CLIMATE AND CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

SCIENTIFIC ADVISORY PANEL 2013 ANNUAL SCIENCE UPDATE

CCAC

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TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

This briefing has been developed by the Scientific Advisory Panel of the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC).

This document and more information on the CCAC are available at: http://www.unep.org/ccac/

EXECUTIVE SUMMARY

This report provides basic information about short lived climate pollutants (SLCPs) as well as new scientific findings relevant to policy.

What do the Latest Scientific Findings say about the Actions Undertaken by the CCAC?

Multiple recent studies indicate that the benefits of targeted actions to reduce SLCPs may be even larger than previously estimated owing to greater climate impacts of black and brown carbon, greater leak rates of methane, and additional long-term impacts of SLCP mitigation that increase the urgency of reductions. The latest estimates of the health impact of particulate matter reinforce the importance of emissions reductions for public health, especially of women and children in developing nations.

Which substances are short-lived climate pollutants?

SLCPs are a subset of climate forcers with a lifetime in the atmosphere of 15 years or less, which include: black carbon, methane, tropospheric ozone, and some hydrofluorocarbons (HFCs).

How are SLCPs different from CO2 and other long-lived greenhouse gases?

The most important difference between SLCPs and long-lived greenhouse gases, such as CO_2 and N_2O, is that SLCPs have a much shorter lifetime in the atmosphere. This means that if emissions of SLCPs are reduced, their atmospheric concentrations will decrease in a matter of weeks to years, with a noticeable effect on global temperature during the following decades. Comparatively, while 50-60% of CO_2 is removed from the atmosphere in the first hundred years, as much as 25% will remain for many millennia accumulating in the atmosphere with a long legacy effect. Hence, reducing SLCPs will slow the near- term rate of warming, but deep and persistent cuts in CO_2 and other long-lived greenhouse gases are necessary to stabilize global temperature rise through 2100 and beyond. Aside from HFCs, the SLCPs are also air pollutants (or precursors of air pollutants) with serious adverse impacts on human and ecosystem health (including crop and forest yields).

How much can SLCP reductions slow global warming?

Black carbon and methane are emitted from a variety of natural and anthropogenic sources, a 2011 UNEP/WMO assessment identified a set of 16 optimal measures, out of 130 existing controls, which if realized worldwide can reduce 90% of the total mitigation potential of the 130 measures from black carbon, methane, and tropospheric ozone (these measures include immediately feasible actions such as upgrading brick kilns, installing particle filters on diesel vehicles, and recovering fugitive methane from energy facilities). Implementing these measures in all parts of the world by 2030 can slow the speed of global warming between now and 2050 by half, relative to a reference case with no reductions beyond current policies. Globally this means that temperatures in 2050 would be 0.5°C lower than the reference value, and even lower in the Arctic.

HFCs, widely used as refrigerants and propellants, are a small contributor to global warming today, but are the fastest-growing emissions of greenhouse gases (increasing by 10% to 15% annually) in many countries and regions, including the United States, the European Union, China, and India. A recent study concluded that replacing high-GWP HFCs with more climate-friendly alternatives can avert 0.1°C of warming by 2050 relative to a reference case with uncontrolled growth in HFCs. The avoided warming from replacing high-GWP HFCs is additional to the benefit of cutting black carbon, methane, and tropospheric ozone.

What are the near-term climate benefits SLCP mitigation?

Slowing the rate of near-term climate change reduces its impacts on those alive today. It will reduce biodiversity loss, provide greater time for adaptation to climate change, and reduce the risk of crossing dangerous climate thresholds (e.g. the melting of permafrost which leads to the further emissions of greenhouse gases). Reducing SLCPs is very likely to have the additional benefits of reducing the disruption of rainfall patterns caused by particle pollution, and slowing the melting rate of ice and snow in the Arctic and high elevation regions caused by the deposition of black carbon particles.

What are the long term climate benefits of SLCP mitigation?

New studies are showing that reducing SLCPs can also have long term benefits. Although stringent reductions of CO_2 and other long-lived greenhouse gases are needed to avoid a substantial rise in sea level, one set of model experiments showed that cutting SLCPs could reduce cumulative sea level rise by as much as 22% at the end of the century relative to long-term uncontrolled SLCP emissions. Delayed reductions in SLCPs substantially reduced this benefit. Slowing the near-term rate of warming would also provide long-term benefits by slowing the decline in carbon uptake projected to occur in response to warming. These long-term benefits increase the urgency of reducing SLCPs.

What are the other benefits of reducing black carbon and methane?

SLCPs also differ from CO_2 and other long-lived greenhouse gases in that black carbon and tropospheric ozone are important air pollutants and methane contributes to as much as two-thirds of tropospheric ozone production. Black carbon and co-emissions have a particularly large impact on public health because they make up a substantial part of indoor and outdoor particle pollution. A study just published by several universities and the WHO ("The Global Burden of Disease") reported that indoor air pollution is the fourth most important contributor to the global burden of disease and outdoor air pollution the ninth. If women are considered separately, indoor air pollution is the second most important cause of poor health.

Therefore, reducing SLCPs will reduce threats to public health and food security related to air pollution. If the 16 black carbon-related and methane measures are fully implemented, then the reduced air pollution by 2030 will save around 2.4 million air pollution related deaths each year and about 50 million tonnes of crop losses each year, relative to a reference case.

Important new information on sources of SLCP emissions and their impacts

New information useful to policymaking is becoming available about the SLCP sources and impacts:

- Gas flaring in the Arctic is now realized to be a more important source of black carbon particles in the Arctic than in earlier estimates. The deposition of these particles is known to contribute to the accelerated melting of ice.
- The kerosene lamps commonly used in households in South Asia, Africa, and parts of Latin America have been confirmed to be a major source of indoor black carbon air pollution in these regions. Controlling this source would not only reduce air pollution, but also bring regional and global climate benefits. And of particular interest to policymaking, experts note that affordable alternatives to kerosene lamps are already available. A comprehensive view of residential energy use would help identify optimal methods to lower emissions associated with cooking, heating and lighting.
- New information shows that diesel generators are an important source of black carbon emissions in countries where public power supply lags behind electricity demand (e.g. India, Nepal and Nigeria).
- New evidence confirms that reducing black carbon emissions from diesel engines (both generators and vehicles) and some types of cook stoves provides clear climate benefits.
- Recently published data from the US indicate greater leakage of methane from energy facilities than earlier suspected. This includes emissions from fossil fuel production facilities in the Gulf of Mexico and from distribution systems in the LA basin, and suggests leakage rates may be underestimated in most countries.

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1. Introduction to the 2011 UNEP/WMO Integrated Assessment of Black Carbon and Tropospheric Ozone and 2012 UNEP Near-Term Climate Protection and Clean Air Benefits Report

The UNEP/WMO Assessment (UNEP/WMO, 2011) and subsequent publications have highlighted the considerable multiple benefits for climate and air quality impacts that would result from the implementation of identified measures that address Short-Lived Climate Pollutants (SLCPs).

SLCPs are defined as those substances that have a warming effect and are relatively short lived in the atmosphere (from days to a decade or two), compared to long-lived greenhouse gases such as nitrous oxide (~120 years) and carbon dioxide, some of which can remain in the atmosphere for many thousands of years. These are black carbon (BC; emitted as particles from incomplete combustion), methane, tropospheric (lower atmosphere) ozone (O_3) and most hydrofluorocarbons (HFCs) currently in use. Methane (CH_4), tropospheric ozone and black carbon all result in air pollution impacts as well, affecting human health (BC and O_3), crop yield (O_3) and ecosystems (O_3). Methane is part of the air quality story as it is one of the most important precursors of ozone formation, especially affecting background ozone levels in the troposphere. HFCs do not have air pollution impacts, but emissions are increasing rapidly in many countries including the U.S., EU, China, and India (though their current impact on climate is still small). As these substances are short-lived in the atmosphere, the benefits for climate and air quality are realized rapidly in the order of days to a decade or two, and are especially pronounced in the regions making the reductions.

The UNEP/WMO assessment identified 16 measures (7 targeting methane emissions and 9 black carbon emissions) which if implemented globally are capable of reducing the combined climate forcing from black carbon, methane and tropospheric ozone by 90%.[1] Importantly, this was calculated from the change in all co-emitted substances, to provide an indication on the net warming. Thus, measures that substantially reduced sulphate or organic carbon, which act to cool the climate, relative to those substances that warm the climate, were not included as measures of interest. The BC measures reduced about 80% of global black carbon emissions, and substantial reductions in other co-emitted substances, while the methane measures reduced about 40% of emissions relative to the reference scenario in 2030.

The Assessment found that by implementing all of the measures relating to black carbon and methane in all parts of the world by 2030, the rate of warming until 2050 could be halved, resulting in 0.5°C lower warming, globally, in comparison to a Reference Scenario, with even greater climate benefits in the Arctic.[2] The emission changes from implementing the measures also resulted in large health benefits, with about 2.4 million fewer premature deaths, globally from improved air quality.[3] In addition the reduction in ozone precursors (from methane and BC measures) resulted in about 50 million tonnes of avoided crop losses from the reduced impact of tropospheric ozone on four staple crops (rice, wheat, maize and soybean). [4]

[1] UNEP & WMO (2011) *Integrated Assessment of Black Carbon and Tropospheric Ozone*, Nairobi, Kenya

[2] UNEP & WMO (2011) *Integrated Assessment of Black Carbon and Tropospheric Ozone*, Nairobi, Kenya

[3] UNEP (2011) *Near-term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers – A UNEP Synthesis Report*, Nairobi, Kenya; *and* Shindell, D., *et al.* (2012) *Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security*, SCIENCE 335(6065):183-189, doi:11.1126/science.1210026.

[4] UNEP (2011) *Near-term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers – A UNEP Synthesis Report*, Nairobi, Kenya; *and* Shindell, D., *et al.* (2012) *Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security*, SCIENCE 335(6065):183-189, doi:11.1126/science.1210026.

2. The Relationship Between Short-lived Climate Pollutants and Long-lived Greenhouse Gases

Short-lived climate pollutants (SLCPs) have impacts that differ substantially from those of long-lived greenhouse gases, making comparisons between them complex. Any comparison of their impacts is applicable only to a particular quantity at a particular time. For example, SLCPs are responsible for a substantial fraction of both the warming experienced to date and the current rate of global warming. However, their relative contribution to change realized to date does not imply an equivalent contribution to change at any future time. Many of the SLCPs are also dangerous air pollutants, with various detrimental impacts on human health, agriculture and ecosystems, making comparison of their climate impacts alone an incomplete measure of their impact.

The short lifetime of SLCPs in the atmosphere means that reducing their emissions will reduce their atmospheric concentrations in a matter of weeks to years, with a noticeable effect on global temperature during the following decades. In contrast, the long lifetime of CO_2 means that it will take many decades to realize the majority of the climate benefit of near-term reductions. [5] Assuming SLCPs are eventually reduced, however, long-term warming will be essentially determined by total cumulative CO_2 emissions, and will be effectively irreversible on human timescales without carbon removal. Thus SLCPs and CO_2 both have important effects on climate, but these occur on very different timescales.

Mitigation of SLCPs and CO_2 is also typically achieved via different strategies, as the SLCP measures often involve sectors and sources such as HFC coolants in air conditioning and refrigeration and black carbon from residential cook stoves that would not be the main focus of CO_2 mitigation (which would target power plants, for example). Many SLCP reductions may be motivated primarily by the air quality benefits. Hence reducing emissions of SLCPs and CO_2 are distinct and complementary goals.

Slowing the rate of near-term climate change leads to multiple benefits, including reducing impacts from climate change on those alive today, reducing biodiversity loss, providing greater time for adaptation to climate change, and reducing the risk of crossing thresholds activating strong climate feedbacks (e.g. large emissions associated with melting permafrost). Additionally, reducing SLCPs is likely to have enhanced benefits in mitigating warming in the Arctic and other elevated snow and ice covered regions in the Himalayan/Tibetan regions and in reducing regional disruption of traditional rainfall patterns. There are some longer-term benefits as well via carbon-cycle responses and reduced sea-level rise, though the greatest benefits are near-term. Given their rapid response, the timing of SLCP reductions likely does not greatly affect peak warming (as long as reductions are made ~1-2 decades prior to the peak), but a delay in reducing SLCPs would clearly lead to a failure to reap these manifold near-term benefits.

3. Replacing High-GWP HFCs can Avoid Another 0.1°C of Warming by 2050

A recent study concludes that replacing high global warming potential (high-GWP) HFCs with low-GWP or not-in-kind alternatives can avoid 0.1°C of warming at 2050 and up to 0.3°C to 0.5°C of warming by 2100 relative to a scenario with uncontrolled growth of HFCs.[6] While HFC and more generally SLCP mitigation is important for avoiding a significant amount of warming throughout the century, mitigation of both SLCPs and CO2 is essential for keeping the cumulative warming below 2°C, at least until the end of the century.

HFCs, widely used as refrigerants and propellants, are a small contributor to global warming today, but are the fastest-growing greenhouse gases (in percentage) in many countries, including the United States,

[5] Matthews H. D. & Solomon S. (2013) *Irreversible Does Not Mean Unavoidable*, SCIENCE 340:438, doi:10.1125/science.1236372

[6] Xu Y., Zaelke D., Velders G. J. M., & Ramanathan V. (2013) *The role of HFCs in mitigating 21st century climate change*, ATMOSPHERIC CHEMISTRY AND PHYSICS 13:6083-6089.

the European Union, China, and India, increasing by 10% to 15% annually. [7]

The study adapted the climate models used in the UNEP/WMO (2011) and Shindell et al (2012) studies but also included uncontrolled growth of HFCs from Velders et al (2007). It confirms these previous studies, that 0.5°C of additional warming can be avoided by 2050 from the mitigation of black carbon and methane and tropospheric ozone, but concludes that replacing high-GWP HFCs can avoid an additional 0.1°C by 2050.

An earlier study also looked at the avoided warming potential of mitigating HFCs, all SLCPs, and CO_2 through the end of the century. The study concluded that for the 2005 to 2100 period, the mitigated warming by CO_2 and SLCPs was 2.3°C and SLCPs contributed about 50% (1.1°C) to the mitigation. Methane (including ozone), black carbon and HFCs contributed respectively 55%, 23%, and 22% to the 1.1°C mitigation by SLCPs.[8] Estimates of the long-term impact of SLCPs are highly sensitive to uncertainties and assumptions made in the projected reference emissions of the SLCPs, however.

4. Indoor and Outdoor Air Pollution, Including Black Carbon, Kill Millions Annually; Among Leading Preventable Causes for Early Mortality and Chronic Disease Globally

Air pollution in the outdoors and within households is a leading contributor to the global burden of disease, defined as early mortality and years lived at less than full health, with the greatest impacts in regions with high prevalence of solid fuel use. Having to rely on solid fuels for indispensable human activities including cooking and heating continues to be an everyday reality for some 2.8 billion people in this world, largely in poor rural communities of developing countries. The global burden of disease (GBD) 2010 exercise published in 2013 estimates 3.5 million deaths and a 100 million disability-adjusted life years to be attributable to household air pollution resulting from use of solid fuels. This burden is compounded by an additional 3.2 million deaths attributable to ambient air pollution. In addition, ~152,000 premature deaths per year are attributed to exposure to tropospheric ozone. There is some overlap between premature mortality estimates for indoor and outdoor air pollution exposure so they cannot be added together to obtain an overall estimate of mortality.

Indoor air pollution is considered to be the fourth most important contributor to the global burden of disease and ambient air pollution is considered to be the ninth. If women are considered separately, indoor air pollution is the second most important cause of poor health. In South Asia, which includes India, indoor air pollution alone is the leading preventable risk factor for the burden of disease, while in Eastern, Central, and Western Sub-Saharan Africa it is ranked second, and third in South East Asia.

Solid fuel use is estimated to contribute nearly 25% of the global BC emissions (with contributions from some regions as high as 60%). Thus, targeting air quality actions to improve health, especially in the household sector, can provide substantive co-benefits for climate. It is important to frame these actions in a way that neither health nor climate is compromised.

The results of the 2010 Global Burden of Disease study performed by several universities together with the WHO together with the new WHO Indoor Air quality guidelines (WHO-IAQGs, being developed, specifically to provide health based benchmarks for cookstove technologies) provide important directions for air quality actions directed at household air pollution while supporting other initiatives for SLCPs. This includes among others *(i) Aggressive promotion strategies for use of LPG as a cooking fuel, wherever feasible (ii)) Imminent augmentation of R&D on biomass based stove technology to consistently meet WHO-IAQGs and (iii) Facilitation of efforts to interface household air pollution with ambient air quality within*

[7] Velders G. J. M., Fahey D. W., Daniel J. S., McFarland M., & Andersen S. O. (2009) *The large contribution of projected HFC emissions to future climate forcing*, PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCE USA 106(10949), doi:10.1073/pnas.0902817106.

[8] Hu A., Xu Y., Tebaldi C., Washington W. M., & Ramanathan V. (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE-CLIMATE CHANGE, advance online publication, doi:10.1038/nclimate1869.

existing National Air Quality Programs. [9]

5. BC Science Focusing on the Impacts of Specific Emission Sources

Several new studies suggest higher importance of BC emissions from gas flaring, especially for the Arctic. New model runs that include higher BC emissions from gas flaring in the Arctic region than estimated before produced a significant improvement in the match of modeling results with actual measurements of BC concentrations. Thereby, gas flaring in the Arctic appears to be a major source of BC emissions, which might increase further in the future when oil production in several Arctic countries will move further north. [10]

While brick kilns have been addressed in the UNEP/WMO assessment as a major source of BC emissions, new measurements and assessment studies provide improved information on emission factors and mitigation measures. [11]

There is also increasing information on diesel generators, which are important sources of BC emissions in countries where recent economic growth and demand for electricity has not been matched by power supply (e.g., India, Nepal, etc.). Studies to assess the climate and air quality impacts of these additional and revised emissions are a needed next step. [12]

While the health benefits of emissions reductions are unequivocal, recent assessment of the net climate impact of various BC-rich sources suggests that emissions from diesel engines (especially heavy-duty) and some types of cookstoves provide the clearest climate benefits, while reducing emissions from open burning biomass is unlikely to lead to reduced warming.[13] Another very recent study indicates that BC emissions from fossil fuel combustion may represent a larger share of total emissions than previously thought, at least in East Asia, reinforcing the conclusion that large benefits could be obtained from controlling emissions from diesel engines and residential coal use.[14] Another very recent study also highlights the impact of diesel vehicle emissions from South Asia as well as emissions from residential biomass fuel, while showing that the global forcing due to emissions from different regions is highly sensitive to aerosol-cloud effects and thus difficult to quantify. [15]

6. Long-term Carbon-Cycle Response Adds to SLCP Impacts

It is very difficult to evaluate the long-term behavior of the carbon-cycle under a changing climate based on observations, thus the behavior of particular parts of the carbon-cycle such as the response to

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[9] Lim S., Vos T., & Flaxman A. (2013) *A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010* (vol 380, pg 2224, 2012) LANCET 381(9874):1276-1276.

[10] Peters, G.P. et al. (2011) *Future emissions from shipping and petroleum activities in the Arctic*, ATMOSPHERIC CHEMISTRY AND PHYSICS 11(11):5305–5320; Stohl, A. et al.(2013) *Why models struggle to capture Arctic Haze: the underestimated role of gas flaring and domestic combustion emissions*, ATMOSPHERIC CHEMISTRY AND PHYSICS DISCUSSIONS 13(4): 9567–9613.

[11] Maithel, S. et al. (2012) *Brick Kilns Performance Assessment; A Roadmap for Cleaner Brick Production in India*, Shakti Sustainable Energy Foundation and Climate Works Foundation.

[12] Bond, T. C., et al. (2013) *Bounding the role of black carbon in the climate system: A scientific assessment*, J. GEO-PHYS. RES. ATMOS. 118, doi:10.1002/jgrd.50171, 2013.

[13] Bond, T. C., et al. (2013) *Bounding the role of black carbon in the climate system: A scientific assessment*, J. GEO-PHYS. RES. ATMOS. 118, doi:10.1002/jgrd.50171, 2013.

[14] Chen B. et al. (in press 2013) *Source Forensics of Black Carbon Aerosols from China*, ENVIRON. SCI. TECHNOL., doi:10.1021/es401599r.

[15] Streets D. G., Shindell D. T., Lu Z., & Faluvegi G. (in press 2013) Radiative forcing due to major aerosol emitting sectors in China and India, *Geophys. Res. Lett.*, doi:10.1002/grl.50805.

temperature change have large uncertainties. Despite those uncertainties, the response of the carbon-cycle to temperature change has typically been included when evaluating the climate impact of carbon dioxide. This response has typically not been included for non-CO_2 forcing agents however, creating an inconsistency in climate projections and in emissions metrics.

Inclusion of the carbon-cycle response to SLCPs has now been evaluated in several studies. In the most comprehensive, its effects on the estimated future temperature change in response to emissions of several SLCPs were examined. As warmer temperatures reduce carbon uptake, and this effect has already been included for CO_2, temperature changes calculated relative to CO_2 increase (i.e. as this effect is now included in both the numerator and the denominator rather than in the denominator only). Comparison of the temperature change due to a kg of emissions of a particular compound relative to the impact of a kg of CO_2 emissions is called the global temperature potential (GTP), and provides an illustrative comparison, though it is of limited practical value as it considers only a single impact (global mean temperature) at a single time. Given the long residence time of CO_2 in the atmosphere, the increase is relative modest for near-term time horizons, for example adding ~17% to 20 year GTPs. Increases for long time horizons are much larger, however, with 100 year GTP increasing by 170% (i.e. nearly tripled). [16]

Climate projections made with simple models or analytic equations such as those used in the UNEP/WMO Integrated Assessment of Black Carbon and Tropospheric Ozone will similarly underestimate the temperature response to SLCPs at long timescales. Values for near-term climate impacts will be only very slightly larger, and while impacts at long timescales will be greater they will still tend to be small given the short residence time of SLCPs in the atmosphere.

7. SLCP Mitigation Can Reduce Projected Sea-Level Rise by as much as 22% by 2100

The potential impact of rising oceans is one of the most concerning effects of climate change. Many of the world's major cities, such as New York, Miami, Amsterdam, Shanghai, Mumbai, Dhaka and Tokyo, are located in low-lying areas by the water. As glaciers and ice sheets melt and warming oceans expand, sea levels have been rising by an average of about 3 millimeters annually in recent years. If temperatures continue to warm, sea levels are projected to rise by as much as nearly a meter this century. Such an increase could submerge densely populated coastal communities, especially when storm surges hit. A new climate modeling study indicates that mitigating emissions of SLCPs can significantly slow down sea level rise this century.

Mitigation of SLCPs, along with CO_2, reduced the projected sea level rise for 2100 by about 31% relative to a reference case under which methane and BC-related emissions remain large, CO_2 emissions increase steadily, and there is uncontrolled growth in HFCs (other reference scenarios would of course yield different answers). SLCPs mitigation alone accounted for 22% of the reduction. More importantly, mitigation of CO_2 and SLCPs reduced the rate of sea level rise by 50% relative to the business-as-usual scenario in 2100. CO_2 and SLCPs contributed equally (50%) to the reduction in the rate of sea level rise.

The study also found that delaying mitigation of SLCPs by 25 years (to 2040) will decrease the impact of combined CO_2 and SLCP mitigation on sea-level rise in this century by 30% and increase sea-level rise by up to 11%. [17]

[16] Gillett N. & Matthews, H. (2010) *Accounting for carbon cycle feedbacks in a comparison of the global warming effects of greenhouse gases*, ENVIRON. RES. LETT. 5:034011, doi:10.1088/1748-9326/5/3/034011; Sarofim M. C. (2012) *The GTP of methane: modeling analysis of temperature impacts of methane and carbon dioxide reductions*, ENVIRON. MODEL. ASSESS. 17:231–239, doi:10.1007/s10666-011-9287-x; Collins W. J., Fry M. M., Yu H., Fuglestvedt J. S., Shindell, D. T., & West, J. J. (2013) *Global and regional temperature-change potentials for near-term climate forcers*, ATMOS. CHEM. PHYS. 13:2471–2485.

[17] Hu A., Xu Y., Tebaldi C., Washington W. M., & Ramanathan V. (2013) *Mitigation of short-lived climate pollutants slows sea-level rise*, NATURE-CLIMATE CHANGE, advance online publication, doi:10.1038/nclimate1869.

Two important caveats are that: Beyond 2100, CO_2 mitigation will play more dominant role in mitigating both warming and sea level rise, provided the mitigation of CO_2 begins now. Second, simulation of sea level rise by global climate models is in its early stages and global models are unable to realistically account for the melting effects of glaciers and ice sheets. Acknowledging the high uncertainty of sea-level rise projections, the study focused on relative changes in sea-level rise due to SLCP mitigation instead of absolute values.

8. BC Emissions from Kerosene-Wick Lamps Many Times Higher than Previous Estimates

Kerosene-fuelled wick lamps used in millions of developing-country households are a significant but overlooked source of black carbon (BC) emissions according to a recent study.[18] New laboratory and field measurements show that 7 - 9% of kerosene consumed by simple wick lamps is converted to carbonaceous particulate matter that is nearly pure BC. These high emission factors increase previous BC emission estimates from kerosene by 20-fold, to 270 Gg/year (110 - 590 Gg/year), which is about 6% (2-12) of currently estimated anthropogenic total BC emissions.

The high emitting regions for kerosene BC are South Asia, Africa and parts of Latin America, where these emissions represent a significant part of total BC. Aerosol climate forcing on atmosphere and snow from this source is estimated at 22 mW/m^{-2} (8 - 48 mW/m^{-2}), or ~5-10% of BC forcing by all other energy-related sources. Follow on studies are needed to validate the numbers, but the qualitative conclusions appear robust.

Kerosene lamps have affordable alternatives that pose few clear adoption barriers and would provide immediate benefit to user welfare. The net effect on climate is more clearly positive forcing than for many other sources as co-emitted organic carbon is low. No other major BC source has such readily available alternatives, definitive climate forcing effects, and co-benefits. Replacement of kerosene-fueled wick lamps deserves strong consideration for programs that target short-lived climate forcers.

9. Methane Leakage Rates Higher than Previously Estimated

Many new studies suggest that methane release from new gas extraction operations in the U.S. is substantially greater than prior estimates. Measurements taken near the ground across the southern U.S., which compare well with satellite observations for large scales, suggest that emissions are underestimated for Gulf of Mexico fossil-fuel industry methane. Studies in the Los Angeles basin using aircraft measurements indicate that dairy farm and landfill emissions match inventories well, but there are greater than expected fugitive emissions from pipelines and urban distribution systems (and/or geological seeps) and the local oil and gas industry.[19] Similar underestimates are likely in other parts of the world as well, but both in the US and elsewhere additional data on emissions is needed.

10. Implementation Updates

A new study suggests that providing access to modern energy by 2030, as envisioned in the UNEP Assessment, would require policies that lower costs for modern cooking fuels and stoves along with an acceleration of rural electrification and would entail costs of ~65-86 billion $US. Providing access to modern cooking fuels alone, while not inexpensive, is estimated to prevent ~1.2 million premature

[18] Lam N., Chen Y., Weyant C., Venkataraman C., Sadavarte P., Johnson M., Smith K. R., Brem B., Arineitwe J., Ellis J., & Bond T. (2012) *Household Light Makes Global Heat: High Black Carbon Emissions From Kerosene Wick Lamps*, ENVIRONMENTAL SCIENCE & TECHNOLOGY 46(24):13531–13538.

[19] Leifer I., Culling D., Schneising O., Farrell P., Buchwitz M., & Burrows J. P. (2013) *Transcontinental methane measurements: Part 2, Mobile surface investigation of fossil fuel industrial fugitive emissions*, ATMOSPHERIC ENVIRONMENT, 74: 432-441; Peischl R., *et al*. (2013) *Quantifying sources of methane using light alkanes in the Los Angeles basin, California*, JOURNAL OF GEOPHYSICAL RESEARCH ATMOSPHERES 118(10): 4974-4990, doi:10,1002/jgrd.50413; Townsend-Small, A. (2012) *Isotopic measurements of atmospheric methane in Los Angeles, California, USA reveal the influence of "fugitive" fossil fuel emissions*, JOURNAL OF GEOPHYSICAL RESEARCH, doi:10.1029/2011JD016826; O'Sullivan F., & Paltsev S. (2012) *Shale gas production: potential versus actual greenhouse gas emissions*, ENVIRONMENTAL RES. LETT. 7(4):044030.

deaths annually and greatly enhance human well-being. [20]

Field work suggests that the ability of solar powered devices to provide both cooking energy and lightning is highly appreciated in many locations, and provides a way to reduce kerosene-related BC emissions from lamps at the same time as cookstoves are upgraded. This suggests that a broad range of residential activities should be considered in concert to determine optimal ways to mitigate emissions associated with residential cooking, heating and lighting.

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[20] Pachauri S. *et al*. (2013) *Pathways to achieve universal household access to modern energy by 2030*, ENVIRON. RES. LETT. 8:024015.