nature climate change

PERSPECTIVE

https://doi.org/10.1038/s41558-017-0012-x

Corrected: Author correction

Short-lived climate pollutant mitigation and the Sustainable Development Goals

Andy Haines[1,2*], Markus Amann[3], Nathan Borgford-Parnell[4], Sunday Leonard[5], Johan Kuylenstierna[6] and Drew Shindell[7]

The post-2015 development agenda is dominated by a set of Sustainable Development Goals (SDGs) that arose from the 2012 Rio+20 United Nations Conference on Sustainable Development. The 17 goals and 169 targets address diverse and intersecting aspects of human and environmental needs and challenges. Achieving the SDGs by 2030 requires implementing coordinated and concerted strategies and actions that minimize potential trade-offs and conflicts and maximize synergies to contribute to multiple SDGs. Measures to mitigate emissions of short-lived climate pollutants are an example of actions that contribute to multiple outcomes relevant to development. This Perspective highlights the interlinkages between these pollutants and the SDGs, and shows that implementing emissions reduction measures can contribute to achieving many of the SDGs.

Short-lived climate pollutants (SLCPs) are agents that contribute to warming but have relatively short lifetimes in the atmosphere—a few days to a few decades. Consequently, harmful concentrations of SLCPs can be reduced in a matter of weeks to years. Many SLCPs are also powerful air pollutants that are significant contributors to premature death and chronic illness globally, and they also harm the environment. The main SLCPs and their approximate atmospheric lifetimes are black carbon (days), tropospheric ozone (weeks), methane (12 years), and hydrofluorocarbons (HFCs; 15 years). Control of SLCPs, together with urgent efforts to decarbonize the global economy within the limits of cumulative CO_2 emissions[1], are necessary to keep the world on a path to achieving long-term climate targets while simultaneously providing near-term benefits for health, development and the climate[2,3].

Interlinkages between goals

A number of recent studies have identified specific technical and policy measures that, if implemented globally, can achieve multiple benefits by reducing emissions of SLCPs and their co-emitted pollutants[4–10]. The various SLCP emissions reduction measures and potential impacts of these measures on the SDGs, including the potential for trade-offs and conflicts[11], are outlined in Table 1. Selected examples are discussed below.

Goal 1: no poverty. SLCP measures can indirectly contribute to target 1.1 to halve poverty, for example, by reducing household expenditures on energy. The poorest and most vulnerable members of society are often the most dependent upon dirty and polluting fuels to supply their basic cooking, heating and lighting needs. They often spend a substantial percentage of their income purchasing these fuels or significant time collecting fuels, reducing time for income-generating activities (Goal 8). Measures to address HFCs, to supply modern efficient cooking and heating stoves, and to replace kerosene lamps with modern lighting can improve household incomes by reducing energy costs[12] (Goal 3). SLCP measures can also indirectly benefit Goal 1 by reducing vulnerability and near-term impacts of climate change (see Goal 13), improving public health (Goal 3), supporting food security and farm incomes (Goal 2), driving innovation and job creation (see Goal 8), and reducing gender inequalities (Goal 5).

Goal 2: zero hunger. By 2030, SLCP mitigation can avoid the loss of over 50 million tonnes of four staple crops annually—maize, rice, soybean and wheat—from exposure to ground-level ozone concentrations[9] (Fig. 1). Ozone is the major cause of crop yield loss from air pollution, and could reduce global yields of these four staple crops by 3–16% (ref. [13]). Thus, SLCP measures contribute to target 2.3, which aims to double agricultural productivity and incomes of small-scale food producers.

Ground-level ozone can also alter the nutritional value of some plants and vegetables[14,15], impacting targets 2.1 and 2.2, which aim to end hunger and malnutrition. For example, decreased pasture quality in terms of the metabolizable energy content of the vegetation can lead to a potential total reduction in lamb production. In the UK this could amount to approximately a 4% reduction in 2020 compared to 2007 (ref. [14]), resulting in reduced income generation (Goal 1). Improvements in refrigeration energy efficiency through HFC measures can also contribute to targets 2.1 and 2.2 by increasing the affordability of refrigeration and reducing food waste (target 12.3). Furthermore, measures such as intermittent aeration of continuously flooded rice paddies, farm-scale anaerobic digestion of manure from cattle and pigs, and banning of open-field burning of agricultural waste, can contribute to target 2.4 by improving sustainable agricultural production[16].

Finally, climate change is projected to adversely impact crop yields, particularly in low latitude regions through changes in temperature and rainfall patterns[17]. SLCP strategies lead to higher crop yields through reduced ozone concentrations and warming

[1]Department of Social and Environmental Health Research, London School of Hygiene and Tropical Medicine, London, UK. [2]Department of Population Health, London School of Hygiene and Tropical Medicine, London, UK. [3]International Institute for Applied Systems Analysis, Laxenburg, Austria. [4]Climate and Clean Air Coalition, United Nations Environment, Paris, France. [5]Climate and Clean Air Coalition, United Nations Environment, Paris, France. [6]Stockholm Environment Institute, Environment Department, University of York, York, UK. [7]Nicholas School of the Environment, Duke University, Durham, NC, USA. *e-mail: andy.haines@lshtm.ac.uk

Table 1 | SLCP mitigation measures identified by UNEP and WMO (ref. [4]); Xu et al. (ref. [6]) and Carvalho et al. (ref. [7]), with assessment of possible trade-offs and conflicts between different SDGs and their targets

	Selected SLCP reduction measures	Development goals and targets benefitted	Potential for trade-offs and conflicts
Methane measures			
		Achievement of Goal 2 (zero hunger) and Goal 3 (good health and well-being) will benefit from reduced ozone air pollution	
		Goal 13 benefits from reduced climate forcing. In addition, specific targets benefitting are listed below	
1	Pre-mine degasification and recovery, and oxidation of methane from ventilation air from coal mines	Goal 7.1: ensure universal access to affordable, reliable and modern energy services	No significant trade-offs identified
		Goal 8.4: improve progressively global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation	
		Goal 8.8: promote safe and secure working environments	
		Goal 9.2: promote inclusive and sustainable industrialization	
		Goal 9.4: upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency	
		Goal 12.4: achieve the environmentally sound management of chemicals and all wastes throughout their life cycle	
2	Recovery and utilization of gas and unintended fugitive emissions during oil and gas production	Goal 7.3: double the global rate of improvement in energy efficiency	No significant trade-offs identified
		Goals 8.4, 9.2, 9.4 and 12.4	
3	Reduce leakage from long-distance natural gas transmission pipelines and distribution systems	Goals 7.3, 8.4, 9.2, 9.4 and 12.4	No significant trade-offs identified
4	Separation and treatment of biodegradable municipal waste and landfill gas collection	Goals 7.3, 8.4, 9.4 and 11.3: enhance inclusive and sustainable urbanization	No significant trade-offs identified
		Goal 11.6: reduce the adverse per capita environmental impact of cities	
		Goal 12.4	
5	Upgrade wastewater treatment with gas recovery and overflow control	Goal 6.3: improve water quality by reducing pollution, halving the proportion of untreated wastewater and substantially increasing recycling and safe re-use globally	No significant trade-offs identified
		Goals 9.2, 9.4, 11.3, 11.6 and 12.4	
6	Livestock anaerobic digestion (cattle and pigs)	Goal 2.4: ensure sustainable food production systems and implement resilient agricultural practices that increase productivity	No significant trade-offs identified
		Goals 7.1, 8.4, 9.2, 9.4 and 12.4	
7	Intermittent aeration of continuously flooded rice paddies	Goals 2.3, 2.4 and 12.4	There may be trade-offs between N_2O emissions and CH_4 emissions, depending on rice paddy water-management practices
Black carbon and co-pollutant measures			
		Goals 2 and 3 both benefit from reduced black carbon pollution	
		Goal 13 benefits from reduced climate forcing	

Continued

Table 1 | (continued)

	Selected SLCP reduction measures	Development goals and targets benefitted	Potential for trade-offs and conflicts
8	Improve diesel vehicle emission standards (EURO VI) and diesel particulate filters (DPF) for on-road and off-road vehicles	Goal 1.4: ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, new technology and so on	DPF reduces vehicle efficiency and hence increases CO_2 emission slightly, but is offset by more efficient modern engine technology (EURO VI). Electric and hybrid vehicles bring additional air pollution and CO_2 emission benefits
		Goal 3.4: reduce by one third premature mortality from non-communicable diseases through prevention	
		Goal: 3.9: substantially reduce the number of deaths and illnesses from hazardous chemicals and air pollution	
		Goal 11.2: provide access to safe, affordable, accessible and sustainable transport systems for all	
		Goal 11.6	
9	Replace traditional cooking and heating stoves with clean-burning modern fuel stoves	Goal 1.1: eradicate extreme poverty for all people everywhere	Replacing solid fuels with LPG results in minor CO_2 emissions, but in areas where fuel-wood collection reduces C stores in forests, the difference from using fuel-wood is likely to be minimal
		Goals 1.4 and 3.2: end preventable deaths of newborns and children under 5 years of age	
		Goals 3.4, 3.9 and 4: ensure inclusive and equitable quality education	
		Goal 5.2: eliminate all forms of violence against all women and girls	
		Goal 5.5: Ensure women's full and effective participation and equal opportunities for leadership	
		Goals 7.1, 7.3, 11.1, 11.6 and 15: promote the implementation of sustainable management of all types of forests, halt deforestation and so on	
10	Eliminate high-emitting on-road and off-road diesel vehicles	Goals 1.4, 3.4, 3.9, 11.2 and 11.6	See DPF discussion. Potential financial barriers to purchasing cleaner vehicles may increase inequities.
11	Replace traditional brick kilns and coke ovens with modern high-efficiency technologies	Goals 3.4, 3.9, 7.3, 8.4, 9.2 and 9.4	No significant trade-offs identified
12	Ban open-field burning of agricultural waste	Goal 2.3: double the agricultural productivity and incomes of small-scale food producers	Some increase in pests, but outweighed by increase in organic matter in soils
		Goals 2.4, 3.4 and 3.9	
13	Replace kerosene wick l amps with modern clean lighting technologies	Goals 1.1, 1.4, 3.2, 3.4, 3.9, 7.1 and 11.1: ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums	Higher initial purchasing cost for solar lighting, but cost over longer term is lower
		Goal 11.6	
14	Eliminate gas flaring	Goals 3.9, 9.2 and 9.4	
15	Promote active travel	Goals 1.1, 3.4, 11.2 and 11.6	May be some increase in road injuries but health benefits of increased exercise are greater[9]. Improved road-safety policies can minimize trade-offs

Continued

Table 1 | (continued)

	Selected SLCP reduction measures	Development goals and targets benefitted	Potential for trade-offs and conflicts
16	Promote healthy diets	Goals 1.4, 3.4 and 12.3	Some communities, for example pastoralists, depend on livestock for nutrition and livelihoods and need special consideration to avoid conflicts between SDGs. Children may benefit nutritionally from consumption of animal products
HFC measures			
		Goal 2 (through improved refrigeration) and Goal 13	
17	Simultaneously replace high-GWP HFCs with low-impact alternatives and super-efficient appliances and equipment	Goals 1.1, 7.1, 7.3, 8.3, 8.4, 11.1, 11.6, 12.3 and 12.4	No significant trade-offs identified

Other measures as identified in other publications include eliminating kerosene wick lighting[8], reducing black carbon from flaring in oil and gas facilities[10], and supporting active travel aided by rapid mass transit and promoting healthy diets[9].

(Goal 13), and SLCP measures appear to offer greater potential benefits compared with CO_2 reduction during the next several decades[4,17]. These SLCP measures, however, do not serve as an effective alternative to CO_2 reduction for mitigating climate change and its impacts over the longer term, where cumulative CO_2 emissions are the most important factor.

Goal 3: good health and well-being. Outdoor (ambient) and household fine particulate matter ($PM_{2.5}$) air pollution is a major source of ill-health globally and is estimated to be responsible for 5.5–7 million premature deaths annually caused by strokes, heart disease, lung cancer, chronic obstructive pulmonary disease (COPD), and acute lower respiratory infections (ALRI)[18–20]. SLCP measures such as reducing diesel engine emissions, and increasing use of clean public transport, together with active travel (walking and cycling), can directly and indirectly improve public health by reducing outdoor air pollution exposure and increasing physical activity[9]. SLCP measures can contribute directly to achieving target 3.9 to reduce the numbers of deaths from pollution by preventing around 2.4 million deaths related to outdoor air pollution annually by 2030 (refs [4,5]).

Millions of additional lives can potentially be saved by reducing sources of household air pollution (HAP). Globally, close to 3 billion people still rely on traditional cooking and heating methods using solid biomass and fossil fuels and many millions rely on kerosene wick lamps, which are major sources of black carbon and HAP[8,21]. Due to their traditional household responsibilities in many cultures, women and children suffer from a higher level of exposure to HAP, in comparison to men. Approximately 60% of HAP-related deaths globally occur in women and children (Goal 5) including more than half of all pneumonia deaths in children under the age of 5 years (ref. [21]). Measures to reduce HAP can thus contribute to target 3.9 and target 3.2 (ending preventable deaths of newborns and children under 5 years of age) as well as target 3.4, to reduce premature mortality from non-communicable diseases (NCDs).

Finally, adopting diets that conform to WHO guidelines can reduce methane emissions, while also improving health—through reduced NCD risks (target 3.4)—largely due to increased consumption of vegetables, fruit, nuts and seeds and decreased consumption of animal products (particularly red and processed meat) in high-consuming populations[22]. Dietary change and reduction in food waste can also reduce emissions from CO_2 and N_2O.

Goal 4: quality education. A number of SLCP measures can indirectly support Goal 4 by reducing poverty, HAP, improving public health, and increasing education opportunities[23]. Access to modern energy and lighting is important to support education. Clean cooking and heating measures can increase time for education, particularly for girls (see Goal 5), by reducing time spent collecting fuel; these and HFC measures can also support educational opportunities by reducing household fuel costs and supporting poverty reduction (Goal 1). School-aged children also suffer from a high burden of ill-health due to HAP (Goal 3), which contributes to missed school days (as does ambient air pollution) and lowered educational outcomes.

Eliminating kerosene for lighting can indirectly support education by reducing household fuel costs, and also directly by improving the quality of light available for studying[23]. A typical kerosene wick lantern produces 0.7% of the illumination recommended for reading and as little as 0.1% of the light produced by an equivalent LED lantern[24].

Goal 5: gender equality. Women and children are often responsible for fuel collection. This limits time available to engage in income-generating activities (Goals 1 and 8), or in the case of children, to focus on education (Goal 4). This also places them at greater risk of injury or gender-based violence outside the home[25]. For these reasons, measures to provide modern cooking, heating, and lighting can benefit target 5.2 by reducing violence against women and target 5.5 by affording greater opportunities to participate equally in political, economic, and public life.

Goal 6: clean water and sanitation. SLCP measures could help improve water availability and quality for the estimated 663 million people lacking access to improved drinking water sources globally and at least 1.8 billion people without reliable access to potable water[26]. For example, in areas where sewerage and wastewater treatment infrastructure is already in place, upgrading secondary and tertiary sewerage and waste treatment to collect and utilize methane can support target 6.3 to halve the proportion of untreated wastewater. Using composting toilets may produce much lower methane emissions than pit latrines and can be economically competitive with other methane measures in organic waste sectors[27].

SLCP measures can also improve access to water resources by increasing rainfall in regions where drought and water shortages are

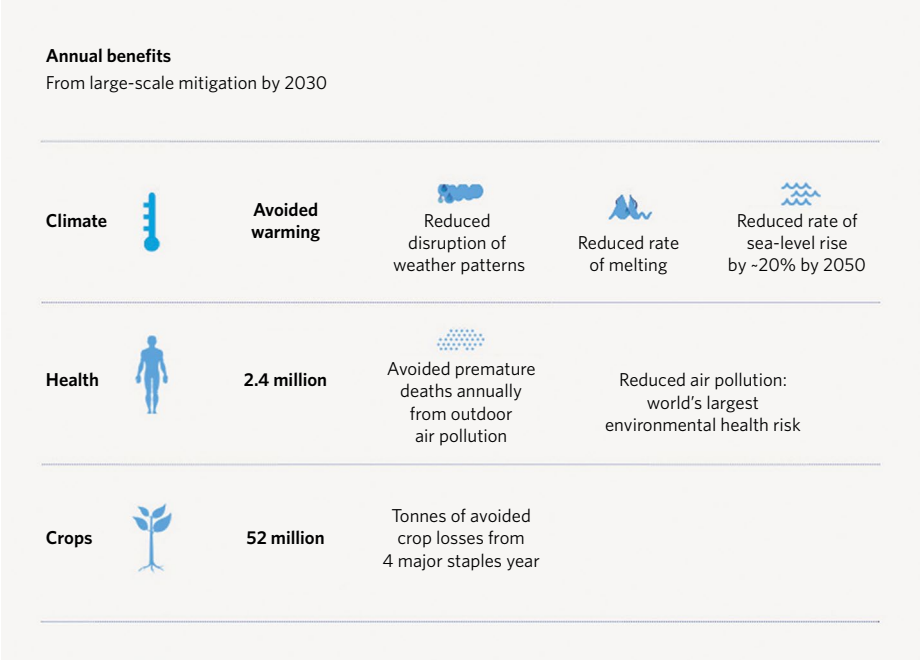

Fig. 1 | Estimated annual benefits by 2030 from SLCP mitigation. Adapted with permission from ref. [44].

projected to occur[28], or where black-carbon-loaded pollution causes a significant shift in the distribution of rainfall towards heavier downpours[29].

Goal 7: affordable and clean energy. SLCP mitigation measures offer numerous opportunities for improving energy access. For example, the recovery and utilization of methane from coal mines, from the oil and gas sector, and landfills and wastewater treatment plants offers alternative fuels for energy generation, and contributes directly to target 7.1 on ensuring universal access to modern energy, while also contributing to resource-use efficiency (Goal 12). This will also contribute to income generation (Goal 8); one estimate suggests that about US$30 billion per year in revenue is lost worldwide due to methane leakage from oil and gas facilities[30].

Many SLCP measures also directly contribute to target 7.3 to double global energy efficiency. Measures to modernize brick kilns, coke ovens, and introduce clean cooking and heating alternatives all improve facility and equipment efficiency. Furthermore, simultaneous transitioning to low global warming potential (GWP) refrigerants along with mechanical improvements in energy efficiency in room air conditioning could save between 340 and 790 GW of peak power load globally[31]. Reducing energy demand will also reduce energy-related air pollution (Goal 3), and CO_2 emissions (Goal 13) for a given population.

Goal 8: decent work and economic growth. Many SLCP measures support Goal 8 by decoupling economic growth from environmental degradation though the promotion of more efficient technologies, entrepreneurship and decent job creation. For example, replacement of traditional brick kilns and coke ovens with modern facilities support target 8.2 by promoting high-efficiency technologies and practices and target 8.4 by decoupling of economic growth from environmental degradation. A recent analysis of the brick industry in India found that transitioning to modern kilns could reduce coal consumption by up to 5 million tonnes per year with concomitant reductions in air pollution (Goal 3) and CO_2 emissions (Goal 13) as well as improving profitability of brick enterprizes and working conditions[32].

HFC measures also support efficiency improvements. For example, recent case studies using low-GWP refrigerants have shown energy savings of up to 30% for refrigeration in commercial food stores[33]. HFC measures can also support target 8.3 by driving innovation and decent job creation[34].

The replacement of traditional biomass cooking and heating stoves with more efficient alternatives will also improve resource efficiency and reduce deforestation (Goal 15). Cooking and heating stove projects can also support target 8.3 by creating opportunities for job creation and entrepreneurship[35]. Finally, capturing and utilization of methane from coalmines alongside good safety practices will reduce the risk of methane-related explosions[36], thereby promoting safe and secure working environments (target 8.8).

Goal 9: industry, innovation and infrastructure. SLCP measures can contribute to target 9.4 aimed at upgrading infrastructure and retrofitting industries to make them sustainable. For example, replacing traditional brick kilns and coke ovens results in the adoption of cleaner, more energy efficient, and environmentally friendly technologies (Goal 8). HFC measures can also foster innovation as companies compete to manufacture better products[12].

SLCP measures can also protect infrastructure by slowing the rate of sea-level rise by approximately 18% by 2050 (ref. [37]). The impact of rising oceans will impact key sectors in coastal and island states, including water resources (Goal 6), agriculture (Goal 2), and infrastructure, and will increase vulnerability of coastal communities (Goal 11) and their citizens (Goal 1) to flooding and storm surges.

Goal 11: sustainable cities and communities. Today, more than half of the world's population lives in cities and 88% of cities worldwide fail to achieve the WHO guideline levels for air pollution[38]. SLCP measures can directly contribute to target 11.6 to reduce the adverse environmental impact of cities by significantly reducing urban air pollution, improving public health, saving lives (Goal 3), and encouraging municipal waste management.

Clean cooking, heating, and lighting measures and improving appliance efficiency through HFC measures support target 11.1 to ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums by reducing household fuel costs (Goal 1), providing affordable clean energy (Goal 7), and reducing HAP (Goal 3). Measures to reduce diesel engine emissions and

support active travel directly support target 11.2 on safe, affordable, accessible and sustainable transport systems.

Goal 12: responsible consumption and production. Measures to reduce fugitive methane emissions from the oil and gas sector, from coal mines and farms, and municipal solid waste directly contribute to target 12.4 to achieve environmentally sound management and minimize adverse impacts on human health and the environment (Goals 2 and 3). HFC measures in the refrigeration sector can help achieve target 12.3, which aims to halve per-capita global food waste at the retail and consumer levels, and can also contribute to food security (Goal 2). Municipal solid waste measures, including separation and treatment of biodegradable waste, can also support target 12.5 through prevention, reduction, recycling and re-use.

Goal 13: climate action. Damages due to climate change are already upon us, affecting health and livelihoods, especially the poorest and most vulnerable. Furthermore, climate change is expected to increase the intensity and frequency of extreme events[39]. These impacts hamper the achievement of national development priorities, threaten to reverse many of the hard-fought improvements in public health, poverty reduction, education, and other development indicators, and put into peril the success of all SDGs.

Implementing SLCP measures with simultaneous deep cuts in CO_2 emissions increases the likelihood of meeting the 2 °C or less target in the twenty-first century. Mitigation of SLCPs can significantly reduce the rate of warming and protect against the increasing impacts of climate change during the near-term period relevant to the post-2015 development agenda[5]. Mitigation of SLCPs could help avoid 0.6 °C temperature rise by 2050 (refs [5,6]) and can cut the rate of global warming in half over this period[4,5]. Significant mitigation of CO_2 is crucial to avoid later warming and decarbonization of the world economy is needed during this century: SLCP measures must be additional to, rather than a substitute for, decarbonization.

Nevertheless, reducing the near-term rate of warming can contribute directly to target 13.1 by allowing more time for ecosystems and human societies to adapt. A decrease in the rate of near-term global warming also can decrease intensity and frequency of extreme weather events[40], which have been identified as important causes of poverty (Goal 1)[41] and which reduce the rate of sea-level rise[37] (see Goals 9 and 11).

A number of SLCP measures can also directly and indirectly reduce CO_2 emissions through, for example, improvements in efficiency and therefore reduced energy and fuel use in a range of sectors. Promoting active travel and clean public transport can reduce fossil-fuel emissions by reducing vehicle use. Reducing household wood use for fuel can also reduce emissions from deforestation and protect carbon forest stocks (Goal 15).

Goal 15: life on land. Collecting wood for fuel and making charcoal, particularly in Least Developed Countries[42], constitutes the second most important driver of forest degradation after timber extraction, responsible for about 31% of forest degradation globally[43]. SLCP measures such as clean cooking and heating stoves can support target 15.2 on sustainable management of forests and halting deforestation by reducing or eliminating domestic solid fuel use.

Implementing the SDGs

Implementing SLCP mitigation measures can contribute to the achievement of multiple SDG targets. As countries seek to incorporate SDG implementation into their national policy and planning processes, it is important that multiple benefits are assessed to identify actions and strategies that can help achieve several SDG targets, while minimizing conflicts and trade-offs. For most SLCP measures, there are synergies, often between many different SDGs and their targets. SLCP mitigation is complementary to CO_2 mitigation; many SLCP mitigation strategies can yield CO_2 mitigation co-benefits[10] and vice versa.

The significant role that SLCP mitigation can play in achieving multiple SDGs suggests a need to develop nationally relevant SLCP-specific indicators. SLCP mitigation could also be a thematic area of focus in SDG implementation to mobilize stakeholders and resources for action.

The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) is a partnership among countries, intergovernmental and non-governmental organizations, with a secretariat in United Nations Environment (UNEP), which has the goal of catalyzing action towards the reduction of SLCPs (http://www.ccacoalition.org/en). The CCAC can provide guidance and institutional support both for developing national-level indicators and for implementing identified strategies through its 7 sectoral and 4 cross-cutting initiatives. These include the SNAP (Supporting National Action and Planning on SLCPs) initiative that helps partners in building capacity and strengthening institutions with the ultimate goal of helping them embed nationally appropriate SLCP mitigation strategies and actions in their policies. Prioritization of mitigation strategies will depend on national development objectives, an emission inventory, barriers to implementation and available technologies, together with the availability of finance. Priority setting is part of the implementation of national planning by countries involved in the SNAP initiative. Our paper provides a framework to inform this and other decision-making by making linkages to the SDGs.

To capitalize on the inherent synergies between SLCP mitigation and the SDGs, it will be important to quantify the multiple benefits of SLCP mitigation policies, whilst addressing potential trade-offs, using standardized methodologies. Targeted efforts to communicate these multiple benefits to decision-makers are needed to incentivize deep cuts in SLCPs, for example through the Nationally Determined Contributions under the UNFCCC and regional air pollution cooperation initiatives (for example, the Regional Action Plan for Intergovernmental Cooperation on Air Pollution in Latin America and the Caribbean). The SDGs offer a powerful mechanism to address climate and development imperatives simultaneously. Integrating SLCP mitigation into the implementation of the SDGs can yield many benefits and is complementary to accelerated decarbonization efforts required to reduce long-term climate change.

Received: 4 December 2015; Accepted: 23 October 2017;
Published online: 30 November 2017

References

1. Rogelj, J. et al. Energy system transformations for limiting end-of-century warming to below 1.5 °C. *Nat. Clim. Change* **5**, 519–527 (2015).
2. Shindell, D. T. et al. A climate policy pathway for near- and long-term benefits. *Science* **356**, 493–494 (2017).
3. Xu, Y. & Ramanathan, V. Well below 2 °C: Mitigation strategies for avoiding dangerous to catastrophic climate changes. *Proc. Natl Acad. Sci. USA* **114**, 10315–10323 (2017).
4. *Integrated Assessment of Black Carbon and Tropospheric Ozone* (UNEP, Nairobi, WMO, Geneva, 2011).
5. Shindell, D. et al. Simultaneously mitigating near-term climate change and improving human health and food security. *Science* **335**, 183–189 (2012).
6. Xu, Y., Zaelke, D., Velders, G. J. M. & Ramanathan, V. The role of HFCs in mitigating 21st century climate change. *Atmos. Chem. Phys.* **13**, 6083–6089 (2013).
7. Carvalho, S., Andersen, S. O., Brack, D., & Sherman, N. J. *Alternative to High-GWP Hydrofluorocarbons* (Institute for Governance & Sustainable Development, 2015).
8. Lam, N. L. et al. Household light makes global heat: high black carbon emissions from kerosene wick lamps. *Environ. Sci. Technol.* **46**, 13531–13538 (2012).
9. *Reducing Global Health Risks through Mitigation of Short-Lived Climate Pollutants* (CCAC, Paris, WHO, Geneva, 2015).
10. *AMAP Assessment 2015: Black Carbon and Ozone as Arctic Climate Forcers* (AMAP, Oslo, 2015).

11. Nilsson, M., Griggs, D. & Visbeck, M. Policy: Map the interactions between Sustainable Development Goals. *Nature* **534**, 320–322 (2016).
12. *Spreading the Net: the Multiple Benefits of Energy Efficiency Improvements* (IEA, Paris, 2012).
13. Avery, S., Mauzerall, D. L., Liu, J. & Horowitz, L. W. Global crop yield reductions due to surface ozone exposure: 1. Year 2000 crop production losses and economic damage. *Atmos. Environ* **45**, 2284–2296 (2011).
14. Hayes, F. et al. Consistent ozone-induced decreases in pasture forage quality across several grassland types and consequences for UK lamb production. *Sci. Total Environ* **543**, 336–346 (2016).
15. Broberg, M. C., Feng, Z., Xin, Y. & Pleijel, H. Ozone effects on wheat grain quality—a summary. *Environ. Pollution* **197**, 203–213 (2015).
16. Kang, Y., Khan, S. & Xiaoyi, M. Climate change impacts on crop yield, crop water productivity and food security—a review. *Prog. Nat. Sci.* **19**, 1665–1674 (2009).
17. Shindell, D. Crop yield changes induced by emissions of individual climate-altering pollutants. *Earth's Future* **4**, 373–380 (2016).
18. Forouzanfar, M. H. et al. Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* **386**, 2287–2323 (2015).
19. *Burden of Disease from Ambient and Household Air Pollution* (WHO, Geneva, 2016).
20. *World Energy Outlook 2016 Special Report Energy and Air Pollution* (IEA, Paris, 2016).
21. *Burning Opportunity: Clean Household Energy for Health, Sustainable Development, and Wellbeing of Women and Children* (WHO, Geneva, 2016).
22. Aleksandrowicz, L., Green, R., Joy, E. J. M., Smith, P. & Haines, A. The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: a systematic review. *PLoS ONE* **11**, e0165797 (2016).
23. Barnes, D. F., Samad, H. & Banerjee, S. G. In *Energy Poverty Global Challenges and Local Solutions* (eds Halff, A., Sovacoal, B. K. & Rozhon, J.) (Oxford Univ. Press, Oxford, 2014).
24. Mills, E. The specter of fuel-based lighting. *Science* **308**, 1263–1264 (2005).
25. *Evaluation of the Dadaab Firewood Project, Kenya* (UNHCR, Geneva, 2001).
26. *The United Nations World Water Development Report 2016: Water and Jobs* (UNESCO, Paris, WWAP, Paris, 2016).
27. Reid, M. C., Guan, K., Wagner, F. & Mauzerall, D. L. Global methane emissions from pit latrines. *Environ. Sci. Technol.* **48**, 8727–8734 (2014).
28. Stohl, A. et al. Evaluating the climate and air quality impacts of short-lived pollutants. *Atmos. Chem. Phys.* **15**, 10529–10566 (2015).
29. Yang, Y. et al. Mechanisms contributing to suppressed precipitation in Mt. Hua of Central China. Part I: Mountain valley circulation. *J. Atmos. Sci.* **73**, 1351–1366 (2016).
30. Larsen, K., Delgado, M. & Marsters, P. *Untapped Potential Reducing Global Methane Emissions from Oil and Natural Gas Systems* (Rhodium Group, New York, 2015).
31. Shah, N., Wei, M., Letschert, V. E. & Phadke, A. A. *Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning* (Lawrence Berkeley National Laboratory, Berkeley, 2015).
32. Greentech Knowledge Solutions et al. *Performance Assessment: A Roadmap for Cleaner Brick Production in India* (2012).
33. *Low-GWP Alternatives in Commercial Refrigeration: Propane, CO_2 and HFO Case Studies* (UNEP, Nairobi, CCAC, Paris 2014).
34. Kemna, R. & Kemma, B. V. *Ecodesign Impact Accounting: Part 1* (VHK, Delft, 2014).
35. Shankar, A. et al. Maximizing the benefits of improved cookstoves: moving from acquisition to correct and consistent use. *Glob. Health Sci. Pract* **2**, 268–274 (2014).
36. Karacan, C. Ö., Ruiz, F. A., Cote, M. & Phipps, S. Coal mine methane: A review of capture and utilisation practices with benefits to mining safety and to greenhouse gas reduction. *Int. J. Coal Geol.* **86**, 121–156 (2011).
37. Hu, A., Xu, Y., Tebaldi, C., Washington, W. M. & Ramanathan, V. Mitigation of short-lived climate pollutants slows sea-level rise. *Nat. Clim. Change* **3**, 730–734 (2013).
38. *WHO Global Urban Ambient Air Pollution Database* (WHO, accessed 31 October 2017).
39. IPCC *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (Cambridge Univ. Press, Cambridge, 2012).
40. Fan, J. et al. Substantial contribution of anthropogenic air pollution to catastrophic floods in Southwest China. *Geophys. Res. Lett.* **42**, 6066–6075 (2015).
41. Shepherd, A. et al. *The Geography of Poverty, Disasters and Climate Extremes in 2030* (Overseas Development Institute, London, 2013).
42. *Cookstoves and REDD+ Understanding Woodfuel's Impact on Tropical Forests* (GACC, Washington DC, 2014).
43. Hosonuma, N. et al. An assessment of deforestation and forest degradation drivers in developing countries. *Environ. Res. Lett.* **7**, 4009 (2012).
44. *Science* (Climate and Clean Air Coalition, accessed 28 September 2017); http://www.ccacoalition.org/en/science-resources.

Acknowledgements

The authors are members of the Scientific Advisory Panel of the CCAC, S.L. is the former Secretary of the SAP, and N.B.P. is the Science Affairs Officer of the CCAC.

Author contributions

A.H. had the original idea for the paper and coordinated the drafting process. All authors contributed to the drafting and approved the final draft for submission.

Competing interests

The authors declare no competing financial interests.

Additional information

Reprints and permissions information is available at www.nature.com/reprints.

Correspondence and requests for materials should be addressed to A.H.

Publisher's note: Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.