SCIENCE ADVISORY PANEL REPORT ON METRICS & INVENTORY DEVELOPMENT WORKSHOP

16 - 17 March 2017 - Ottawa, Canada

1. BACKGROUND

Metrics can help in quantifying the benefits from implementing measures to reduce emissions of short-lived climate pollutants (SLCPs). For the Climate and Clean Air Coalition (CCAC), such metrics can help standardize the reporting on its activities and actions including through its new Demonstrating Impacts Framework[i]. Metrics would allow for easy quantification of the main impacts and benefits associated with SLCP mitigation, including changes in warming, as well as benefits related to human health, ecosystem structure and function, including agriculture and forest productivity.

Along with improving metrics, there is interest in developing emissions inventories for the Coalition's targeted SLCPs – black carbon, methane, tropospheric ozone and hydrofluorocarbons (HFCs), as well as their co-emitted substances. This is needed to estimate the health, climate and crop yield benefits of reducing SLCPs. The inventories will provide a baseline (historical or future scenarios) that emission reductions can be set against and improve confidence in quantified reductions. Knowledge of a country's, or sector's, current emission levels will lead to better documentation of the effectiveness of emissions reduction measures. Along this line, some members of the Coalition have committed to prepare emissions inventory for black carbon in their countries.[ii]

Recognizing the importance of establishing appropriate metrics for SLCPs, in May 2016, the Working Group of the Climate and Clean Air Coalition (CCAC) requested that the Scientific Advisory Panel (SAP) "*work on more clear metrics to reflect the climate and multiple benefits from black carbon and methane.*"[iii] The SAP and CCAC Secretariat, organized a workshop on "Metrics for evaluating and reporting on black carbon and methane interventions" on March 16 and 17, 2017, in Ottawa, Canada. The workshop was hosted by Environment and Climate Change Canada. Day 1 focused on accounting metrics for black carbon and methane, while Day 2 focused on black carbon inventory development (see Annex 1 for annotated workshop agenda). The workshop was attended by experts with diverse expertise across the topics discussed at the workshop (see Annex 2 for final participants list). This document provides a highlight of discussions at the workshop, including the recommendations and suggested follow-up actions. The background documents prepared for the workshop as well as presentations made during the workshop are available at: http://ccacoalition.org/en/resources/background-documents-metrics-evaluating-and-reporting-black-carbon-and-methane.

2. OVERVIEW OF RECOMMENDATIONS[iv]

Table S1 presents the recommendations on metrics for evaluating the impacts and benefits of methane and black carbon interventions. The major aspects are summarized below:

Metrics Parameter	Climate [Stabilization][v]	Climate [Rate of Change]	Health	Agriculture and Vegetation
Emissions	Tonne/yr *[CO_{2e} and tonnes of each emitted substance affecting climate]*	Tonne/yr *[CO_2;CH_4;BC;OC;SO_2;HFCs; NOx;CO; N_2O; NH_3; nmVOC]*	Tonne/yr *[$PM_{2.5}$ / O_3 and precursors – of $PM_{2.5}$ include BC, OC, mineral dust, NOx, SO_2, NH_3]*	Tonne/yr *[O_3 precursor emissions – NOx, nmVOC, CH_4, CO]*[vi]
Exposure	GWP GWP* AGTP (year)	Mean AGTP25	Population weighted annual average µg/m³ Daily maximum 8-hour mean daily maximum one hour ozone concentration averaged over 6 months annual average ppb (8-hr max)	M7 M12 AOT40 Ozone flux
Response impact and benefits (domestic/global public good)[vii]	Temperature (°C)	Temperature (°C) 25 years out Mean Temperature (°C) over 25-yr Temperature (°C) by region/latitude bands	Equivalent Attributable Deaths & Illness Attributable deaths Years of Life Lost (YLL) Other metrics accepted by GBD/WHO communities	Tonnes of yield loss/yr for four staple crops[viii], and other crops, vegetation types for which there are agreed CRFs
Economic valuation (domestic: global public goods)[ix]	Social Cost of Carbon[x] Social Cost of Methane[xi]	Social Cost of Methane[xii] Social Cost of Black Carbon[xiii] Social Cost of Atmospheric Release	DALY = YLL+YLD Cost of Illness Willingness to Pay (WTP) Value of a Statistical Life (VSL) Forgone Output	US$/Tonne of each staple (and other crops as appropriate)
Finance (Price)[xiv]	Will be set by regulations and market			
Policy objectives	SDG 13: <2°C in 2100	1.5 - <<2.0˚C in 2100 25-year rate of warming target	SDG 3 WHO AQ Guidelines	SDG 2

- Based on current scientific knowledge, participants agreed that the mean $AGTP_{25}$ is a reasonable metric for assessing the impact of individual substances (including long-lived and short-lived substances) on near-term global warming as well as the effectiveness of emissions reduction in mitigating the rate of warming in the near term.[xv] While various metrics such as the GWP* and the AGTP were discussed as possible metrics to evaluate long-term impacts, the experts recognized that the use of 100 year GWP is already in widespread use in international frameworks (such as the UNFCCC), and chose not to make alternative recommendations.
- For health impacts, metrics should align with those used in the analysis of the Global Burden of Disease (GBD)[xvi] and those suggested by the World Health Organization (WHO). These include Equivalent Attributable Deaths, Years of Life Lost (YLL), Years Lived with Disability (YLD), and Disability Adjusted Life Years (DALYs). However, further work is needed to ensure that these impacts are properly understood and correctly interpreted.
- Metrics already being used by different countries could also be useful. Other health outcomes such as emergency room visits, doctors' visits, school absence, lost work days, respiratory symptoms, medication use, and lung function decrements are also metrics that could be promoted as they are more understandable, and tend to resonate more with the public and policy community.
- For agricultural impacts, the relative yield loss, expressed either as a percentage of expected yield (relative loss) or as total amount of yield loss in tonnes is recommended. More work is needed to increase the number of crops covered in this analysis beyond the four staple crops currently available.
- The "social cost of emissions" is recommended as a method for assessing monetary value of the climate and air quality impacts of emissions as it attempts to incorporate monetized market and non-market impacts over time. The "cost of illness", "willingness to pay", "value of a statistical life" and "forgone output" (which are already incorporated into social costs) are among the metrics that can be used for the economic valuation of health impacts/benefits, but it is important to take into consideration what is acceptable and the local context in different countries. Further work is needed to describe the robustness of calculations through the impact pathway from emission to impact and value: this needs to stress 'certainty' as well as 'uncertainty'.
- To be able to accurately estimate the impacts of methane and black carbon using the recommended metrics, it is important that all co-emitted substances that affect the various parameters to be evaluated (that is, climate, health, agriculture) from a particular emission source are reported and included in the calculations as individual species (i.e. not aggregated into a measure such as CO_2e).

With respect to black carbon inventory development, the following were suggested as the Coalition's possible role:

- Support the collection of regionally-relevant activity data for the different black carbon emission sources and sectors.
- Support the improvement in emission factors especially through the activities of CCAC initiatives; for example, partnering with the waste management community to develop emission factors for trash burning.
- Support research institutions and help build institutional capacity aimed at supporting data gathering and building reporting expertise and knowledge.
- Aid institutions applying for funding for inventory development purposes.
- Work with leading organizations, such as CLRTAP and the LEAP-IBC community, to adapt existing inventory methodologies, support data and reporting protocols for ease of use by developing countries, and cover emissions sources that are currently lacking.
- Convene inventory expertise from leading organizations and inventory practitioners from countries that might not otherwise have access to such expertise.
- Achieve a relatively simple, but complete (Tier 1),[xvii] black carbon inventory for all countries.

The full highlights and recommendations from the workshop are presented in the next section of this report.

3. DETAILED WORKSHOP HIGHLIGHTS AND RECOMMENDATIONS

DAY 1: ACCOUNTING METRICS

Summary: The objective of Day 1 was to evaluate approaches for quantifying the multiple benefits of interventions to reduce methane and black carbon emissions, taking into consideration climate, health, agricultural, economic and other development perspectives. There were four sessions including plenary, panel and breakout sessions, which entailed several presentations and discussions. The highlights and recommendations from Day 1 are outlined below:

Climate Metrics

- It is important to ascertain the purpose for metrics, as climate metrics can be used for different reasons, including as a tool for assessing climate impacts, regionally as well as globally, for guiding or informing policy making, and for emissions/carbon trading purpose. Emissions/carbon trading requires a relative metric value which compares substances – for example, the global warming potential (GWP) which compares the climate impact of other substances with that of CO_2. In some circumstances, because short-lived and long-lived substances effect the climate over very different timescales, a single comparison metric that implies equivalency may be misleading. In contrast, absolute metrics provide a direct linkage between an emission and their climatic and other impacts.
- Given that the Coalition's objective is to address short-lived climate pollutants in order to slow the rate of near-term climate change, it was concluded that the Coalition should focus on metrics that can be used to assess the near-term benefits from emission reduction rather than focus on metrics for long-term climate stabilization.
- Several emissions metrics were highlighted during presentations and discussions including GWP, the GWP*, a two-valued GWP metric, the Global Temperature-change Potential (GTP), the Absolute Global Temperature-change Potential (AGTP) and the Absolute Regional Temperature Potential (ARTP). Box 1 provides the description of these metrics.
- ***Recommended metrics***: based on current scientific knowledge, participants agreed that the mean AGTP25 is a reasonable metric for assessing the impact of different substances (including long-lived and short-lived substances) on near-term global warming as well as the effectiveness of emissions reduction in mitigating the rate of warming in the near term.
- AGTP was discussed, among others, in the IPCC Fifth Assessment Report (AR5) as a potential metric depending on the purpose[xviii]. AGTP provides estimates of the temperature change for a given year for a given emission profile. These metrics incorporate the radiative efficiency and lifetime of emitted substances (or climate drivers produced from those substances) and the time-dependent response of the climate system to estimate the surface temperature response to a tonne of emission over time.
- The 25-year timescale chosen here for the AGTP is illustrative, and was selected because simulations indicate that there is at least a 50% likelihood of exceeding 2°C warming during the 2040s under a reference scenario, and because this time-scale is comparable to the timescales of societal/technological transitions (e.g., air quality improvements) and the implementation of policies to achieve the SDGs by 2030.[xix]
- The AGTP can therefore be used to calculate the progression of temperature change in annual time steps and thus compare the influence of different emission scenarios on regional and global temperature change over a short or long time period. This means that the AGTP takes into consideration timescale and continuity of emissions reduction actions and how such actions contribute to achieving warming targets at any timescale (e.g. near-term or long-term temperature targets). Hence, the AGTP can provide an estimate of temperature change from emission increase or reduction over the course of the century if the emissions over this time frame for all required substances are available. It also does not compare the climate impacts of different substances but provide the warming impacts of each substance separately. However, the AGTP is a function of climate sensitivity and the rate of heat uptake by the oceans, increasing the uncertainty of the metric.

Box 1: Climate Metrics Definition	
GWP	The GWP is a relative index that enables comparison of the global climate effect of the emissions of various greenhouse gases (and other climate warming substances). Carbon dioxide is chosen as the reference gas. Technically, GWP is also defined as an index based on the radiative forcing of a pulsed injection of a unit mass of a given well-mixed greenhouse gas in the present-day atmosphere, integrated over a chosen time horizon [usually 20 years (GWP_{20}) and 100 years (GWP_{100})], relative to the radiative forcing of carbon dioxide over the same time horizon.
Two-valued GWP	The proposed two-valued GWP[xx] metric acknowledges the dominant role of GWP in the policy arena and its resistance to replacement, and therefore proposes that warming impacts should be reported based on (1) the 20- and (2) 100-year timescales together as an inseparable pair (similar to the reporting of systolic and diastolic blood pressure and city and highway gas mileage). Regardless of whether 20 and 100 years are the most appropriate time horizons, they have evolved as defaults within the climate policy community, just as GWP is the default metric. Because 20 and 100 year timescales capture near- and long-term climate effects, this simple dual-GWP approach may help clarify the temporal tradeoffs.
GWP*	The GWP* is a newly proposed GWP-based metric that accounts for the near-permanence of the atmospheric CO_2 perturbation resulting from a pulse of CO_2 emissions. It is a calculated equivalency between the pulse emission of CO_2 and a sustained emission of SLCPs. That is a permanent increase of 1 tonne yr^{-1} of SLCP = a one-off CO_2 emission of GWP* tonnes. Unlike other metrics which generally either provide an equivalency for an integrated value (the GWP) or at a single point in time (the GTP) but generally ignore the temporal path that led to that equivalency, the GWP* yields very similar impacts over the entire time period.[xxi]
GTP	The Global Temperature-change Potential (GTP) represents the global temperature change at a given time due to either a pulse emission of a unit mass of a gas (or other climate forcing agent) or a sustained emission change relative to a similar emission change of CO_2. The GTP is therefore a cause-effect type metric, based on assessing the temperature that might be reached in future years and can be linked directly to adopted temperature targets. Technically, it is defined as the ratio between the global mean surface temperature change at a given future time horizon following an emission (pulse or sustained) of a compound relative to a reference gas (for example CO_2)
AGTP	The Absolute Global Temperature-change Potential (AGTP) represents the temperature change at a given time due to a pulse emission of a unit mass of a gas (or other climate forcing agent) at a given time. Hence the AGTP represents the GTP without comparison to a reference gas. The average temperature change for each year over a particular time period (usually years) can be calculated using the AGTP metric (defined above) from the time of a pulse emission of a gas (or other climate forcing agent). For example, the mean $AGTP_{25}$ for a particular climate forcing agent is the average temperature change over 25 years calculated using the AGTP metric for each year over the next 25 years following a pulse emission of the climate forcing agent.
RTP & ARTP	The concept of Regional Temperature-change Potential (RTP) and Absolute Regional Temperature-change Potential (ARTP) extend the GTP and AGTP metric concept to include surface temperature changes at the regional level due to regional emissions.

- *Regional climate metrics*: Mean AGTP25 provides global-mean temperature change and does not traditionally account for the potential dependence of the temperature change where the emissions occur. This is expected of global metrics as they usually hide regional details, from driver (emissions) to temperature impact or response. However, global metrics can also be established for emissions in separate source regions (and potentially seasons), allowing the possibility of capturing how emission location matters for the subsequent impact on global climate.[xxii] For example, mean AGTP25 can be scaled by the regional value for an emission of black carbon relative to the global mean value both calculated for another metric (e.g. GWP_{100}) as the regional/global ratio is largely independent of metric.
- Regional metrics are particularly useful in the case of the Arctic (latitude bands), but increasingly more fine resolution of regional climate impacts is possible, which is especially the case for snow and ice regions (Himalayas, Alps etc.) where black carbon impacts are far greater.[xxiii]
- Some studies have examined AGTP for emissions of various substances in selected regions/sectors and further work could expand this to additional source regions. To capture regional variability of climate impacts,

the average temperature change in four latitudinal bands can be calculated using a regional variance of the AGTP; that is the Absolute Regional Temperature change Potential (ARTP)[xxiv].

- *Emissions data requirements*: All emitted substances that effect radiative forcing must be reported to accurately calculate the temperature response from any mitigation action made to a particular emission source. Specifically, these substances include CO_2; methane; black carbon, organic carbon, sulphur dioxide; HFCs; NOx; carbon monoxide, N_2O; ammonia; non-methane Volatile Organic Compounds (VOCs) and where possible intermediate volatility organic compounds (IVOCs). Estimates for these emissions are needed for the present year and future years included within scenarios as well as the regional distribution of emissions.
- *Further priorities and considerations*: Given that there already exists a globally accepted metric for long term climate warming (climate stabilization) and that the choice is in the purview of the UNFCCC, the group did not propose any metrics for this. However, the group discussed examples of metrics that are scientifically useful, for example the GWP* which can provide equivalencies for impacts on long-term warming, or for estimating the absolute temperature increase in any year using the AGTP. It was further noted that moving from GWP would have cost implications giving that international frameworks are already using GWP as metrics for comparing the impact emissions of different substances have on warming.
- Furthermore, more work is needed to develop robust metrics for estimating the regional impact of emissions, for example weather: including regional surface temperature change and change in precipitation patterns in different world regions. Also, estimates of permafrost release of carbon[xxv] and/or ice sheet melt in relation to regional (Arctic, Antarctic, Himalayan Plateau) changes in temperature are becoming more fine-tuned and can be addressed climate impacts (permafrost thaw, loss of sea ice/snow cover and related albedo) or social impacts (sea-level rise).To determine how this could be best done, targeted discussions about what such a metric should look like (e.g., whether it should build on the currently used ARTP) and its intended application would be useful.

Health Metrics

- Many methodologies exist for evaluating health impacts from air pollution and many of these methodologies are relatively advanced in their use. Examples of existing methodologies include those used in the Global Burden of Disease (GBD) analysis, the World Health Organization (WHO) methodology[xxvi], as well as those used by regulatory authorities in various countries such as the US EPA Regulatory Impact Analysis and the External Cost of Energy (ExternE) Impact Pathway Analysis used for instance in evaluation of Clean Air For Europe program (CAFE).
- Typically, health metrics used to estimate global health impacts and their values have included: Premature mortality (or mortality attributable to air pollution) resulting from ambient and household exposure to $PM_{2.5}$ and ozone; Years of Life Lost (YLL); Years Lived with Disability (YLD); and Disability Adjusted Life Years (DALYs). Box 2 provides definitions for these metrics.
- ***Health impact and valuation metrics***[xxvii]: it was agreed that the Coalition should promote health impact and valuation metrics that have been accepted by the GBD, the WHO and other international bodies such as the European Commission and OECD. Furthermore, health metrics used by regulatory authorities in various countries, which in some cases can be used more widely, could also be promoted. It is also important that the Coalition is conversant with constant updates to existing metrics in the peered-reviewed literature, and should seek to evaluate these updates for quality and transferability, in order to be able to justify them for use by the Coalition and its partners.
- One advantage of adopting metrics that have been accepted by the GBD and the WHO is that these methodologies are constantly being assessed within the scientific community. Hence, as knowledge continues to evolve in the field, the metrics being promoted by the Coalition, if consistent with the GDB, would evolve as well.

Box 2: Health Metrics Definition	
Premature mortality	A death that would not have occurred in the absence of the air pollution exposure or deaths brought forward due to exposure to air pollution
Years of Life Lost (YLL)	The number of years someone would have lived had they not died prematurely due to air pollution. Also, defined as the years lost due to premature mortality, calculated by subtracting the age of death from the standard age-specific life expectancy
Years Lost due to Disability (YLD)	Years of life lost due to less than ideal health, calculated as the prevalent number of cases multiplied by a disability weight for that condition
Years Lived with Disability	Years lived in less than ideal health, calculated as the prevalence of the condition multiplied by disability weight for that condition
Disability Adjusted Life Years (DALYs)	One year of healthy life lost, calculated as the addition of YLL and YLD

- *Exposure metrics*: The exposure metrics used by the GBD related[xxviii] to ambient exposure are recommended. Essentially this needs to include the impact of long- and short-term exposures. For $PM_{2.5}$, the annual average $PM_{2.5}$ concentration or population-weighted annual average $PM_{2.5}$ concentration will be required. For ozone, the daily maximum one hour concentration over 6 months[xxix] with the highest ozone concentration (Jerrett et al.[xxx]) or annual average daily maximum 8 hour concentration (Turner et al.[xxxi]) is needed.
- Concentration-Response Functions (CRF) are used to quantify the number of deaths and illnesses associated with a unit change in air pollution. These are used to assess the impact of different levels of exposure of an organism to an air pollutant within a specific time period and are needed in estimating health impacts and outcomes. Different CRF have been used to assess the effect of exposure to ambient $PM_{2.5}$, which includes black carbon. One example is the Integrated Exposure Response (IER), (developed for the GBD[xxxii] and used to characterise the causes of mortality due to stroke, heart disease, lung cancer and chronic obstructive pulmonary disease (COPD) as well as acute lower respiratory infections (ALRI) in children less than 5 years old), which has been applied increasingly in a wide range of case studies in the literature. Whilst the IER is still being assessed for its role in decision-making, it is recommended the Coalition promotes it because of its wide acceptance, including by the GBD and WHO communities.[xxxiii] Some regional alternatives may also be appropriate where backed by good evidence (for example in the EU or North America, drawing on epidemiological studies specific to those regions). It should be noted that the IERs only cover a subset of health outcomes known to be associated with air pollution, and thus their use likely underestimates the total health burden.
- For the impact of long term ozone exposure on premature mortality, the GBD study has used CRFs developed by Jerrett et al.[xxxiv] for total respiratory deaths or for COPD deaths. However, established CRFs exist for the acute health impacts of short-term exposure to ozone including for mortality and morbidity (hospital admissions, asthma symptoms, restrictions on activity, etc.). The WHO HRAPIE – (Health Risks of Air Pollution in Europe) recommended using the daily maximum 8-hour mean for a range of health outcomes[xxxv] with a threshold of 35 ppb but the more recent review by the UK Committee on the Medical Effects of Air Pollutants recommended the use of a zero threshold.[xxxvi]
- There are other health impact outcomes that have a well-documented causal relationship with PM and ozone but that are not effectively represented by the above suggested metrics such as emergency room visits, doctors' visits, school absence, lost work days, respiratory symptoms, medication use, lung function decrements, and incidence of diseases such as asthma attack, inflammation, and cardiac effects. CRFs have been used in the US and the EU to project these types of health outcomes and such methodologies are worth considering as possible indices that the Coalition could also promote. This is particularly so because these indices maybe more understandable by decision-makers and the general public and therefore may be more effective in influencing policy decisions. However, the use of these indices, or more-specifically their economic or quality of life implications, needs careful consideration to understand if they are relevant in the context of a particular country.
- *Emissions data requirements*: As in the case of climate impacts, all emitted substance must be included in the assessment of health outcomes, including co-emitted pollutants and precursor gases so that the health indices reflect the benefits of the full emission reduction achieved. This will vary by source. Hence, for the health

outcomes due to $PM_{2.5}$, primary particle emissions of black carbon, organic carbon and mineral particles as well as secondary particles including sulphur dioxide, NOx, ammonia, VOCs and IVOCs should be reported. For health outcomes due to ozone, all ozone precursors including methane, carbon monoxide, NOx and non-methane volatile organic compounds should be reported.

- *Important considerations*: it is also important to note that many of the existing methodologies for assessing health impacts have already been adopted and are being used in many countries. Hence, such countries may not want to change without sufficiently convincing reasons. It is therefore imperative that the Coalition is sensitive to this situation when encouraging new (or modifications to existing) metrics.
- Furthermore, as indicated earlier, it is important to consider the targeted audience when choosing health metrics since different stakeholders understand health outcomes differently. For example, DALYs are a useful metric to many health professionals, but are not always well understood by other stakeholders, for whom the use of a mortality or life expectancy metric may be more understandable. And for many other stakeholders, the direct impacts from daily exposure of people to pollutants (such as emergency room visits, doctors' visits, school absence, lost work days, and others mentioned above) can be particularly useful.
- While the quality of life based measures, such as DALYs and QALYs, suit well for carrying the cost-effectiveness analysis and are not suited for the benefit-cost analysis, the economic valuation of specific health outcomes including premature mortality through the willingness to pay suit well for performing welfare impact and the benefit-cost analysis. However, more work is required to test the wider use of the direct impacts metrics in developing countries, for example, where fewer studies quantifying CRFs have been conducted.
- *Further work:* There is a lack of data on the exposure-response relationships between air pollution and many health outcomes at high exposure levels observed in many low- and middle-income countries where a small change can have a large difference in the reported indices. However, while awaiting future studies, the IERs provide useful estimates of the high-exposure CRFs.
- It would also be useful to further develop methodologies that take into consideration the impacts of exposure to pollutants on the quality of life of affected people, that is, metrics that could be seen as 'quality of life indicators'.
- Further, there is insufficient evidence that black carbon is more or less toxic than $PM_{2.5}$ overall. However, there is some evidence for heightened health potency of black carbon as compared with other PM components (see e.g., Janssen et al., EHP 2011) and some recent studies have directly linked black carbon to respiratory disease as well as with cardiovascular outcomes than $PM_{2.5}$ in a number of studies[xxxvii]. It would be useful to do more work on the health impacts of black carbon to understand whether there are different health effects for components of $PM_{2.5}$.
- There is also a need for a finer spatial scale for exposure assessments and to improve tools used in estimating the impacts. Since non-fatal health outcomes are sometimes more tangible and understandable to different audiences, some work is needed to develop methods for quantifying benefits of particulate matter, including black carbon, and methane mitigation in terms of avoided non-fatal health outcomes. The various multi-national air pollution health impact assessment tools should also be compared to improve understanding of different methods and health impact estimates.

Agricultural and Vegetation Metrics

- Emissions of climate altering pollutants can affect ecosystems via multiple pathways. For example, ecosystem structure and function, including species composition, crop yield and forest productivity, can be affected by changes in ground-level ozone concentrations (which are toxic to plants), by changes in aerosol optical depth due to $PM_{2.5}$ including black carbon (which will alter radiation quality and quantity affecting photosynthesis and hence growth and productivity), changes in CO_2 concentration (which may enhance photosynthesis for some plant species - especially those which have a C3 photosynthetic mechanism - through the 'CO_2 fertilization effect') and by changes in climate (temperature, rainfall etc.) which can alter environmental limits of ecosystem growth, productivity and functioning.
- ***Recommended metrics***: one metric that has been widely used to access the impact of emissions on crops and vegetation is relative yield loss (expressed either as a percentage of expected yield or as total amount of loss in tonnes). This metric is recommended for evaluating the impact of emissions on crop yield.
- Like in the case of health metrics, CRFs are used to assess the impact of different levels of exposure of plants or ecosystem to air pollutants within a specific time period and are needed in estimating agricultural and vegetation impacts and outcomes. CRFs have been developed for rice, wheat, maize and soybean[xxxviii] and have been widely used to estimate yield loss. CRFs also exist for other crops that could also be used.

- Other agricultural impact metrics focus on effects of emissions on crop or vegetation quality (rather than quantity), for example forage quality, grain protein and energy content. Such quality metrics may be important for processes (such as bread making and brewing) where specific aspects of grain quality could affect product quality. Hence, quality impacts metrics would be "crop" and "use" specific.
- *Exposure metrics:* Historically, ozone exposure to crops has been assessed through concentration-based exposure metrics which have been successfully used to develop statistically robust CRFs with crop yields. These include:
  - M7 and M12, defined as the 7 and 12 hour mean ozone concentration over growing season respectively;
  - AOT40: accumulated concentration above 40 parts per billion over a growing season
- However, the emissions impact on crops is more closely related to the ozone that is taken up into the leaves through the stomata than the amount of ozone that crops are exposed to and hence a "flux-based exposure metric" (rather concentration-based exposure metrics) is considered to be more biologically relevant (and has now been adopted in Europe) and is the best metric to relate ozone impacts on crops. It would therefore be useful to explore whether existing CRFs could be used to define flux response relationships, at least in terms of defining groups of crops of differing sensitivities (i.e. sensitive, moderate and resistant crops).
- *Emissions data requirements*: In order to be able to estimate the impacts due to ozone on crops and other vegetation, ozone concentration will need to be characterised and this will require information on the emissions of all ozone precursors in different regions, including methane, NOx, carbon monoxide and non-methane Volatile Organic Compounds.
- *Further work*: Apart from the above impacts, pollution causes other effects such as changes in soil carbon. There is currently not enough information to quantify these impacts and it is recommended that future research explore this further to better understand the size of effects.
- Also, there is a need to identify robust CRFs (or ideally flux–response functions) for additional crop species beyond those that already exist, as well as for pasture and forest biomass so that estimates of crop impacts due to ozone can be produced.
- With regard to aerosols and black carbon impacts on vegetation, there is a dearth of information, and little is known of the existence of any exposure metrics for the impact of these pollutants on agriculture or ecosystems. This is a knowledge gap that needs to be addressed. A modelling approach combining the different pollutant influences on crop growth (i.e. aerosol and ozone in combination) may offer the best approach for providing further information on the trade-offs and associated absolute exposure metrics between ozone (which will reduce biomass and yields) and aerosols (which may increase biomass and yields through an enhancement in diffuse radiation).
- Climate changes also affect crop growth, yield and quality and a lot of work has been done on this, particularly by the IPCC. However, the effects of climate change (e.g., temperature and precipitation changes) in combination with ozone, aerosols and black carbon on crops and vegetation in different regions have not yet been explored. These interactions are difficult (resource intensive) to investigate through empirical study. However, it may be possible to assess these impacts (and trade-offs) through the development of models (to assess the effects of multi-pollutants). The outcome of such modelling could then be used to develop and implement empirical investigation
- *Follow up actions*: to develop flux calculations in order to use flux-response relationships, in addition to exposure-response relationships.

Economic Valuation of Impacts/Metrics for Financing

- Economic valuation provides estimates of the monetary costs associated with the impacts of emissions to society, as well as the monetary value of benefits (climate, health, agriculture etc.) that can be achieved through mitigation action. Standard methods exist for deriving relevant direct market cost estimates, for example, the direct market costs of air pollution on the health expenditures, for different countries.[xxxix]
- Standard methods are also available for quantification of non-market benefits such as improved wellbeing. Methods are available to transfer estimates to countries and regions where costs have not been estimated directly under existing research. However, further discussion on the precise metrics to be used will be needed in some regions, recognising that 'human capital approaches (HCA)[xl]' are considered outdated (and not in line with welfare economic theory) in Europe, North America and elsewhere where measures of welfare are preferred.
- Indirect costs due to secondary effects, for example a shift in trade or crop substitution due to impact of air pollution or climate change, are more challenging to estimate and there are substantial differences between the methods and standards used in different parts of the world.

- ***Recommended metrics***: The "social cost" of emissions is a type of economic metric that attempts to incorporate monetized market and non-market impacts over time. This has mostly been used to account for the climate, human health, and agricultural impacts when they occur via climate change, with particular focus on CO_2 emissions. However, several recent studies are now addressing social cost of methane, incorporating both climate change- and air quality-related impacts.
- An estimation of the "social cost" of the different released atmospheric substances is recommended as a method (metric) for assessing monetary or economic value of both the climate and air quality impacts of emissions or of the benefits from emissions mitigation, incorporating the climate, health and agricultural aspects (Table 1).
- For the economic valuation of health impacts/benefits, several metrics (which are already incorporated into social costs) have been used. Impacts on morbidity consists of the "cost of illness[xli]" that comprises the medical treatment costs and loss of productivity due to sickness, and "willingness to pay[xlii]" to avoid suffer, pain, and other inconveniences if one gets ill. Impacts on premature mortality is usually valued through "value of a statistical life[xliii]" when VSL is derived from the willingness to pay for reducing risk of dying. Some argue to also consider "forgone output[xliv]" especially in the cases when the above metrics can't measure certain impacts, for instance, when pollution directly affect labour productivity (not through sickness day) or when health system is not properly functioning (especially in developing world).
- For the valuation of crop yield impacts, only direct costs based on the market value of crops tend to be estimated and this remains very useful. However, recent modelling studies have also estimated the indirect market costs, including substitution by other crops and changes in trade patterns. Nevertheless, a focus on market transactions neglects impacts on subsistence farmers excluded from the formal economy and does not capture the effect of changes in, for example, grain quality on nutrition. Assessment of variations in vulnerability of different communities around the world to different threats is therefore relevant even when impacts are valued using conventional approaches.
- *Data requirements*: As shown in Table 1, estimating "economic values" takes into consideration the emissions, exposure and impact metrics recommended for climate, health and agriculture. Hence, the estimation will require data from the full chain described by these metrics parameter as shown in Table 1. Although this may appear challenging in the extreme, it is to be noted that analysis at a global, country by country, level has already been achieved.

Metrics Parameter	Climate [Stabilization][xlv]	Climate [Rate of Change]	Health	Agriculture and Vegetation
Emissions	Tonne/yr *[CO_2e and tonnes of each emitted substance affecting climate]*	Tonne/yr *[CO_2; CH_4; BC; OC; SO_2; HFCs; NOx; CO; N_2O; NH_3; nmVOC]*	Tonne/yr *[$PM_{2.5}$ / O_3 and precursors – of $PM_{2.5}$ include BC, OC, mineral dust, NOx, SO_2, NH_3]*	Tonne/yr *[O_3 precursor emissions – NOx, nmVOC, CH_4, CO]*[xlvi]
Exposure	GWP GWP* AGTP (year)	Mean AGTP25	Population weighted annual average µg/m^3 Daily maximum 8-hour mean daily maximum one hour ozone concentration averaged over 6 months annual average ppb (8-hr max)	M7 M12 AOT40 Ozone flux
Response impact and benefits (domestic/global public good)[xlvii]	Temperature (°C)	Temperature (°C) 25 years out Mean Temperature (°C) over 25-yr Temperature (°C) by region/latitude bands	Equivalent Attributable Deaths & Illness Attributable deaths Years of Life Lost (YLL) Other metrics accepted by GBD/WHO communities	Tonnes of yield loss/yr for four staple crops[xlviii], and other crops, vegetation types for which there are agreed CRFs
Economic valuation (domestic: global public goods)[xlix]	Social Cost of Carbon[l] Social Cost of Methane[li]	Social Cost of Methane[lii] Social Cost of Black Carbon[liii] Social Cost of Atmospheric Release	DALY = YLL+YLD Cost of Illness Willingness to Pay (WTP) Value of a Statistical Life (VSL) Forgone Output	US$/Tonne of each staple (and other crops as appropriate)
Finance (Price)[liv]	Will be set by regulations and market			
Policy objectives	SDG 13: <2°C in 2100	1.5 - <<2.0˚C in 2100 25-year rate of warming target	SDG 3 WHO AQ Guidelines	SDG 2

- *Financing mitigation actions*: The metrics in rows 1-4 of Table 1 can feed into policy making at national scales for example, or they can be used to accelerate finance at scale. In order to better understand how this data can be used for these different purposes, especially financing projects, it is recommended that a market assessment analysis be conducted to understand what attributes of SLCPs interventions are in demand by philanthropic donors, finance professionals and potential market participants for potential indicators. Such a study should also consider what form these attributes should be, for effective finance (e.g. a separately certified attribute, or some kind of verified enhanced attribute to existing Certified Emission Reductions (CERs) such as Clean Development Mechanism (CDM), Emissions Trading System (ETS) or Regional Greenhouse Gas Initiative (RGGI) certificates).
- This will help the CCAC consider the use of potential finance products for policy development (regulation) and market based mechanisms to reduce emissions (finance). Further work to provide knowledge on how

different policy making and financing mechanisms would use scientific information would be useful to improve the development and use of metrics.

- The fact that estimates of the mortality burden of air pollution extend to several million deaths annually should not necessarily be regarded as 'bad news'. In the sense that we have identified a substantial burden on mortality, and know what can be done to reduce that burden, this is the start of a good news story provided appropriate action is taken. This is an important message that should be used to influence organisations that may be willing to finance necessary actions.
- *Future research needs*: while there are many indicators and impacts that can be currently quantified and valued, work remains to be done to make benefits assessment more accurate and more comprehensive. For example, while current methods value the financial cost of lost productivity, and welfare approaches estimate the utility of good health. Additionally, tools are available that estimate the routine crop losses associated with changes to average atmospheric concentrations of ozone. These tools can now be updated with methodologies based on ozone fluxes through stomata in the leaf surface, which has been implemented in the EMEP model for use under the LRTAP Convention. These approaches are more accurate determinants of plant health and should be routinely used in calculators and models. Impacts of decisions surrounding burn or no burn regulations should be incorporated into such tools as these decisions have quantitative impacts on crop yields.
- Health impacts related to climate change, such as changes in malnutrition due to climate change, need to be included in valuations. A lot of work is being done to look at sensitive areas – most vulnerable areas at the moment are forecast to get worse. Also, food supply needs to be related to food access, including the purchasing power of different parts of society. Further work could also look at sensitivity of food supply, impact on food security, including supply, access and affordability.
- *Follow up actions*: A balanced and comprehensive framework is needed to assess the robustness of estimates. The term 'balanced' is important: discussions of robustness seem to inevitably focus on 'uncertainties' to the exclusion of things that we know with a very high level of confidence (here described as 'certainties'). So, for example, whilst there may be debate about whether to use the GBD Integrated Response Functions in a specific place, there should be no debate that the mortality effects of exposure to fine particles are real. This is supported by the results of thousands of research papers and the conclusions of numerous expert groups that have reviewed them. The development of a systematic robustness assessment method or tool is most appropriate at the economic end of the analysis as this stage needs to capture the full effect of uncertainty through the full impact pathway from demand for (polluting) services, to quantification of impacts, and their valuation, and then to the comparison of costs and benefits. Analysis at this stage can highlight the most policy relevant uncertainties elsewhere in assessment, providing a mechanism for precise targeting of further research on the parameters of most concern. A framework for such assessment already exists in work for the European Commission, though has found little application so far. Review and possible refinement of this framework offers a way of moving forward on this aspect quickly.

DAY 2: BLACK CARBON EMISSIONS INVENTORY AND REPORTING

Summary: The objective of Day 2 was to agree on a way forward on the development of widely applicable emission inventory methodology and reporting guidelines for black carbon. The day featured three sessions including two plenary sessions and a breakout session. The highlights and recommendations are outlined below:

Black carbon regulatory and policy framework

- There is currently no global agreement for addressing black carbon emissions from either a climate or air pollution perspective. Within the EU and among other member countries of the UN Economic Commission for Europe (UNECE), black carbon is indirectly addressed as an air pollutant under the 2012 amendment to the Gothenburg Protocol[lv], which requires a reduction in the emission of $PM_{2.5}$ by 22% from 2005 levels by 2020. The Protocol specifically recommends that priority should be given to $PM_{2.5}$ sources with high black carbon fractions when implementing emission reduction activities and includes the voluntary reporting of black carbon emission estimates. The EU also has a National Emissions Ceilings Directive (NECD)[lvi] agreed in 2016 which promotes and prioritises the reduction of black carbon emissions in achieving the required reductions in $PM_{2.5}$.
- The Arctic Council's non-binding Framework for Action on Black Carbon and Methane is possibly the only example of countries committing to address black carbon from a climate perspective. In the framework. Member States committed to "reducing the overall black carbon and methane emissions from their countries" and to "work with Arctic Council Observer States and others to also reduce emissions produced

beyond the borders of Arctic States". Under the framework, Member States agreed to report on emissions and track progress.

- Several countries have specific air quality regulations or standards with targeted limits for particulate matter emissions driven by health effects. These can lead to substantial black carbon reductions from certain black carbon-rich sources. For example, there are regulations limiting PM emissions from diesel vehicles in the EU, the United States, Canada, China and several others.
- Mexico, Chile and Nigeria have specifically considered black carbon mitigation in their Intended Nationally Determined Contributions (INDCs) with Mexico pledging an unconditional 51% reduction in black carbon emissions by 2030, compared to business as usual, and increasing to up to 70% dependent on provision of support. Other countries address black carbon through their PM strategies as complementary to their INDC strategies. Furthermore, the State of California in the United States recently developed a SLCPs reduction strategy[lvii].
- Overall, there seems to be no direct action to directly regulate ambient black carbon concentrations. This could be due to the lack of agreement on the direct toxicity of black carbon as opposed to total $PM_{2.5}$. The ambient concentration of black carbon is primarily addressed through ambient health standards for PM and for many countries, BC levels have already begun a significant downward trend and are projected to come down even further. Regulation of ambient black carbon concentrations would be inhibited by the absence of a standard measurement method, although work is under way in Europe and North America to develop such a method. Advances in standard measurement methods and information on the direct health effect of black carbon could facilitate further focus on black carbon.

Status of black carbon emissions inventory/reporting and challenges

- The leading example of black carbon emissions inventory development is the United Nations Economic Commission for Europe's (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP). For this effort, additions have been made to the EMEP/EEA Emissions Inventory Guidebook, to provide methodologies that are fully consistent with IPCC guidelines for greenhouse gases.[lviii;lix] An inventory of black carbon emissions between 1990 and 2014 in the 28 EU member states was published based on this guidance[lx]. The United States and Canada, as signatory to CLRTAP, have also produced black carbon inventories using a comparable methodology. The methodologies provided in the EMEP/EEA [lxi] Emissions Inventory Guidebook are also the basis for the black carbon inventories developed by all eight Arctic States and their eight observer organizations[lxii].
- Another example of black carbon inventory development is the CCAC-supported "Long-range Energy Alternatives Planning system-Integrated Benefits Calculator" (LEAP-IBC). The tool, which was used to support some CCAC member states in their inventory development, has the advantage of being able to calculate emissions of not only black carbon, but also co-emitted substances. This is a feature that is important to effectively estimate the climate, health and agricultural benefits of emissions reduction (see section on emissions data requirement in the highlights and recommendations from Day 1).
- Black carbon inventories are also being developed in several countries outside of the CLRTAP geographical scope, including in Mexico, Nepal, Chile, India, China, and Japan,[lxiii]. There are also several academic works on the development of source specific, regional, or global emission inventories[lxiv]. Many of these support the development of guideline protocols or emission factor databases used in several tools and models.
- Despite recent successes in black carbon emission inventory development, there are still significant challenges to developing robust and reliable inventories. These include:
  - Most of the time emission factors used in inventories depend on what is available in peer-reviewed literature. This evidence base can result in very high uncertainty ranges, even where there have been multiple studies on a specific source type in a specific geographical region.
  - Black carbon inventories will be more useful when they include emissions of co-emitted substances such as organic carbon or other pollutants impacting climate and health. Unfortunately, some sources of black carbon do not have emission factor values for the co-emitted substances. Additional effort is needed to determine these emission factors as they are not typically collected when estimating black carbon.
  - Existing guidance and methodologies do not have adequate coverage geographically or for different emissions sources. Guidance may therefore not be applicable in different locations, and methodologies cannot be easily transferred from one emitting sector to another. Furthermore, emission factors used in

one geographical region may not be readily transferable or applicable to other regions because of difference in environmental conditions.

- There are still significant uncertainties associated with estimating black carbon emissions. The issue of large uncertainties (which can undermine comparability and interpretation) was a key finding of the IPCC expert meeting on aerosols in 2005.
- There remains a challenge of standardized direct black carbon measuring methodology for various emission sources. For example, it is considered probable that the black carbon emission methodologies in the EMEP/EEA Emissions Inventory Guidebook represent a mixture of different emission metrics, such as black carbon, elemental carbon and organic carbon.
- The development of guidelines for inventory development as well as efforts to develop the inventories themselves face resource constraints. One reason for this is because black carbon is not seen as a priority within the air quality and climate discourse.

RECOMMENDATIONS

Inventory and reporting objectives and goals

- Given that a black carbon emission inventory by itself is less useful, and that full information on co-emitted substances is needed to estimate the benefits of emission reductions, it is recommended that the focus should cover all $PM_{2.5}$ precursors and not just black carbon. Hence, the goal should be to develop inventories for pollutants giving rise to $PM_{2.5}$ concentrations in all sectors and regions. This includes speciation information of all co-emitted substances including black carbon, organic carbon, SO_2, NOx, etc.
- Where inventories for $PM_{2.5}$ already exist, these can serve as a starting point for the compilation of black carbon emission estimates. It is also recommended that a top-down and bottom-up approach be adopted for inventory development. The results from the two approaches could then be compared for convergence, which may help reduce uncertainties. An important starting point for this is gathering basic activity data for different sectors needing improvement (see below). This can then be followed by refinement to improve consistency and accuracy.

Sectoral gap in black carbon emission inventories

- The following sources were identified as lacking adequate black carbon emissions inventories and reporting protocols: the mining sector, off-road transport, the shipping industry, diesel generators, flaring, household energy (cook and heat stoves), open agricultural burning, trash burning, and forests/savannah fires. With regards to on-road transportation, especially in developing countries, there is a gap in accurate emission factors that takes into consideration deterioration of imported second-hand vehicles. There is also a possibility that there exist sources of black carbon that are currently unknown.
- However, it was noted that emission factors exist for most sectors in the academic literature (although with wide ranges and associated uncertainties) and these need to be built upon in order to ensure accuracy and consistency and improve data quality across regions.

Data collection and reporting

- Given that CLRTAP is considered to provide the most progressed guidance on estimating black carbon emissions, any improvement to reporting guidelines and protocol should start there. However, it is noted that the CLRTAP's EMEP/EEA Emissions Inventory Guidebook was compiled with a somewhat European focus. The LEAP-IBC tool can help countries (especially outside of the EU and North America) develop their inventories, prior to the development of adequate guidance relevant to their regional circumstances.
- It is recognized that there may be a need for regional initiatives, similar to the CLRTAP, to build similar inventory development momentum. There are existing regional/sub-regional air pollution initiatives in some regions that can be adapted to move this forward, for example, APCAP, Clean Air Asia and the Malé Declaration in South Asia.
- *Time series*: it is important that historical emissions data are revisited whenever methodologies are updated in order to ensure consistency and accuracy as well as to ensure correct historical data interpretation. Data collection and reporting should also be geared towards providing future emissions projections, taking into consideration current and future regulations/legislations and policy interventions.

- It is recognised that emissions reporting is a political decision, therefore reporting obligations should be voluntary and national estimates should supersede estimates developed outside of the national effort, e.g., in the academic literature.
- There is an array of possible bodies to whom emission estimates can be reported, including CLRTAP, UN Environment (as the UN agency with the mandate of "keeping the global environment under review"), the CCAC (although there are very few State members), WHO (because of health effect of black carbon and of climate change), UNFCCC (as the custodian of climate impacts; however black carbon is not included in UNFCCC substances). Ultimately, inventory development should be the immediate priority.

MOVING FORWARD

- There is a need to prioritize which emission sources to focus on: those with largest impacts, largest emission sources, largest mitigatable fractions, easiest to estimate, easiest to implement mitigation measures, or sources that have most political impact.
- There is a need consider how to improve emissions measurements in order to provide more accurate input data for the emissions inventories. One way is to make methodologies simpler, increasing the number of measurement trials, and making calibration gases more readily available (e.g., through creating a calibration gas network).
- It might be a good idea to develop different tiers of reporting that reflect increasing levels of granularity, improvements and sophistication. The idea will be that countries start developing their inventories at the lowest tier and then step up to higher tiers as capacity improves. This is the approach currently used for national reporting of both greenhouse gas and air quality pollutant emissions.
- It might be useful to convene a group of national inventory experts to identify the gaps, challenges, as well as best practices in different countries.

POSSIBLE CCAC ROLE

- The following were suggested as potential roles for the CCAC with respect to black carbon inventory development:
  - Support the collection of regionally-relevant activity data for the different black carbon emission sources and sectors.
  - Support the improvement in emission factors especially through the activities of CCAC initiatives; for example, partnering with the waste management community to develop emission factors for trash burning.
  - Support research institutions and help build institutional capacity aimed at supporting data gathering and building reporting expertise and knowledge.
  - Aid institutions applying for funding for inventory development purposes.
  - Work with leading organizations, such as CLRTAP and the LEAP-IBC community, to adapt existing inventory methodologies, support data and reporting protocols for ease of use by developing countries, and cover emissions sources that are currently lacking.
  - Convene inventory expertise from leading organizations and inventory practitioners from countries that might not otherwise have access to such expertise.
  - Achieve a relatively simple, but complete (Tier 1),[lxv] black carbon inventory for all countries.

Glossary

SLCP – Short-Lived Climate Pollutants
CCAC – Climate and Clean Air Coalition
HFCs - Hydrofluorocarbon
SAP – Scientific Advisory Panel
CO2e – Carbon dioxide equivalent
CO2 – Carbon dioxide
CH4 - Methane
BC – Black Carbon
OC – Organic Carbon
PM2.5 – Particulate Matter
O3 - Ozone
GWP – Global Warming Potential
GWP* -
AGTP – Absolute Temperature Potential
SO2 – Sulphur dioxide
NOx -
CO – Carbon monoxide
N2O -
NH3 - ammonia
nmVOC – non-methane Volatile Organic Compounds
M7 – seven hour mean ozone concentration over growing season
M12 – twelve hour mean ozone concentration over growing season
AOT40 – accumulated concentration above 40 parts per billion over a growing season
YLL – Years of Life Lost
YLD – Years Lived with Disability
GBD – Global Burden of Disease
WHO – World Health Organization
DALY – Disability Adjusted Life Years
EAD – Equivalent Attributable Deaths
WTP – Willingness to Pay
VSL – Value of a Statistical Life
SDG – Sustainable Development Goals
AQ – Air quality
UNFCCC – United Nations Framework Convention on Climate Change
CLRTAP – Convention on Long-Range Transboundary Air Pollution
LEAP-IBC – Long-range Energy Alternatives Planning system-Integrated Benefits Calculator
ARTP – Absolute Regional Temperature Potential
IPCC – Intergovernmental Panel on Climate Change
RTP – Regional Temperature Potential
IVOCs – Intermediate Volatility Organic Compounds
US EPA – United States Environmental Protection Agency
CAFE – Clean Air For Europe
ExternE – External Cost of Energy
OECD – the Organization for Economic Co-operation and Development
CRF – Concentration-Response Functions
COPD – Chronic Obstructive Pulmonary Disease
IER – Integrated Exposure Response
ALRI – Acute Lower Respiratory Infections
HRAPIE – Health Risks of Air Pollution in Europe
QALY – Quality-Adjusted Life Year
VSL – Value of a Statistical Life
Ppb – parts per billion
CER – Certified Emission Reduction
CDM - Clean Development Mechanism
ETS – Emissions Trading System
RGGI – Regional Greenhouse Gas Initiative
EMEP – European Monitoring and Evaluation Programme
UNECE – United Nations Economic Commission for Europe
NECD – National Emissions Ceilings Directive
INDC – Intended Nationally Determined Contributions
APCAP – Asia Pacific Clean Air Partnership

ANNEX 1: ANNOTATED WORKSHOP AGENDA

Climate and Clean Air Coalition
Scientific Advisory Panel Expert Workshop
"Metrics for Evaluating and Reporting on Black Carbon and Methane Interventions"
16-17 March 2017
ANNOTATED AGENDA

Overarching Objectives:

1. *Advance efforts toward a scientifically credible consensus on metrics for accounting for black carbon and methane interventions*
2. *Agree on a way forward on the development of a widely applicable inventory and reporting guideline for black carbon.*

DAY 1 – ACCOUNTING METRICS

Time	Duration	Agenda Item
08:30-09.00		**ARRIVALS AND REGISTRATION**
09.00-09.10	10 mins	**WELCOME AND REASON FOR WORKSHOP** *[Rita Cerruti, CCAC Co-Chair]*
09.10-09.25	15 mins	**KEYNOTE ADDRESS** *[Dan McDougall, Assistant Deputy Minister Strategic Policy Branch, Environment & Climate Change, Canada]*
09:25–10:25	60 mins	**SESSION 1 - PLENARY** **CONTEXT SETTING; LATEST SCIENCE AND KNOWLEDGE ON METHANE AND BLACK CARBON** ***Session Description and Objective:*** This session will aim to provide context for the overall goal of the workshop. It would include highlights of latest science and knowledge on black carbon and methane, including latest understanding of emissions sources, trends, projections and policy implication of current trends and projection. It will also feature presentation on the role of black carbon and methane in current global agreements and actions such as the Post-2015 Development Agenda including the Sustainable Development Goals (SDGs) and the Paris Agreement including the associated Nationally Determined Contributions (NDCs). The session will also highlight why having accounting metrics and methodology for quantification and reporting is important. **MODERATOR**: *Rita Cerruti* ***Presentations:*** • A pathway to achieving the climate and development targets and why metrics are needed 20 minutes *[Drew Shindell]* • Overview of recent science on black carbon and methane and their implications 20 minutes *[AR Ravishankara/V. Ramanathan, TBD]* • Questions and Discussions 20 minutes ***Expected outcome***: At the end of the session, participants would have a clear understanding of the context of the workshop and latest knowledge on methane and black carbon. It is expected that participants would have a common understanding of the emission sources, trends, projections and impacts of black carbon and methane, as well as their role in achieving the Paris Agreement and the SDGs, hence will be well prepared for the discussions on accounting metric and reporting. ***NOTE***: The moderator for this session would seek to gear the discussion towards ensuring that all participants have a common understanding of the latest knowledge on black carbon and methane and their role in the Paris Agreement and the SDGs. This will be important for achieving the overarching

		objectives of the workshop. **Background documents:** *Review of recent publications on methane and black carbon emissions and impacts; A pathway to the target paper; SLCPs and SDGs paper.*
10:25-10.45	20 mins	Health Break
10:45–12:30	105 mins	**SESSION 2 - PLENARY PANEL SESSION** **ACCOUNTING METRICS FOR BLACK CARBON & METHANE** ***Session description and objectives:*** This panel session would seek to discuss the latest knowledge on metrics for evaluating the impacts of black carbon and methane from the climate, health, agriculture, economic and development perspective. The session will set the stage for the breakout discussions, providing an overview of issues to be discussed in greater details during the breakout groups. **MODERATOR**: *Ray Minjares* • ***Panellist 1 – Metrics for evaluating the climate impacts of methane and black carbon interventions –*** A presentation on the general landscape of climate metrics for black carbon and methane. Talk would highlight available metrics, their merits and drawbacks, the uncertainties, and propose which of the available metrics are most appropriate with justification. *[Keith Shine]* 20 minute • ***Panellist 2 – Metrics for accounting for the health impacts of black carbon and methane interventions*** - A presentation on the general landscape of available metrics for accounting for the health impacts and benefits of black carbon and methane interventions, with highlights of the merit and demerit of available options and associated uncertainties. *[Susan Anenberg]* 15 minute • ***Panellist 3 – Metrics for evaluating the agricultural impacts of black carbon and methane interventions*** – A presentation on agricultural-related metrics to characterise black carbon and methane interventions. Presentation would provide insight on available metrics, their merits and demerits, the uncertainties, and propose which is most appropriate with justification. *[Lisa Emberson]* 15 minute • ***Panellist 4 – Economic perspective on accounting metrics for black carbon and methane interventions*** - A presentation on economic valuation of impacts related to black carbon and methane interventions, including market and non-market cost as well as some mention of implementation cost and monetization of the benefits. Presentation could also touch on appropriate metrics relevant to attracting black carbon and methane mitigation finance. *[Mike Holland]* 15 minute • ***Panellist 5 – Social impact of methane and black carbon and associated metrics*** - A presentation on the interactions between climate, health, agricultural and economic impacts of methane and black carbon emissions providing a context for appropriate metrics for accounting for these impacts. Presentation could also include the variation of impacts on different socio-economic groups as well as linkage to the SDGs *[Drew Shindell]* 15 minute • Questions, comments and discussions - 25 minutes ***Expected outcome***: This session will prepare the ground for further discussion at the breakout session after lunch. At the end of the session, all participants

		should have a clear understanding of the metrics that are out there, their merit and demerits. ***Background documents:*** *CCAC/SAP Paper: Good practice for quantifying, estimating, and reporting on SLCP interventions; relevant publications on accounting metrics, Brief on Quantification Methodologies for Black Carbon (BC) Reduction Benefits* NOTE: Moderator of this session should agree on breakout group participants before breaking for lunch
12:30-14:00	90 mins	Lunch Break
14:00-15:45	105 mins	**SESSION 3 - BREAKOUT GROUPS** **DEEPER DIG INTO ACCOUNTING METRICS** ***Session description and objectives:*** The breakout session will dig deeper into the various aspects of accounting metrics for black carbon and methane. There will be four breakout groups: climate, health, agriculture, and economic valuation. Each of the four groups will look into the impacts of methane and black carbon, the benefits of mitigation actions, and discuss appropriate metrics for quantifying these impacts and benefits. The overall goal will be to achieve some form of agreement and/or set of recommendations, at the end of the group discussion, on the appropriate metrics for characterizing these impacts/benefits, with adequate justification, further work as needed, remaining questions, and how to pursue the recommendations. The breakout group will start with 2 or 3 presentations digging deeper into the topics and would be followed by a moderated discussion. **SESSION MODERATOR**: *Johan Kuylenstierna* • **Group 1: Climate Metrics** *[Group Moderator – Borgar Aamaas]* ***Presentation 1***: How climate metrics work: climate impacts of methane and black carbon and relevance for metrics development *[Marianne Tronstad Lund] - 15 minutes* ***Presentation 2:*** Accounting metrics for climate impacts and benefits of black carbon and methane interventions; challenges and barriers: a deeper look. *[Tami Bond] - 20 minutes* ***Moderated group discussion*** - 70 minutes • **Group 2: Health Metrics** *[Group Moderator – Jeff Brook]* ***Presentation 1:*** How health metrics work: Health impacts relevant to estimating the impact of BC and methane interventions and relevance for metrics development *[Jill Baumgartner] - 15 minutes* ***Presentation 2:*** Accounting metrics for health impacts and benefits of black carbon and methane interventions; challenges and barriers: a deeper look. *[Patrick Kinney] - 20 minutes* ***Moderated group discussion*** - 70 minutes

		• **Group 3: Agricultural Metrics** *[Group Moderator – Harry Clark]* ***Presentation 1***: How agriculture metrics are developed: agricultural impacts relevant to estimating the impact of BC and methane interventions and relevance for metrics development *[Fidelity Hayes] - 15 minutes* ***Presentation 2:*** Accounting metrics for agricultural impacts and benefits of black carbon and methane interventions; challenges and barriers: a deeper look. This should also include the climate and air pollution impacts on agriculture *[Keith Smith] - 20 minutes* ***Moderated group discussion*** - 70 minutes • **Group 4: Economic Valuation and Metrics** *[Group Moderator – Gary Kleimann]* ***Presentation 1:*** Economic valuation of the impacts of black carbon and methane mitigation from climate perspective and relevant metrics *[Steffen Kallbekken/Stine Aakre] - 20 minutes* ***Presentation 2***: Economic valuation (market and non-market) of the impacts of black carbon and methane interventions from development perspective and relevant metrics *[Milan Ščasný] - 20 minutes* ***Moderated group discussion*** - 70 minutes minimum ***Expected outcome***: At the end of the breakout groups, there should be some form of agreement and/or set of recommendations from each group on possible metrics for accounting for the climate, health, agriculture and economic impacts of methane and black carbon, with credible scientific justification. The breakout groups should also provide recommendations on further activities related to the discussion in the groups. This may include developing scientific publications, preparing briefings, reports or guidance documents on how to use the metrics, or further research on the metrics. ***NOTE***: Moderators for this should take note of the expected outcomes and guide discussion towards achieving them.
15:45-16:00	15 mins	Health Break
16:00-18:00	120 mins	**SESSION 4: PLENARY** **SESSION MODERATOR**: *Johan Kuylenstierna* **REPORTING BACK FROM THE GROUPS AND FURTHER DISCUSSIONS** ***Session description and objectives***: Each group will report on their outputs, including main findings, conclusions and recommendations. Participants will discuss these further in the plenary, with the goal of strengthening the recommendations and achieving some form of agreement and/or set of recommendations. • ***Group 1 Presentation: Climate Metrics*** *[Nominated Presenter]* 10 minutes • ***Plenary Discussion on findings*** 15 minutes • ***Summary and agreement on next steps*** *[Johan Kuylenstierna]* 5 minutes

		• *Group 2 Presentation: Health Metrics* *[Nominated Presenter]* 10 minutes • *Plenary Discussion on findings* 15 minutes • *Summary and agreement on next steps* *[Johan Kuylenstierna]* 5 minutes • *Group 3 Presentation: Agriculture Metrics* *[Nominated Presenter]* 10 minutes • *Plenary Discussion on findings* 15 minutes • *Summary and agreement on next steps* *[Johan Kuylenstierna]* 5 minutes • *Group 4 Presentation: Economics Metrics* *[Nominated Presenter]* 10 minutes • *Plenary Discussion on findings* 15 minutes • *Summary and agreement on next steps* *[Johan Kuylenstierna]* 5 minutes *Expected outcome*: The session will improve on the recommendations from the breakout groups and come up with a final agreements on the recommendations and way forward.
18:00-18:10	10 mins	Close of Day 1
19:30		**Reception hosted by Environment and Climate Change, Canada**
DAY 2 – BLACK CARBON INVENTORY AND REPORTING PROTOCOL		
Time	**Duration**	**Agenda Item**
08:30-09.00		**ARRIVALS AND REGISTRATION**
09.00-09.10	15 mins	**RECAP OF DAY 1 AND PLANS FOR DAY 2** *[Drew Shindell]*
09:10–09:50	40 mins	**SESSION 5A - PLENARY** **BLACK CARBON IN CURRENT REGULATORY AND POLICY FRAMEWORKS** ***Session Description and objective:*** This session aims to set a context for Day 2 discussion on inventory development and reporting on black carbon. It will discuss how black carbon are being managed under current regulatory and policy frameworks at the national, regional and global levels. It will also highlight existing and emerging reporting protocol taking into consideration relevance to the Paris Agreement including the associated NDCs and the SDGs. **SESSION MODERATOR**: *Farhan Akhtar* *Presentations:* • Overview of black carbon in current regulatory/policy frameworks, including reporting (inventory) protocols as well as gaps and challenges *[Martin Williams]* 20 minutes • **Questions and Discussions** 20 minutes *Expected outcome*: At the end of the session, participants would have a broad overview of how black carbon is currently regulated at the national, regional and

		global levels as well as existing reporting mechanisms and methodologies. This is expected to help prepare participants for further discussion on developing improved inventory and reporting methodology. *Background documents:* *Review of recent publications on methane and black carbon emissions and impacts; CCAC secretariat paper: an overview of black carbon policy framework.*

09:50–11:35	105 mins	**SESSION 5B - PLENARY PANEL SESSION**
		INVENTORY AND REPORTING: EXAMPLES; GAPS AND CHALLENGES; EMERGING SOLUTIONS
		Session Description and Objective: The panel discussion will look at the gaps and challenges in inventory and reporting black carbon and will also seek to highlight emerging solutions putting them in the context of the NDCs and the SDGs. The session will set the stage for the breakout groups by providing an overview of issues to be discussed in greater details during the breakout groups.
		
		SESSION MODERATOR: *Zbigniew Klimont*
		
		• ***Panellist 1 – Black carbon emissions inventory and reporting; successes, gaps and challenges: an example from CLRTAP*** – A short presentation/talk on CLRTAP activities on black carbon emissions inventory, successes, drawbacks, needed improvements, and emerging solutions *[Chris Dore, Aether Ltd]* 15 minute
		• ***Panellist 2 – Black carbon emissions inventory and reporting; successes, gaps and challenges: an example of the CCAC SNAP LEAP-IBC*** – A short presentation/talk on the CCAC SNAP LEAP-IBC tool for black carbon inventory development, highlighting its successes, drawbacks, as well as opportunities for improvement. It talk will also highlight relevance for emissions sources in industrialized and developing countries *[Harry Vallack, SEI]* 15 minute
		• ***Panellist 3 – IPCC perspective on inventory development including for black carbon*** - *[Dominique Blain]* 10 minute
		• ***Panellist 4 – Perspective from the Multilateral Fund for the Implementation of the Montreal Protocol on data reporting*** - *[Ico San Martini]* 10 minute
		• ***Panel 5 – National perspectives to black carbon emission inventory, challenges, gaps, opportunities for improvement and emerging solutions*** - A brief (5 minutes) intervention from selected countries on the challenges they have faced in developing black carbon inventory.
		    o ***Mexico*** *[Abraham Ortinez]* 5 minute
		    o ***Japan*** *[Satoru Chatani, TBC]* 5 minute
		    o ***Chile*** *[Mauricio Osses]* 5 minute
		    o ***China*** *[Kejun Jiang]* 5 minute
		
		• **Questions, comments and discussions** – 25 minutes
		
		Expected outcome: This session will prepare the ground for further discussion at the breakout group session. At the end of the session, important gaps and needs, as well as emerging solutions and their relevance to the NDCs and SDGs would have been identified, thereby preparing participants for the breakout group aimed at identifying solutions and way forward.
		
		Background documents: *CCAC/SAP Paper: Good practice for quantifying,*

		estimating, and reporting on SLCP interventions; Review of recent publications on methane and black carbon emissions and impacts
	NOTE	Coffee/Tea will be available during Session 5B
11:35-13:00	85 mins	**SESSION 6 - BREAKOUT GROUPS** **IMPROVING BLACK CARBON INVENTORY AND REPORTING** ***Session Description and Objective:*** This breakout session will discuss further the issues raised during the panel discussion with the goal of coming to an agreement on how to improve existing inventory and reporting protocols for black carbon across different sectors, taking into consideration differences between industrialized and developing countries as well as relevance to the NDCs and the SDGs. **SESSION MODERATOR**: *Gregory J Smallwood* There will be three groups all focusing on inventory and reporting for black carbon. • **Group 1: Inventory and reporting on black carbon** *[Moderator – Amanda CurryBrown]* • **Group 2: Inventory and reporting on black carbon** *[Moderator – Neeraja Penumetcha]* • **Group 3: Inventory and reporting on black carbon** *[Moderator - Kevin Thomson]* • **Group 4: Inventory and reporting on black carbon** *[Moderator - Johan Kuylenstierna]* The breakout group will seek to answer the following questions moderated discussion. Suggested questions to guide discussions: 1. Which black carbon emitting sector lacks inventory/reporting protocols? How can this be developed? 2. Are some existing protocols less robust that others? If so, which would most benefit from refinement? 3. How can existing methodologies be adapted for black carbon sectors? 4. What are the underlying data needs for supporting robust inventories? How can we address these gaps? 5. How can inventory and reporting protocols be aligned with NDCs and SDGs reporting? 6. How can protocols be made relevant for both industrialized and developing countries? 7. What are the issues with consistency in the measuring and reporting of black carbon emissions? How does sampling affect the measurements? What is the impact of using different measurement instruments? What should we be measuring (mass concentration, number concentration, absorption, etc.)? 8. What are the needed actions to ensure broad acceptance & implementation of new protocols? 9. What are the next step actions in developing a robust, widely acceptable and easy-to-implement reporting protocol ***Expected outcome***: Each group will come up with recommended actions on how to improve existing methodologies for black carbon emissions inventory

		and reporting for all emitting sectors, taking into consideration relevance for the climate and sustainable development. The groups will also provide suggestions on how to pursue the recommendations. The breakout group could also provide recommendations on further activities related to the discussion in the groups, which could include developing scientific publications, preparing briefings, reports and further research needs. ***NOTE***: Moderator for this should take note of the expected outcome and guide discussions toward achieving this.
13:00-14:00	60 mins	Lunch Break
14:00-15:30	90 mins	**SESSION 7: PLENARY** **REPORTING BACK FROM THE GROUPS AND FURTHER DISCUSSIONS** Each group will report their outputs to the plenary, including main findings, conclusions and recommendations. Participants will discuss these further in plenary, with the goal of strengthening the recommendations and achieving plenary agreement on the findings and recommendations. **SESSION MODERATOR**: *Gregory J Smallwood* • ***Group 1 outcomes presentation:*** *[Nominated Presenter]* 10 minutes • ***Group 2 outcomes presentation*** *[Nominated Presenter]* 10 minutes • ***Group 3 outcomes presentation*** *[Nominated Presenter]* 10 minutes • ***Group 4 outcomes presentation*** *[Nominated Presenter]* 10 minutes • ***Plenary Discussion on findings***: 40 minutes • ***Summary and agreement on next steps*** *[Gregory J Smallwood]* 10 minutes ***Expected outcome***: The session will improve on the recommendations from the breakout groups and come up with a final agreements on the recommendations, as well as way forward.
15:30-15:50	20 mins	Health Break
15:50-17:10	90 mins	**SESSION 8: PLENARY** **WORKSHOP CONCLUSION AND AGREEMENT ON FOLLOW-UP ACTIONS** This session will seek to pull together the discussions of the past two days and agree on way forward on the two core goals of the workshop: *advancement of efforts toward a scientifically credible consensus on metrics for accounting for black carbon and methane interventions* and *a way forward on the development of a widely applicable inventory development and reporting protocol for black carbon.* **SESSION MODERATOR**: *Drew Shindell, TBC*
17:10-17:30	20 mins	**CLOSING STATEMENTS** • Helena Molin Valdes – Head, CCAC Secretariat • Drew Shindell – Chair, CCAC Scientific Advisory Panel • Rita Cerutti –Co-Chair, CCAC
17:30pm		**Close of Workshop**

ANNEX 2: WORKSHOP PARTICIPANTS

Climate and Clean Air Coalition (CCAC) Scientific Advisory Panel Expert Workshop
"Metrics for Evaluating and Reporting on Black Carbon and Methane Interventions"

PARTICIPANTS LIST

	Name	Affiliation
		SAP Members
1	Andy Haines**	London School of Hygiene & Tropical Medicine, London, UK
2	AR Ravishankara	Colorado State University, Fort Collins, CO, USA
3	Drew Shindell	Duke University, Durham, NC, USA
4	Graciela Binimelis de Raga**	Universidad Nacional Autonoma de Mexico (UNAM), Ciudad Universitaria, Mexico
5	Johan Kuylenstierna	Stockholm Environment Institute, York, UK
6	Harry Clark	New Zealand Agricultural Greenhouse Gas Research Centre, AgResearch
7	Lisa Emberson	Stockholm Environment Institute, York, UK
8	V. Ramanathan**	Scripps Institution of Oceanography, University of California, San Diego, California, USA
		External Experts
9	Abraham Ortinez Alvarez	National Institute of Ecology and Climate Change (INECC), Mexico
10	Alan Silayan	DENR-EMB, Climate Change Division, Philippines
11	Amanda Curry Brown	US Environment Protection Agency
12	Borgar Aamaas	CICERO, Norway
13	Carmen Gloria Contreras Fierro	Ministerio del Medio Ambiente, Chile
14	Chris Dore	Aether, Oxford, UK
15	Daniel Johansson**	Chalmers University & Gothenburg University, Sweden
16	Davor Vesligaj	UNFCCC, Bonn, Germany
17	Dominique Blain	IPCC / Environment and Climate Change, Ottawa, Canada
18	Elizabeth Bush	Environment and Climate Change, Ottawa, Canada
19	Farhan Akhtar	U.S. Department of State, USA
20	Felicity Hayes	Centre for Ecology and Hydrology, Bangor, Wales
21	Gary Kleimann	World Bank Group, Washington, DC, USA
22	Gregory J. Smallwood	National Research Council, Canada
24	Harry Vallack	Stockholm Environment Institute, York, UK
25	Hua Zhang	China Meteorological Administration; Beijing, China
26	Ico San Martini	Secretariat of the Multilateral Funds, Montreal Canada
27	Ilissa Ocko**	Environmental Defense Fund
28	Immaculate Simiyu	National Environment Management Authority, Kenya
29	Jeff Brook	Environment and Climate Change, Ontario, Canada
30	Jennifer Kerr	Government of Canada
31	Jill Baumgartner	McGill University, Montreal, Canada
32	Jorge Alberto Castro	Ministry of Housing, Territorial Planning and Environment

33	Julie Cerqueira	U.S. Department of State, USA
34	Keith Shine	University of Reading, UK
35	Keith Smith	University of Edinburgh, UK
36	Kevin Thomson	National Research Council Canada
37	Koriko Moursalou	University of Lome, Lome, Togo
38	Marcus Sarofim	US Environment Protection Agency, USA
39	Marianne Tronstad Lund	CICERO, Norway
40	Martin Williams	Kings College London, UK
41	Martyn Howells	World Bank Group, Washington, USA
42	Matthew Johnson	Carleton University, Ottawa, Canada
43	Mauricio Osses Alvarado	Center for Climate Science and Resilience, Chile
44	Maygan McGuire	Environment and Climate Change, Canada
45	Mike Holland	EMRC, Reading, UK
46	Milan Scasny	Charles University, Prague, Czech Republic
47	Myles Allen**	University of Oxford, UK
48	Nathan Borgford-Parnell	Institute for Governance & Sustainable Development
49	Neeraja Penumetcha	Global Alliance for Clean Cooking, Washington DC, USA
50	Nzioka Muthama	University of Nairobi, Kenya
51	Pam Pearson	International Cryosphere Climate Initiative
52	Patrick Kinney	Columbia University, New York City, New York
53	Ray Minjares	International Council on Clean Transportation, San Francisco, CA, USA
54	Rita Cerutti	Environment and Climate Change Canada
55	Rita Van Dingenen	EU JRC, Ispra (VA), Italy
56	Satoru Chatani	National Institute for Environmental Studies (NIES), Japan
57	Steffen Kallbekken	CICERO, Norway
58	Stine Aakre	CICERO, Norway
59	Susan Anenberg	George Washington University, Washington, DC, USA
60	Tami Bond	University of Illinois at Urbana-Champaign, USA
61	Valentin Foltescu	Science Division, UN Environment, Nairobi, Kenya
62	Virginia Gorsevski	Science & Technology Advisory Panel, GEF, Washington DC, USA
63	Zbigniew Klimont	International Institute for Applied Systems Analysis, Austria
	CCAC Secretariat	
64	Elsa Lefevre	CCAC Secretariat
66	Helena Molin Valdes	Head, CCAC Secretariat
67	Seraphine Haeussling	CCAC Secretariat
68	Sunday Leonard	CCAC Secretariat

[i] The CCAC Demonstrating Impacts Framework was designed to help partners and the secretariat in the collection and organization of data on the actions and activities of the Coalition. Impact indicators for the framework include changes in emissions, energy efficiency benefits, near term climate benefits, health benefits as well as agriculture and ecosystem benefits (cf. WG/DEC2015/02)
[ii] http://www.ccacoalition.org/en/resources/marrakech-communique
[iii] CCAC (2016) How to Make SLCP Action a Policy Priority: Opportunities 2016-17/ WG/APR2016/02 bis Annex to WG Report.

[iv] It should be noted that these recommendations are primarily developed by the SAP and other scientists who participated in the workshop, as part of the role of the SAP to keep the Coalition abreast of new scientific developments and to provide policy relevant scientific information to the Coalition but not recommend policy. The recommendations presented here are therefore that of the Advisory Panel but do not represent buy-in from CCAC Partners. It should be further noted that the recommendations provided here, including on metrics, are to be considered for used in complementary to those under the UNFCCC and other relevant frameworks including for health, agriculture and economic valuation.
[v] In recognition of the fact that the use of 100 year GWP is already in widespread use in international frameworks (such as the UNFCCC), participants chose not to make alternative recommendations
[vi] While it is noted that $PM_{2.5}$ has an impact on crops, there are not yet sufficient metrics or methodologies to robustly calculate impacts such as for use in developing financeable projects.
[vii] Both impact estimates and valuations should distinguish those benefits that accrue within the jurisdiction that undertake measures, those that accrue regionally and those which are global public goods
[viii] The most widely used response relationships are for rice, wheat, maize and soybean, but evaluation of relationships for other crops and vegetation which are ready for wider use is necessary
[ix] Both impact estimates and valuations should distinguish those benefits that accrue within the jurisdiction that undertake measures, those that accrue regionally and those which are global public goods
[x] As calculated by the US Interagency Working Group on Social Cost of Carbon: https://www.epa.gov/climatechange/social-cost-carbon
[xi] See Shindell et al. The Social Cost of Methane: Theory and Applications. Faraday Discuss. DOI: 10.1039/C7FD00009J, 2017
[xii] See Shindell et al. The Social Cost of Methane: Theory and Applications. Faraday Discuss. DOI: 10.1039/C7FD00009J, 2017
[xiii] There is current no analysis of the social cost of black carbon, hence this is an area for further works
[xiv] Valuation estimates may be very different than the value attributed to benefits by donors or market participants – witness the relatively lower price of CERs relative to the Social Cost of Carbon – which is usually determined by stringency of regulation or philanthropic value. An important enabler of SLCP finance at scale is a market assessment of the demand for various attributes and the form of desired documentation (e.g. CER for emissions, or other impact indicators).
[xv] The AGTP can be used to calculate the progression of temperature change in annual time steps and thus compare the influence of different emission scenarios on regional and global temperature change over a short or long time period. This means that the AGTP takes into consideration timescale and continuity of emissions reduction actions and how such actions contribute to achieving warming targets at any timescale (e.g. near-term or long-term temperature targets). Hence, the AGTP can provide estimate of temperature change due to emission increase or reduction over the course of the century if the emissions over this time frame for all required substances are available. It also does not compare the climate impacts of different substances but provide the warming impacts of each substance separately. However, the AGTP is a function of climate sensitivity and the rate of heat uptake by the oceans, increasing the uncertainty of the metric. It should also be noted that the 25 years timescale is illustrative and was chosen because simulations indicate that there is at least a 50% likelihood of exceeding 2 °C warming during the 2040s under a reference scenario, and because this time-scale is comparable to the timescales of societal/technological transitions (e.g., air quality improvements) and the implementation of policies to achieve the SDGs by 2030. However, some workshop participants felt that more discussion of the timescale is still needed.
[xvi] Institute for Health Metrics and Evaluation, Global Burden of Disease (GBD). Available at: http://www.healthdata.org/gbd.
[xvii] Tier 1 here refers to a minimum level of inventory of black carbon which could be inventory of total $PM_{2.5}$ from which black carbon content can then be determine.
[xviii] Myhre et al. 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, et al (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA
[xix] However, some workshop participants felt that more discussion of the timescale still needed.
[xx] This is based on a publication currently under review by Ocko et al. Unmask temporal tradeoffs in climate policy debates (under review)
[xxi] Based on Allen et al 2016. Nature Climate Change 6, 773–776 (2016) doi:10.1038/nclimate2998 and another paper still in preparation.
[xxii] This can be done by modelling the effect of emission in separate source regions on atmospheric concentrations and radiative forcing of the SLCPs, and then calculating emission metrics values using such region-specific input. Several studies have done this for selected sectors/regions; for example: Aamaas et al. Regional emission metrics for short-lived climate forcers from multiple models. Atmos. Chem. Phys., 16, 7451-7468, 2016; Collins et al. Global and regional temperature-change potentials for near-term climate forcers. Atmos. Chem. Phys., 13, 2471-2485, 2013; Lund et al. Emission metrics for quantifying regional climate impacts of aviation, Earth System Dynamics doi:10.5194/esd-2017-11
[xxiii] World Bank and ICCI, On Thin Ice, 2013. https://openknowledge.worldbank.org/handle/10986/16628
[xxiv] See for example, Aamaas et al. Regional temperature change potentials for short lived climate forcers from multiple models. Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-141, 2017
[xxv] Schuur et all (2015). Climate change and the permafrost carbon feedback. Nature 520, 171-179. Doi10.1038/nature14338.
[xxvi] See for example: http://www.who.int/phe/health_topics/outdoorair/databases/AAP_BoD_methods_March2014.pdf and http://www.euro.who.int/__data/assets/pdf_file/0006/238956/Health-risks-of-air-pollution-in-Europe-HRAPIE-project,-Recommendations-for-concentrationresponse-functions-for-costbenefit-analysis-of-particulate-matter,-ozone-and-nitrogen-dioxide.pdf
[xxvii] The health impact 'valuation' metrics here refers specifically to the use of Years Lived with Disability (YLD), which is one of the components of the DALY metric. This is defined as the years lived in a less than ideal health or with a degraded quality of life due diseases. The YLD therefore is a metric that provides a valuation of the negative effects of exposure, rather than the direct physical impact (such as the disease caused).
[xxviii] The outdoor air pollution estimates for GBD combine satellite-based estimates, chemical transport model simulations, and ground measurements of air pollution from 79 countries to produce global estimates of annual average fine particle (PM2.5) and ozone concentrations at 0.1° × 0.1° spatial resolution for five-year intervals from 1990 to 2010 and the year 2013. See Brauer et al. 2015. Ambient air pollution exposure estimation for the global burden of disease 2013." Environmental science & technology 50, no. 1 (2015): 79-88.
[xxix] Note that the GBD uses a 3-months averaging period
[xxx] See Jerret et al. Long-Term Ozone Exposure and Mortality. http://www.nejm.org/doi/pdf/10.1056/NEJMoa0803894.

[xxxi] Turner et al. Long-Term Ozone Exposure and Mortality in a Large Prospective Study. http://www.atsjournals.org/doi/abs/10.1164/rccm.201508-1633OC.
[xxxii] See Burnet et al. https://ehp.niehs.nih.gov/wp-content/uploads/122/4/ehp.1307049.pdf. This IERs is widely recommended because of their applicability over a range of exposure levels that extends far beyond the range at which the 'traditional' log-lin CRF were established (i.e. typical for US and European exposure levels). This makes it possible to conduct a globally consistent evaluation of the health impact of PM2.5, including regions with extremely high pollution levels.
[xxxiii] See Henschel S. & G. Chan (2013) Health risks of air pollution in Europe – HRAPIE project: New emerging risks to health from air pollution – results from the survey of experts. World Health Organization Regional Office for Europe. Copenhagen, Denmark.
[xxxiv] See Jerret et al. Long-Term Ozone Exposure and Mortality. http://www.nejm.org/doi/pdf/10.1056/NEJMoa0803894
[xxxv] See Henschel S. & G. Chan (2013) Health risks of air pollution in Europe – HRAPIE project: New emerging risks to health from air pollution – results from the survey of experts. World Health Organization Regional Office for Europe. Copenhagen, Denmark.
[xxxvi] See Public Health England (2015) Quantification of mortality and hospital admissions associated with ground-level ozone. ISBN 978-0-85951-776-8. https://www.gov.uk/government/publications/comeap-quantification-of-mortality-and-hospital-admissions-associated-with-ground-level-ozone.
[xxxvii] For example, Hussey et al. Air pollution alters Staphylococcus aureus and Streptococcus pneumoniae biofilms, antibiotic tolerance and colonisation", Environ Microbiol. doi:10.1111/1462-2920.13686, 2017; Norris et al. A panel study of the acute effects of personal exposure to household air pollution on ambulatory blood pressure in rural Indian women." Environmental research 147 (2016): 331-342; Janssen, et al. Black Carbon as an Additional Indicator of the Adverse Health Effects of Airborne Particles Compared with PM^ sub 10^ and PM^ sub 2.5^." Environmental health perspectives 119, no. 12 (2011): 1691 and Baumgartner et al. Highway proximity and black carbon from cookstoves as a risk factor for higher blood pressure in rural China. Proceedings of the National Academy of Sciences, 111(36), 13229-13234, 2014.
[xxxviii] This is dependent on the exposure metric used. For AOT40, more crop CRF are available (Mills et al., 2007)
[xxxix] Note that in some countries additional health expenditures may be a benefit and not a net cost to the health sector.
[xl] In the human capital approach, the value of a human life is equated to the discounted market value of the output produced by an individual over an expected lifetime. This approach can be used to estimate the discounted value of future earnings or lost future earnings resulting from an extension or shortening in life respectively
[xli] The aim of the "cost of illness (COI)" analysis is to assess the economic burden of illness to society. The COI encompasses the different aspects of the disease impact on the health outcomes in a country, specific regions, communities, and even individuals (Jo et al. 2014. Cost-of-illness studies: concepts, scopes, and method. Clin Mol Hepatol., 4, 327–337. doi: 10.3350/cmh.2014.20.4.327
[xlii] The Willingness to Pay (WTP) estimates the maximum amount people or a society would be willing to pay to achieve a specific health outcome/benefit. This assumes that such an amount, which is based on the capacity of the people to pay, provides an indication of value their desired health outcome.
[xliii] The Value of a Statistical Life (VSL), "represents the value a given population places ex ante on avoiding the death of an unidentified individual. VSL is based on the sum of money each individual is prepared to pay for a given reduction in the risk of premature death, for example from diseases linked to air pollution." OECD (2012) Mortality Risk Valuation in Environment, Health and Transport Policies, OECD Publishing. http://dx/doi.org/10.1787/9789264130807-en.
[xliv] Forgone output refers to the monetary value of the loss output due an individual or a society is not producing at its potential level due to poor health outcomes. Foregone output approach should not be however used to value the impacts on premature mortality as this approach is not consistent with welfare economics theory.
[xlv] In recognition of the fact that the use of 100 year GWP is already in widespread use in international frameworks (such as the UNFCCC), participants chose not to make alternative recommendations
[xlvi] While it is noted that $PM_{2.5}$ has an impact on crops, there are not yet sufficient metrics or methodologies to robustly calculate impacts such as for use in developing financeable projects.
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[xlix] Both impact estimates and valuations should distinguish those benefits that accrue within the jurisdiction that undertake measures, those that accrue regionally and those which are global public goods
[l] As calculated by the US Interagency Working Group on Social Cost of Carbon: https://www.epa.gov/climatechange/social-cost-carbon
[li] See Shindell et al. The Social Cost of Methane: Theory and Applications. Faraday Discuss. DOI: 10.1039/C7FD00009J, 2017
[lii] See Shindell et al. The Social Cost of Methane: Theory and Applications. Faraday Discuss. DOI: 10.1039/C7FD00009J, 2017
[liii] There is current no analysis of the social cost of black carbon, hence this is an area for further works
[liv] Valuation estimates may be very different than the value attributed to benefits by donors or market participants – witness the relatively lower price of CERs relative to the Social Cost of Carbon – which is usually determined by stringency of regulation or philanthropic value. An important enabler of SLCP finance at scale is a market assessment of the demand for various attributes and the form of desired documentation (e.g. CER for emissions, or other impact indicators).
[lv] CLRTAP (2013) Amendment of the text of and annexes II to IX to the 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone and the addition of new annexes X and XI. C.N.155.2013.TREATIES-XXVII.1.h. https://treaties.un.org/doc/Publication/CN/2013/CN.155.2013-Eng.pdf.
[lvi] http://europa.eu/rapid/press-release_MEMO-16-4372_en.htm and http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2016.344.01.0001.01.ENG
[lvii] https://www.arb.ca.gov/cc/shortlived/shortlived.htm
[lviii] https://www.unece.org/fileadmin/DAM/env/documents/2015/AIR/EB/English.pdf
[lix] http://www.eea.europa.eu/publications/emep-eea-guidebook-2016
[lx] http://www.eea.europa.eu/publications/lrtap-emission-inventory-report-2016
[lxi] European Monitoring and Evaluation Programme (EMEP)/European Environment Agency

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lxii https://oaarchive.arctic-council.org/handle/11374/1168 and https://oaarchive.arctic-council.org/handle/11374/1169

lxiii Progress of these efforts were presented during the workshop

lxiv For example, Klimont et al. Global anthropogenic emissions of particulate matter including black carbon. Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-880, 2016

lxv Tier 1 here refers to a minimum level of inventory of black carbon which could be inventory of total $PM_{2.5}$ from which black carbon content can then be determine.