional negative impact of using traditional biomass is the cost of fuelwood and/or the time allocated to retrieving fuelwood, with women, children, and men in many developing countries spending large portions of their day harvesting wood or charcoal to burn (IEA, 2016). For example, the World Bank (2014) estimates that the amount spent on solid fuels and time used to collect fuelwood in sub-Saharan Africa were part of an approximately $32 billion opportunity cost in 2010 (or 3 percent of regional GDP) associated with cooking with traditional fuels and stoves. Solid fuel use therefore has an especially high cost to those living in poverty, where in some cases, families spend as much as one-third of their annual income on fuel sources for their daily cooking and heating needs.[20] The time lost on burdensome labor such as fuelwood collection could be used for other things—like more time for paid labor, education, constructing wares, managing a business, tending a garden or field, or doing a hobby or leisure activity. Illness and death compound this lost labor, which leads to a net decrease in productivity.

Relying upon mostly woody biomass can also negatively affect the environment, putting trees on farms and nearby forests at risk—a pressure that is likely only to grow with global human population growth and the increased need for fuel. Approximately half of global wood harvested is used for energy such as cooking, but provides just 9 percent of the global energy supply (Bailis et al., 2015). Moreover, an estimated 27–34 percent of wood harvested is done so unsustainably (Bailis et al., 2015). There is risk that some 275 million people who live in areas in unsustainable fuelwood depletion “hotspots” (particularly in east Africa and southern Asia) may eventually deplete the resource base (Bailis et al., 2015). In spite of these negative impacts, fuelwood gathering and charcoal production do provide secondary and, in some cases, primary income generation streams for many people around the world. Therefore, replacing wood and charcoal could come at a cost to local employment.

In developing countries, there are two primary means to address black carbon emissions in the residential sector: first, the introduction of improved or clean-burning biomass cookstoves for cooking and heating,[21] and second, the substitution of clean-burning cooking technology using modern fuels for traditional biomass cookstoves. There are several approaches that can be used to implement these strategies (and this paper focuses on those specific to cooking applications). For example, cooking with cleaner biomass cookstoves could include the use of fireboxes that better retain heat and improve the efficiency of the burn, speed up cooking time, and reducing overall fuelwood use (Boy et al., 2000). Incorporating chimneys, flues, exhaust fans, and other technologies that remove combustion gases from a household or building can help achieve health benefits, although they are unlikely to reduce emissions

20. http://cleancookstoves.org/resources/272.html

21. There is an estimated potential deployment of 100 million or more cookstoves to households around the world (Bailis et al., 2015).

substantially.[22] Importantly, not all "improved" or "clean" cookstove models actually reduce black carbon emissions; they can therefore vary in their climate impacts. In order to have actual climate benefits, considerations need to be taken with respect to model selection (see, for example, Kar et al., 2012).

Replacing biomass stoves with more modern fuels, including liquid hydrocarbons (*e.g.,* LPG), or renewable energy sources (*e.g.,* solar power or methane gas from anaerobic digesters), would further reduce the time and labor needed to gather fuelwood and reduce localized emissions even more substantially than improved biomass cookstoves alone. Replacing wood with LPG or another hydrocarbon fuel source would help reduce local air pollution, but increased emissions of carbon dioxide from the fuel source would negate some of the potential climate benefits. However, emissions of carbon dioxide from widespread uptake of LPG to replace traditional cooking methods are not estimated to be a large source of emissions globally (IEA, 2017). Nevertheless, concerns over the future cost of hydrocarbon fuel sources and the technical difficulties of getting poor communities access to these fuels have inspired a search for more sustainable technologies. It may be possible to leapfrog from traditional biomass straight to cooking with electricity (Smith, 2014)[23] from renewables, such as photovoltaic solar, which has decreased in price significantly over the past five to 10 years (Barron and Torero, 2017). Moreover, a large number and variety of electrical cooking devices (*e.g.,* stoves, ovens, rice cookers, tea kettles, etc.) are already being mass-produced around the world at competitive costs. Such advances notwithstanding, there is a significant body of literature that makes clear that electrification has very limited impacts on household fuel use, with households adopting fuel stacking techniques rather than simply switching to electricity (*e.g.,* see Morrissey, 2017; Rewald, 2017; and references therein).

Despite these opportunities, challenges remain to widespread adoption and sustained use of clean cookstoves (Schlag and Zuzarte, 2008), which are

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22. The potential negative consequences of any intervention need to be carefully considered. For example, Bailis et al. (2007) report that many recipients of stoves quit using them after about six months. The authors explain the reason thus: "The region suffered a very heavy monsoon that year in both areas, causing the chimneys to leak and making the stoves damp. In some cases, the kitchen floor also became wet. Participants removed the stoves and reinstalled their traditional stoves. In some cases they also demanded compensation for the roof and reimbursement for the cost of the stoves."

23. Importantly, many believe that electrified cooking is likely to be impractical for most populations in developing countries. However, Smith (2014) argues that, "It is sometimes ignored that electricity is part of the solution for clean cooking. In the rich world, electric cooking devices include a wide range of appliances that are starting to appear in poor areas, such as rice cookers, water pots, microwaves, and specialized devices often tailored to local foods. These do common tasks conveniently and efficiently with no household pollution, and can be expected to become increasingly important as electrification progresses. Rice cooker production in China, for example, has grown annually at more than 20% over 15 years. The availability of inexpensive portable induction cookstoves—a leapfrog technology that is safer and more efficient than traditional electric or gas stoves—is shifting the balance more toward electric cooking. This is occurring mainly in cities because of cost and power availability, but these constraints are changing as electrification expands and prices for induction stoves fall with scale. In India, more than 20 domestic and international companies are selling these stoves, and the projected growth rate is 35% a year for the next 5 years; in China, annual sales are more than 40 million. More must be done to boost the growth rate of electric cooking, such as targeted subsidies and the development of appliances that are designed and priced for rural areas. Ecuador, for example, is working to install induction stoves in every household in the country. Along with advanced biomass combustion, biogas, liquefied petroleum gas, natural gas, and other clean fuels, electric cooking needs to be directly incorporated into modernization plans for the world's poorest people."

necessary if the purported benefits of cookstoves are to be realized (Ruiz-Mercado et al., 2011). For example, one of the main barriers is cultural—cooking is passed between generations through culinary customs and traditions and asking someone to change a cooking style and set-up, even if it provides potential benefits, can be a significant request. This is particularly true if a stove adds complexity to a cooking routine and detracts from time allocated for other responsibilities. If a stove is not appropriate to its place and to the people who use it—if, for instance, it can't make tortillas in Guatemala, cook rice in Bangladesh or India, or prepare ugali in Kenya—people will not use it, it will not be adopted, and the potential benefits will not be realized. Education and training, especially among women who are more likely to be involved in the cooking process, have been identified as key components in some areas for successful adoption (Slaski and Thurber, 2009).

An additional factor is cost. According to one study, the average cost of an improved biomass cookstove can range from $10–50 (Jeuland and Pattanayak, 2012), although the authors have observed projects with costs as high as $120.[24] The amount of money saved for a household using an improved cookstove without subsidies ranged from $ -1.6 to 3.3 per month, with the median figure being $0.20 per month (Jeuland and Pattanayak, 2012). Although more detailed monetized costs and benefits are needed for a wider range of stoves and in different locations, it is likely that many potential users will not invest in cookstoves without some sort of subsidy and incentive, since initial costs are high, whereas returns are low and amortization rates are long (Ruiz-Mercado et al., 2011). Purchasing a photovoltaic solar system large enough (*i.e.,* with enough kilowatt-hours, kWh) to provide cooking and other household heating is likely to be two to three greater orders of magnitude more expensive than an improved biomass cookstove, and therefore even more unaffordable. On the other hand, if a conventional electrical grid or solar mini-grid is accessible, then there is the potential ability to transition quickly to cooking with little to no household air pollution, although the aforementioned cultural challenges may still be relevant.

An additional consideration of improved biomass cookstove projects is that they still require fuelwood. Thus, there is also a need to consider availability, distance to, cost, labor, and quality of fuelwood to be used. As we have mentioned, a large number of people, approximately 275 million, live in areas where fuelwood is already being harvested unsustainably (Bailis et al., 2015). In such areas, strategies are needed to replenish fuelwood resources through agroforestry, reforestation, and afforestation at rates that exceed demand[25] or to abandon

24. This was for an improved cookstove, which included full plancha (large heat surface for cooking tortillas), firebox burn chamber, cinder blocks for exterior, and double-wall stainless pipe for the flue, the latter being one of the more expensive costs.

25. Using trees such as *Acacia*, *Leucaena*, and *Sesbania* that regenerate rapidly after being cut, often called "coppicing" (Kennedy, 1998), and the growth of energy crops such as *Arundo donax*, *Miscanthus*, willow, and hybrid poplar. Finally, another important consideration for improved biomass

wood altogether as a source of energy, opting instead for other energy sources for household cooking and heating.

RESILIENT RICE

Rice is the staple crop in much of Asia, Africa, and the Middle East and provides the bulk of caloric intake for more than 3 billion people around the world (Muthayya et al., 2014). Rice production supports the livelihoods of more than 1 billion people, many of whom are food-insecure smallholder farmers in developing countries. It is also the largest source of employment opportunity and income for people living in rural regions (Oxfam America, Africare, and World Wildlife Fund, 2010; Uphoff, 2011). Globally, approximately 144 million hectares of land are under rice production (Muthayya et al., 2014), most of these using flooded paddies where soils are kept saturated year ’round or drained only after the crop is harvested. This flooding creates a saturated environment in which anaerobic bacteria, or methanogens, produce methane. For this reason, rice production contributes about 11 percent of total methane emissions each year worldwide (IPCC, 2013).

However, there are a number of improved rice production strategies that may decrease methane emissions.[26] In particular, through the adoption of strategies to increase water use efficiency, rice producers may simultaneously increase resilience and adaptive capacity—especially in water-stressed or drought-prone areas—and, at the same time, reduce methane emissions. One frequently cited technique is “alternate wetting and drying” (AWD) by which fields are flooded and drained intermittently. An additional approach is the “System of Rice Intensification” (SRI), which has also been suggested as a system for reducing water use and methane emissions (Stoop et al., 2002; Uphoff, 2011). SRI incorporates a variety of practices that promote sustainability while maintaining yields, including earlier transplanting, singulated planting (one seed per planting location), and grid spacing, as well as intermittent aeration of paddy fields.

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cookstoves is that households understand the importance of and have access to appropriately dry biomass (typically no more than 5 percent moisture content), which is essential to producing a clean burn and reducing household air pollution levels (McCarthy et al., 2008). This generally means that the biomass needs to be kept under a roof, out of the rain but accessible to the drying wind and warming sunlight that drives off moisture, and given enough time to dry.

26. Additional strategies (not discussed in this paper) that may reduce methane emissions include: first, transitioning away from flooded rice production to “upland” or “aerobic” rice cultivars and growing systems in which the fields are never or rarely kept intentionally flooded (Bouman et al., 2005). Aerobic rice is most promising in areas where water is limited or expensive—generally higher elevation terrain. Yields from aerobic rice are often far less than with paddy-based rice cultivation so aerobic rice is really only feasible where water is unavailable or very expensive. Second is reusing and recycling on and between farms through improved drainage, on-farm water storage structures such as ponds and dams, and through solar-powered pumps (Tuong and Bouman, 2003). Third, methane emissions have been found to be substantially lower if organic residues in the paddies are composted first (Cole et al., 1997; Majumdar, 2003) or pyrolyzed to produce biochar (Zhang et al., 2010), either of which can be added back to the soils prior to the sowing of the next crop. In other words, soils amendments can be made more recalcitrant (stable) in order for them to resist decomposition by microorganisms and reduce methane emissions.

Both AWD and SRI encourage farmers to adopt the practice of allowing the field to dry and rewet periodically throughout the growing season instead of keeping paddies in a permanently flooded state. Researchers have found that these intermittent aeration practices can significantly decrease methane emissions while maintaining crop yields at levels similar to continuously flooded paddies (Upoff, 2011). Overall, intermittent aeration is considered to be an extremely scalable technique that could be deployed widely across countries where rice paddy cultivation is common, for example, China, Bangladesh, India, Indonesia, Japan, Korea, Myanmar, Nepal, Philippines, Sri Lanka, Thailand, and Vietnam (Upoff, 2011). However, applications in Africa may be increasingly important as rice production continues to grow in the region (Muthayya, et al., 2014). Although intermittent aeration practices are appropriate for both large and small farmers at multiple scales of production, generally, periodic wetting and drying is only recommended in irrigated systems, not rain-fed systems in which irrigation scheduling is difficult if not impossible for farmers, particularly when they lack on-farm water storage and where improper irrigation timing can lead to large yield declines (Bouman et al., 2007).

In addition to reducing methane emissions, the AWD and SRI systems have been found to reduce overall water use by 10–30 percent in irrigated systems (Uphoff, 2011). Increased water use efficiency can simultaneously reduce energy use on farms for electricity or petrol for water pumping, which, in turn, also decreases greenhouse gas emissions and improves farm resource efficiency/reduces costs. For example, one study in Bangladesh showed that farmers realized a five-to-six-fold savings in irrigation water and a 20 percent savings in irrigation water costs.[27] Another study in Bangladesh (Kürschner et al., 2010) reviewed the application of AWD techniques in the country's northwestern divisions and found that 81 percent of farmers applying AWD to their rice production realized some form of economic benefit, largely as a result of reduced irrigation costs, which decreased by nearly 20 percent on average (Kürschner et al., 2010). The reduced need for potentially scarce or expensive resources therefore increases the resilience of the farming household to climate-induced stressors and shocks, such as droughts and increased energy costs. In some areas, the reduced need for irrigation water could also help mitigate other challenges, including the risk of aquifer depletion from "groundwater mining," and, in coastal areas, saltwater intrusion into groundwater, which is a major problem in many low-lying countries such as Bangladesh.

Barriers to the adoption of intermittent aeration practices such as AWD and SRI include farmer access to training and technical support, as well as risk aversion and a resistance to changing culturally well-established practices (see, for example, Howell et al., 2015). Rice cultivation practices tend to be deeply

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27. http://www.ccacoalition.org/en/resources/case-studies-farmers-perceptions-and-potential-alternate-wetting-and-drying-awd-two

ingrained (rice having been cultivated using flooded paddies for 6,000 years or more), and many farmers tend to be risk adverse and therefore may be hesitant to adopt new practices. Although paddy drainage has been practiced for decades in some locations, for most, additional time and labor is required to learn how to apply intermittent aeration practices appropriately. For that reason, insufficient technical training and a lack of supportive institutions prevent its adoption, since proper implementation requires, among other things, that farmers carefully manage water levels, identifying when they need to be maintained (during flowering and grain-filling stage) and when they can be allowed to drain to a particular depth. As we have mentioned, if intermittent aeration is not applied properly or in years of climate extremes, it is possible that the system can lead to decreased yields and profits for farmers (see, for instance, Carrijo et al., 2017). Early adopters' negative experience could therefore cause many other farmers to bypass such practices on their own farms.

Another drawback of intermittent aeration is that weeds tend to grow more vigorously in drained fields. SRI advocates that farmer use both manual and mechanized weeders, typically either a simple push-behind rotary wheel or a small walk-behind tractor, to address this challenge. Notably, weeding responsibilities can often fall to women and children, which can lead to unintended negative consequences to gender equity and social dynamics. In addition, the increased prevalence of weeds may require farmers to hire additional laborers to remove them or apply additional herbicides, (Kürschner, et al., 2010), which may reduce the benefit to farmers' net income and create greater exposure to agrochemicals.

Finally, although intermittent aeration has been found to substantially reduce methane emissions substantially, it can increase emissions of nitrous oxide (N_2O), another potent greenhouse gas (Chu et al, 2015). Most studies suggest that the increased production of nitrous oxide cancels out some of the potential benefits of the reduced methane emissions, but not all (see, for example, Johnson-Beebout et al., 2009).

A combination of intermittent aeration and strategies to more efficiently use and reduce the use of inorganic nitrogen—such as those proposed through SRI—is likely to lead to larger emissions reductions than is one strategy alone. Deep placement of nitrogen, for example, has been found to reduce nitrous oxide emissions while increasing crop productivity (see, for example, Liu et al., 2015). Importantly, one determining factor with respect to farmer adoption of intermittent aeration practices such as AWD and SRI include the structure of water payment systems. Where farmers do not have to pay for water or pay only a flat fee for the entire season, there is little economic incentive for farmers to adopt the technology. However, where water is more scarce or expensive, or it can only be accessed by pumping water, farmers automatically have an incentive to increase water use efficiency.[28] Other investments for overcoming challenges to the adoption of intermittent aeration practices include: increased on-farm water storage through ponds, tanks, and other catchment structures, as well as irrigation capacity that could be important for providing irrigation water; information communication technologies that provide seasonal weather forecasting and planting date recommendations; and increased farmer education and extension, including farmer field schools, and participatory research projects that can help spread the concept among farmers. Payments for ecosystem services, including carbon sequestration, reduced methane emissions, and protection of local water resources, could also play an important role in increasing the adoption rate and scaling up of AWD and SRI systems.

FIRE-FREE FARMING

An estimated 250 to 500 million farmers practice slash-and-burn agriculture alone (Brady, 1996). In many places, biomass is burned not only to clear the land but also to provide a quick but temporary release of nutrients (phosphorus, potassium, sulfur, calcium, etc.) and a liming effect in soil (especially important in acidic soils in the tropics).[29] Fire can also reduce the weed seed bank and destroy pests and pathogens (Randriamalala et al., 2015). As an agricultural management tool, it is inexpensive, requires little labor, and provides some benefits for soil quality in the short-term (Peters, 2000).

However, as a technique, fire also causes many negative impacts. Slash-and-burn and the burning of crop residues contribute to global emissions of black carbon, as well as of carbon dioxide and nitrous oxide.[30,31] Additional negative impacts on biodiversity can result, and the short-term benefits of nutrient release and liming are offset by long-term declines in soil quality from erosion and loss of organic matter in soils (Kleinman et al., 1995). Addressing emissions from burning of crop residues and forests—particularly in Eastern Europe, where black

28. For example, the study by Kürschner et al. (2010), observes that the irrigation cost benefits only accrued to farmers who used a consumption-based payment system for their water, as opposed to farmers who used a fixed-rate payment system, as the latter were unable to change the fixed amount they had previously set for irrigation, limiting the utility of water-saving practices.

29. Many of these nutrients are quickly leached out of the soil profile, especially in sandy soils with low organic matter content, or, in the case of phosphorus in acidic soils common throughout the tropics, can bind strongly to iron and aluminum hydroxides (a process known as "chelation") making it unavailable for crop uptake and use. The liming effect is usually also temporary. Thus, farmers often have to move or "shift"—hence "shifting cultivation" is another term used for slash-and-burn, to another location to grow crops within three to five years of burning.

30. Globally, it is estimated that conversion of tropical forests to agriculture and pasture, with large portions of this being cleared through burning, is responsible for approximately 10 percent of net annual carbon dioxide emissions (Le Quéré et al., 2018) and as much as 10 percent of global nitrous oxide emissions (a powerful but long-lived greenhouse gas this paper does not examine) (Palm et al., 2004). Emissions of other air pollutants also occur during burning, such as carbon monoxide, nitrogen oxides, sulfur dioxide, non-methane hydrocarbons, volatile organic compounds (Zhang et al., 2011).

31. Another poorly understood source of localized emissions and deforestation is that from "flue-cured" tobacco (as opposed to air-dried "Burley" tobacco) production, which requires the burning of large quantities of wood in kilns or barns. The largest producers of tobacco are, in order of size, China, Brazil, India, the US, Indonesia, Pakistan, Malawi, Argentina, Zambia, and Mozambique.

carbon emissions have a disproportionate impact on Arctic ice melt, and in northern India, Pakistan, Nepal, Tibet, Bhutan, and other countries where black carbon emissions have a disproportionate impact on the Himalayas—may be critical for reducing the likelihood of snow-ice albedo tipping points in the climate system (Ramanathan and Carmichael, 2008).

Alternatives to slash-and-burn and the burning of crop residues can improve human health and livelihoods of farmers while eliminating emissions of black carbon, sequestering atmospheric carbon, and protecting biodiversity, among other benefits. The search for fire-free farming solutions—especially those geared to the tropics—is evolving, with many potential practices and technologies, each having its costs, benefits, and tradeoffs. This paper does not describe all of these in detail. However, it does provide a broad overview of some of the more salient practices and technologies that can help reduce the use of fire in agriculture. Practices such as good soil fertility and pH management, agroforestry, conservation agriculture, and composting provide feasible alternatives to agricultural burning. In many cases, these practices can reduce black carbon emissions while decreasing soil erosion and carbon dioxide emissions from soils associated with intensive tillage, and aid in sequestering carbon in soils (Kassam et al., 2009).

Increased access and affordability of conventional “inorganic” and organic sources of crop nutrients and soil liming agents by farmers is, in many cases, a prerequisite to ensuring soil fertility and shifting away from slash-and-burn and burning of crop residues (Vitousek et al., 2009). Farmers who have access to fertilizer (*e.g.,* manure, compost, urea, or nitrogen, phosphorus, and potassium blends) and agricultural lime (*e.g.*, calcium oxide, magnesium oxide, and magnesium carbonate) no longer need to use fire to provide these inputs. In the case of purchased inputs such as fertilizer or lime, many farmers may simply not have the resources necessary. However, even if they do have the means to purchase, there is still a very significant risk that a large investment could be made to purchase an input—for example, fertilizer—but there is an uncontrollable exogenous impact such as low rainfall or drought, that leads to low production despite the significant investment in crop fertility. In such a situation this could leave the farmer with significant debt or reduced savings (Glover et al., 2012).

Agroforestry—the integration of trees on farms—has also been proposed as a strategy for reducing slash-and-burn agricultural practices (see, for instance, Fischer and Vassuer, 2000), although the use of agroforestry does not necessarily ensure that fire no longer be used as a land-clearing technique, since the two systems are not entirely mutually exclusive (*e.g.,* fire can still be used in mature agroforestry stands in the understory). Palm et al. (2004) found that agroforestry and plantation systems in most cases provided the highest rates of return from a variety of alternative land uses beyond slash and burn agriculture, however it was both place and tree-system dependent. For instance, they found that oil palm plantations in Indonesia were highly profitable, whereas rubber plantations were not as profitable, and that diversified cocoa-fruit agroforestry systems were more profitable than monoculture cocoa plantations due to early harvests and more diversified revenue streams (Palm et al., 2004).

Conservation agriculture encompasses a suite of management strategies that aim to reduce tillage, retain crop residues on the soil surface, and increase crop rotation, practices that may also reduce crop-residue burning. In many cases, conservation agriculture has been found to promote economic benefits and environmental ones, including conserving soil moisture, decreasing runoff from farm fields, and reducing emissions from land preparation and planting. For example, a study of conservation tillage in south and east Africa found that conservation tillage reduces time for land preparation by 65 percent, fuel use and cost for tractor services by 50 percent, and soil disturbance by 85 percent, compared with conventional methods (Aagaard, 2011). However, the yield impacts of conservation agriculture remain widely debated, with recent research showing yield increases in some locations, neutral impacts in others, and declines in yield in many locations (Pittelkow et al., 2015). Challenges related to smallholder farmer adoption of conservation agriculture also include financial, physical, and informational constraints (Brown et al., 2017). One particular issue in discussions of conservation agriculture practices is the use of herbicides, which are sometimes needed for the successful uptake of conservation agriculture, although "organic" approaches to conservation agriculture have also been proposed.[32] Herbicides may help farmers reduce the need to overturn the soil surface with tillage; in addition, they may be able to reduce the labor required for weeding.[33] However, potential drawbacks of herbicide use also need to be carefully weighed. For example, toxicological impacts, including potentially carcinogenic impacts to humans,[34] as well as impacts to biodiversity and air and water quality, need to be carefully considered (Myers et al., 2016). Other potential trade-offs for development may exist as well. For example, in many developing countries, weeding is typically performed with a hoe or by hand and often predominantly by women and children. In some cases, this is paid labor and in other cases it is not. Reducing the need for hand weeding through the uptake of herbicides could therefore decrease the drudgery in the case of uncompensated labor. On the other hand, it could also reduce the income-generation potential in the case in which women are being paid for weeding that is subsequently replaced by herbicide.

32. See, for example, Rodale Institute work on organic no-till using cover crop crimpers. The crimper technology, however, requires a larger tractor and is unlikely to suit many low-input farmers in developing countries. Moreover, there has been very limited uptake of the technology, despite its invention and promotion in the past two decades.

33. Farmers, however, are often not trained properly on the use of herbicides and pesticides and/or may lack the right clothing for application.

34. A recent assessment by the International Agency for Research on Cancer (the WHO specialized cancer agency) considered the most prevalent herbicide—glyphosate—and found that it is "probably carcinogenic." For more information, see http://www.who.int/foodsafety/faq/en/. However, controversy around this finding ensued. See for example, https://www.reuters.com/investigates/special-report/glyphosate-cancer-data/.

Composting is another alternative to burning crop residues, especially in locations where traditionally the practice is to collect, pile, and burn crop residues and weeds in a single location. Farms with sources of concentrated nutrients such as confined livestock or crop wastes are particularly well suited for composting operations. Spreading compost on agricultural fields and pastures has been found to help sequester carbon in soils, potentially improving soil quality and mitigating climate change (Gay-des-Combes et al., 2017).

Despite the suite of benefits that come from adopting fire-free, sustainable agricultural practices, challenges remain to farmers' shift away from slash-and-burn and crop-residue burning, since these are inexpensive and effective techniques. For example, high-investment equipment costs, lack of knowledge and training, and lack of complementary basic inputs can create barriers to adoption (Giller et al., 2009). Farmers, especially those in developing countries, are extremely income constrained and risk averse. In addition, many of the benefits of conservation agriculture have long amortization rates (*i.e.,* payback periods), as it can take three to five years for yield increases and reduced labor benefits to be realized, and many of the benefits, such as decreasing soil erosion, increased water infiltration, and reduced flooding, and carbon sequestration, are externalities for which there is no direct economic benefit to the farmer.

As a result, incentives, subsidies, and other strategies to assist farmers may be needed in addition to regulations and policies that directly address open burning. In addition, promoting fire-free alternatives to slash-and-burn and crop-residue burning requires a deep understanding of the local farming system, since benefits and the potential barriers to adoption can vary by region, crop, and farming system. A good understanding of practical knowledge and cost and benefits of agronomic systems (crop density and spacing, planting dates, and rotations); weed control (likely noxious weed present, extent of weed seed bank, appropriate herbicides, potential weed tolerance to herbicides, etc.); soil management (present soil conditions, fertility requirements for crops of interest, pH management, soil carbon dynamics, and practices to increase soil moisture retention); livestock (pasture and forage requirements, veterinarian services, etc.); and technologies (tractors with necessary horsepower and attachments, oxen- and horse-driven equipment such as rippers, and maintenance and repair of equipment) are all required for making appropriate recommendations and designing effective intervention points (Aagaard, 2011).

CLIMATE-SMART COOLING

Rising temperatures from climate change are going to lead to both acute and chronic heat stress that, like many other climate impacts, will hit the poor the hardest, particularly those living in places with already high temperatures

(Sherwood and Huber, 2010). Demand for refrigeration and air conditioning by the emerging middle class in many developing countries is therefore likely to expand dramatically in decades to come, which in turn may increase emissions of HFCs and other short-lived, high-global-warming-potential pollutants used as refrigerants. In 2015, there were approximately 900 million room air conditioners globally, a figure that is expected to increase to 1.6 billion by 2030 with increasing market demand (Pera, 2018). China provides a case study in increased demand for air conditioners, since the urban areas of the country shifted from practically zero adoption of household air conditioning, in 1992, to nearly 100 percent adoption, in 2007 (Pera, 2018). If similar trends continue in other developing countries, HFC emissions will likely have a significant impact on the climate system.

A large portion of HFC emissions could be reduced by using climate-friendly alternatives to HFCs such as ammonia, carbon dioxide, and hydrofluoroolefins. In October 2016, countries adopted the Kigali Amendment to the Montreal Protocol. This agreement provides a timetable for the phase-down of HFCs in favor of adopting alternatives, and could prevent an estimated $0.5^{o}C$ of warming by 2100 (UNEP, 2016). It is estimated that the Kigali Amendment will avoid 80 billion tons of carbon dioxide equivalent by 2050 (which is an important achievement), but will only reduce about two-thirds of total HFC emissions from 2019–2050 (UNEP, 2017). Thus, even with full implementation of the Kigali Amendment, there is significant work to be done to reduce the remaining one-third of estimated emissions.

Although much of the effort to reduce HFC emissions directly will be borne by countries agreeing to international agreements and regulating refrigerants, and by companies willing to develop climate- and ozone-safe HFC alternatives, there may be opportunities for development organizations and institutions to address HFCs, as well. This includes considering means of vaccine refrigeration in the health fields and cold-storage temperature-controlled supply chains in the agricultural and food sectors that may be first adopters of HFC alternative refrigerants.[35] In addition, one development-oriented, pro-poor strategy for reducing HFC emissions is to reduce or eliminate the need for cooling entirely through alternative strategies.

There are a number of climate-smart, complementary strategies that can help reduce the need for and improve the efficiency of air conditioning. For example, in addition to working to phase out HFCs for window air conditioning units, one part of the Kigali Amendment (the Kigali-Cooling Efficiency Program), will also be

35. Many developing countries could benefit from the use of refrigerator trucks and cars, reefer ships and containers, and refrigerated warehouses. New methods for tracking cold storage supply chains, such as temperature data loggers and radio-frequency identification tags, can remotely monitor transport and warehousing to ensure product safety and shelf life. This would help reduce post-harvest food waste, which is as high as 30–40 percent in many developing countries (Godfray et al., 2010) and responsible for a significant amount of greenhouse gas emissions, including methane (IPCC, 2013).

investing in delivering efficient cooling through urban design, more efficient buildings, shades, fans, and other less technical, but nevertheless potentially important cooling strategies. Cool roofs, reflective pavement, shading, proper building design, trees, green roofs, and climate-smart urban planning can reduce the risk from heat waves in addition to providing development benefits. Here we focus primarily on several of these complementary strategies: cool roofs, reflective pavements, and urban tree planting, which can help reduce localized warming by using highly reflective surfaces to reduce heat gain and provide evaporative cooling.

Many poor households in both rural and urban settings live in homes that are of inferior quality, constructed of low-quality materials, too small to be comfortable and safely accommodate households, and lacking running water, electricity, sanitation, insulation, and security. Many are extremely vulnerable in cases of extreme weather events, particularly in places subject to high winds and hurricanes (see, for example, the impact of the 1998 Hurricane Mitch on rural poor people in Honduras: Morris et al., 2002). Moreover, many houses have inadequate roofs, which can lead to inconvenience, water leakage into the home, possible health issues from excess moisture and, in the case of rainwater that forms pools around the house, an increase in the likelihood of insect-borne disease such as malaria.

An integrated, systematic approach to upgrading the housing infrastructure of both urban and rural poor people could package together, where appropriate, the installation of high-quality reflective cool roofs with built-in insulation, rainwater catchment for household use, proper sanitation facilities, outdoor or screened kitchens with good ventilation and a flue or chimney to remove air pollutants from the house, running water, solar installations, and other design components. The benefits to human health and well-being of upgrading housing are promising, though limited. For instance, a study of improved housing infrastructure in slum dwellings in El Salvador, Mexico, and Uruguay, for example, found that better housing had a positive correlation with general well-being, happiness, and quality of life. In two of the three countries, there was also a statistically significant correlation with improved children's health (Galiani et al., 2017).

Many countries also lack adequate paved roads, which also leads to a myriad of problems, including dust inhalation, pooling of water, and inefficient transportation, which can decrease productivity and income generation by, for example, making it more difficult for rural farmers to move their crops and livestock to urban markets. Paved roadways can lead to significant economic benefits for households. For example, a study in Mexico found that "within two years of the intervention, households are able to transform their increased property wealth into significantly larger rates of vehicle ownership, household appliances, and home improvements. Increased consumption is made possible by both credit use and less saving. A cost-benefit analysis indicates that the valuation of street asphalting as capitalized into property values is about as large as construction costs" (Gonzalez-Navarro, 2016). The conventional solution would be to use traditional asphalt paving surfaces, which would exacerbate heat island impacts. Cool pavement surfaces could be deployed to help solve the lack of paved surfaces without the problems associated with conventional paving technologies.

In terms of the climate benefits of implementing cool roofs and reflective pavement, one study found that approximately 57 billion tons of CO_2-equivalent emissions could be avoided globally if urban areas uniformly adopted a cool-roof program (Menon et al. 2010). If it is assumed that roofs have a 20-year lifetime, the emissions reduction rate would be equivalent to reducing emissions by approximately 1 billion tons of CO_2-equivalent per year, or around 3 percent of global carbon dioxide emissions (Menon et al., 2010). Although the overall climate benefit is relatively small, cool roofs could be implemented fairly quickly and provide important co-benefits, especially for reducing the "urban heat island" effect in many developing countries at risk of high levels of warming.

Similarly, urban tree planting can quickly, efficiently, and cost-effectively reduce urban heat island effects while sequestering carbon from the atmosphere (McPherson et al., 2016). In addition to providing habitat for other organisms and aesthetic benefits, trees and other vegetation cool the air by providing shade, through evapotranspiration, and by creating increased surface roughness, which increases convection processes. Shade and evapotranspiration can decrease summer temperatures by between 1 to 5°C and, when placed correctly, can dramatically reduce the need for cooling buildings.[36] One study found that, on average, tree planting and care returns the net of $5.82 for each dollar invested (McPherson et al., 2016).

UN Habitat has declared that "housing is an opportune and strategic setting through which achievement of mutually beneficial goals of climate change mitigation and adaptation, as well as of sustainable urban development in general, is feasible. The planning of residential areas, slum upgrading and urban renewal will help reduce the ecological and carbon footprint of cities and the greenhouse gasses of the national building sector."[37] Yet, to date, more efficient and sustainable urban and rural planning, housing, and infrastructure have generally been implemented unsuccessfully in developing countries due to a variety of factors.[38] Challenges to implementation include financing, inclusive planning, and coordination with local and national governments. Development organizations and institutions could play an important role not only in helping improve housing and infrastructure but also doing so in a climate-smart way.

36. http://www.epa.gov/heatislands/mitigation/trees.htm

37. https://unhabitat.org/urban-themes/housing-slum-upgrading/

38. *E.g.,* http://citiscope.org/habitatIII/commentary/2016/08/developing-countries-face-catastrophic-lack-urban-planning-capacity

DISCUSSION

Combatting poverty in the 21st century requires that practitioners undertake a full accounting of development and climate change issues in both their problem assessment and solution design processes. Without this, the effectiveness of policies and programs that are implemented may be jeopardized, or the potential maximum benefit to target constituencies may go unrealized. As we have shown, SLCP mitigation measures provide a useful entry point for undertaking "climate-smart development" and addressing poverty. Activities that reduce SLCP emissions can directly and indirectly improve human health and crop yields, promote the better management of natural resources, create economic opportunity, and contribute to gender equality and female empowerment, among other benefits.[39] In addition, because many SLCP impacts are localized, the benefits derived from measures that reduce SLCP emissions are likely to accrue locally as well. In middle- and low-income countries, this often means that poorer households and communities, which are in many cases at greater risk and more exposed to SLCP and other air and climate pollution, receive the greatest benefit. On a global scale, actions to rapidly reduce SLCPs, implemented alongside decarbonization efforts, would also help slow the rate of global warming, providing indirect benefits for poor and vulnerable communities everywhere. Therefore, governments, financial institutions, and non-governmental organizations could get significant return from supporting and adopting policies and measures that can achieve development outcomes while reducing SLCPs.[40] Development organizations and institutions that are engaged in direct service delivery and/or advocating for policy change to ensure effective delivery of services are particularly well positioned to emphasize the importance of addressing SLCPs for both development and climate reasons and bring forward innovative emissions-reductions efforts that support the poor.

However, realizing a well-resourced development program that advocates or provides for SLCP mitigation solutions that benefit people both now and in the future likely requires significant investments of both time and resources to assess and adapt solutions for particular pollutants and contexts; and such efforts take time. Nevertheless, as the results of this paper suggest, the benefits may be well worth the effort. A starting point for governments, financial institutions, and development organizations and institutions that wish to integrate SLCP mitigation and development/poverty alleviation considerations effectively requires

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39. It should be noted that identifying links between SLCP mitigation and development should be done with caution, given that the multiple dimensions of development are often difficult to 'unpack', particularly with respect to causality. In addition, development outcomes are often location - specific and time -bound, and it may not be appropriate to extrapolate findings to other jurisdictions.

40. These actions should be taken alongside compleimentary decarbonization actions when possible and appropriate (http://www.ccacoalition.org/en/resources/what-role-short-lived-climate-pollutants-mitigation-policy).

addressing issues in at least two broad categories of actions: project and program technical design and strategic alignment.

A full assessment of the former is beyond the scope of this initial review and generally would be most relevant to those entities engaged in direct service delivery and program development. Briefly, however, as this research review suggests, practitioners can seize opportunities to achieve mutual benefits for SLCP mitigation and poverty alleviation in their project design. However, notable challenges and trade-offs at the individual, community, and/or national level (those identified in this report and others) are also likely to arise for any given mitigation measure and development strategy. These should be fully considered as part of planning and discussed with relevant stakeholders. In addition, this is an area ripe for additional research and analysis. For example, a useful contribution might aim to document best practices for development projects with an implicit or explicit SLCP mitigation component based on empirical evidence drawn from a range of implementation contexts. More research that assesses community-level, equitable development and/or poverty-alleviation interventions and explicitly considers climate "co-benefits" (*e.g.,* Mayne, 2016) including SLCP-specific ones, would be helpful especially at the regional or project level. In addition, climate-change-oriented studies that assess SLCP mitigation interventions could put greater emphasis on identifying and quantifying the direct and indirect social and economic impacts for human well-being at a national, sub-national, and local level.

For the latter—that is, improving the strategic alignment of poverty alleviation and climate-change-mitigation goals and supporting a climate-compatible development agenda that mainstreams SLCPs—there are several important initial considerations (and associated challenges) worth noting. These include:

- **Finding a common language.** *Development practitioners should work with climate change practitioners to find a common language that can speak appropriately to the beneficiary communities but can also engage multiple stakeholders around shared goals.*

  In many cases, it is likely not an insignificant step to get development practitioners to recognize climate-change-mitigation strategies—particularly those that reduce SLCP emissions—as complementary to service delivery and policy advocacy activities that seek to achieve poverty alleviation goals. The SLCP mitigation-poverty linkages and selected mitigation measures we have discussed affirm that actions to reduce SLCPs across a range of sectors can help reduce poverty and improve people's lives. And as with efforts to build climate change resilience, there are, of course, development organizations that are already taking advantage of these synergies and supporting climate mitigation (and even SLCP mitigation). However, because poverty alleviation and development activities are often characterized using a lexicon that is different from the one that is familiar to climate change practitioners, this can limit broader ownership and support. For example, helping smallholder rice farmers adopt water-saving practices may be labeled a rural livelihood resiliency project rather than a methane mitigation one; or a clean cookstoves program might focus on women's empowerment and economic opportunity rather than black carbon mitigation. Of course, the reverse is also true: climate and clean air communities often pursue measures that have significant benefits for people, yet prioritize articulating outcomes in terms of metric tons of emissions reduced and dollars saved.

Although development and climate change communities have historically used different language to frame problems and solutions, SLCP mitigation presents a compelling opportunity for collaboration that reaches across various theories of change and desired outcomes. This requires both communities to step outside their own worldview and lexicon to find ways to speak across development and climate agendas. Importantly, despite the recent success of the Climate and Clean Air Coalition and others in raising awareness of SLCPs, and their importance for both development and poverty and climate change issues, one need not make SLCP jargon the focus of specific interventions to enable SLCP mitigation. Instead, seek to find language that can help build a multidisciplinary agenda.

- **Capacity building and empowerment.** *Development practitioners should invest in growing and maintaining targeted stakeholders' technical and social capacities. Areas for focus could include, among others: operational structures; data and information collection; sharing of best practices and challenges across disciplines; and enhancing the institutional and governance systems that enable beneficiaries to have power and a voice in the design and deployment of initiatives at the nexus of development and climate change mitigation.*

  "Capacity building" is a central focus for both development- and climate-oriented organizations. But the term can mean many different things, from a one-off training workshop to the establishment of a long-term post in a single community to provide health services, for example, to improving governance policies or the "enabling environment" in an effort to create additional opportunities for citizens. Particularly in poor or underserved communities, capacity building is often necessary, but it requires thoughtful consideration to ensure that interventions are ultimately constructive and aligned with the interests of the benefitting community, as well as, in many cases, sustained investments. Addressing the dual challenges of poverty and SLCPs provides an opportunity to take stock of existing capacity-building structures and programs to assess whether they are fit for purpose and make improvements.

  In this way, agencies within the same government, organization, or institution that focus on development, climate change, finance, agriculture, and air quality, etc., sometimes do not communicate effectively. As a result, they run the risk that activities will remain ineffective, siloed, or, worse, that they will undermine each other. Aligning institutions to address both development and climate change more ably can lead to a leveraging of synergistic benefits. In addition, actions that address SLCPs frequently require and benefit from the engagement of a diverse array of stakeholders (*e.g.,* farmers, governments, the private sector, academia, the public health community, non-government organizations, development banks, and others). This is because they can provide good impetus for ensuring cross-institutional collaboration, even when associated climate mitigation benefits are not a priority. For example, a first step may be to identify existing development programming that could be "enhanced" with climate change mitigation objectives and expertise—for example, taking black carbon emissions (in addition to health and fuelwood harvesting) into consideration when deploying cookstoves, or working with small-scale rice farmers to adopt resiliency practices that also result in methane reductions through increased water use efficiency. In addition to achieving better development outcomes, such approaches can also support the desire to achieve the goals of the Paris Agreement.

Alongside revisions to institutional structures, improved or expanded data collection and analysis, particularly at the national and sub-national level, can help bridge poverty alleviation and climate change mitigation goals. For example, properly incentivizing SLCP mitigation measures requires a quantification of those measures' impacts at development-relevant scales: household, community, and national levels. Establishing better baseline data relevant to SLCP emissions and their links to development and poverty alleviation is essential to ensuring real world benefits and securing financing. Another important area of research is generating more data that can elucidate the ways in which poverty alleviation and SLCP mitigation can affect genders differently.

Empowering development (and climate) practitioners to become conversant in multiple disciplines is arguably essential if new SLCP mitigation practices or policies are to be championed and implemented. One example of cross-disciplinary capacity building is the Supporting National Action and Planning on SLCPs (SNAP) initiative of the Climate and Clean Air Coalition.[41] SNAP supports integrated national planning on air quality and climate through the development of integrated analysis tools that consider benefits from policy actions such as avoided premature deaths and crop losses.[42] SNAP also seeks to facilitate the regular sharing of policy and project implementation success stories, as well as discuss relevant challenges. Both efforts provide

41. http://www.ccacoalition.org/en/initiatives/snap

42. See the LEAP-IBC model factsheet: http://www.ccacoalition.org/en/resources/factsheet-long-range-energy-alternatives-planning-integrated-benefits-calculator-leap-ibc

more nuances to stakeholder discourse on SLCP mitigation and give greater local-to-national ownership to governments, organizations, and institutions seeking to achieve goals related to the Paris Agreement and/or the SDG agenda.

Finally, despite the technical nature of many of the measures we put forward to achieve development benefits through SLCP mitigation (*e.g.,* clean cookstoves, SRI or AWS, fire-free farming practices, cool roofs), we must not overlook the importance of ensuring beneficiaries have sufficient power and voice. For example, changing cultural norms—a frequently noted challenge in this review, particularly among poor and smallholder farmers—requires that targeted groups play an active role in decision-making and ownership of proposed interventions and that capacity building includes a focus on ensuring governance structures are just and supportive of their rights. Ignoring systemic social and economic capacity-building failings is a threat to all development and climate interventions, including those focused on mitigating SLCPs and poverty.

- **Ensuring effective financing.** *Development practitioners should identify the financial costs to ensure that SLCPs are considered (monitored and/or reduced) as part of a particular development intervention and advocate for funders and donors and support win-wins for poverty and climate change.*

  Financing is one of the primary obstacles to substantially reducing SLCP emissions (Frankfurt School-UNEP, 2016). Although some measures to reduce SLCPs are rational from a purely economic perspective—capturing and combusting methane, for example—there are many measures—reducing open burning, for example—that are not. The problem of open burning is unlikely to have a market-based solution. For other measures, the upfront investment costs are too high or amortization rates (*i.e.,* payback periods) too long for most private companies to consider them a sound investment opportunity. In addition, the financing and scaling up of mitigation measures or technologies may differ considerably based on geography, sector, project size, and SLCP targeted. Further, one of the chief challenges is that the negative impacts SLCPs have on food security, public health, and climate stability are largely externalized in terms of their economic valuation, and there is therefore no direct economic incentive to reduce SLCP emissions within the marketplace. Finally, even if these economic barriers were addressed, additional socioeconomic, policy, regulatory, and information access barriers exist, which could in turn limit financing viability (Frankfurt School-UNEP, 2016).

  A recent report commissioned by the CCAC provides suggestions for addressing financing challenges (financial and non-financial) across several SLCP-relevant sectors (Frankfurt School-UNEP, 2016). Proposed solutions include a finance innovation facility that could help identify and remove financial and market barriers to encourage greater investment in SLCP mitigation. Importantly, however, it also identifies the role development organizations and donors could play in helping to scale up SLCP mitigation projects through concessionary funding and innovative financing mechanisms. This suggests an opportunity to use finance as a means to align poverty alleviation and SLCP mitigation imperatives more closely. For example, although public finance, particularly in developing countries, may be insufficient to cover initial investment costs for SLCP mitigation, non-governmental support and the donor community could provide both the technical skills and marginal cost financing to ensure that government-supported development initiatives fully consider opportunities for SLCP mitigation as well. SLCPs additionally offer an opportunity for developed countries (who must aim to achieve zero emissions well before mid century) to target funding and technological support for developing countries.

To be clear, different investment strategies will be required for the various types of investments that reduce SLCPs. For instance, investment in clean cookstoves may be addressed through a combination of microfinancing in which the beneficiaries cover the costs and subsidy. Larger projects may require significant public-private partnerships. One of the most intriguing options for reducing SLCPs may be a carbon tax that either includes a price on SLCPs (*i.e.,* internalizing the public health, food security, and/or climate costs of SLCP emissions) and/or a mechanism by which some of the tax revenues are used to support SLCP-emissions-reduction measures. Donors, aid organizations, and philanthropy should seek to ensure that programs are compatible with a changing climate and climate stabilization goals given the many types of funding needed to achieve the development benefits of SLCP mitigation.

The results of this initial review suggest that development organizations and institutions that want to ensure that their work aligns with advancing climate change solutions would do well to consider targeting SLCP mitigation as part of their strategy. SLCPs are arguably an excellent focal point for developing cross-disciplinary strategies and breaking down existing silos (between development and climate spaces, as well as climate mitigation and resilience/adaptation spaces). Although significant barriers to action on SLCPs remain, there are also untapped opportunities for more effective implementation of actions that support poverty alleviation and address climate change; more work is needed to test, quantify, and scale these solutions. Certainly there is no one-size-fits-all approach—the appropriateness, feasibility, and affordability of integrated solutions will need to be evaluated given the specific context. But a first step is to consider how current development-oriented interventions and activities can also result in SLCP emissions reductions; these may be especially relevant to sectors such as agriculture and food and residential energy. Some development organizations may be well positioned to carry out their own integrated SLCP mitigation-development activities as part of service delivery programs. Others may be better served by incorporating SLCP mitigation into their awareness raising and policy advocacy strategies, putting pressure on governments, financial institutions, and/or companies to: ensure coordination between development and climate goals; target, resource, and take credit for development and climate mitigation win-wins; and ensure responsible and sustainable service delivery through public policy or technological innovation.

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