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

METRICS FOR ACCOUNTING FOR SLCPS MITIGATION BENEFITS

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Background

Metrics are needed to quantify the benefits of emission reductions associated with implementing SLCP measures. For the Climate and Clean Air Coalition (CCAC), such metrics are needed for reporting on its activities and actions including in the context of its new Demonstrating Impacts framework[1]. Such metrics would allow for easy quantification of the main impacts and benefits associated with SLCP mitigation, including changes in warming and other aspects of climate change, as well as benefits related to human health, ecosystem structure and function, and agricultural and forest productivity.

Climate Benefit Metrics

- Climate metrics that compare the effect of SLCP emission reductions to that of carbon dioxide are problematic because the impacts of SLCPs and long-lived greenhouse gases such as carbon dioxide happen over very different temporal and spatial scales;
- The climate metric recommended by the Scientific Advisory Panel (SAP) of the CCAC for surface temperature, based also upon IPCC recommendations, is the AGTP (Absolute Global Temperature Potential) and the related ARTP (Absolute Regional Temperature Potential) as these will provide 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 ton of emission over time.
- The AGTP or ARTP 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).
- Some SLCP emission reductions also provide other climate benefits including reducing weather disruption (e.g. rainfall pattern and associated impacts on agriculture, ecosystems, and water provision to cities). However, there are currently no simple metrics for accounting for these type of effects.
- The relationship between impacts and the rate of climate change is seldom addressed in metrics, but may have a considerable effect depending on the overall climate trajectory, e.g. reduction in biodiversity loss owing to provision of greater time for adaptation to climate change with a slower rate of change to a given peak warming.
- Virtually all metrics examine surface temperature only (with the exception of a few studies that have begun to explore metrics for precipitation). This is in partly based on the assumption that most impacts of climate change are proportional to surface temperature changes. This does not take into account clear physical differences between climate forcers. For example, CO_2 causes ocean acidification and fertilizes terrestrial ecosystems whereas non-CO_2 do not. This means that they will cause different ecosystem responses per unit surface temperature change. These ecosystem responses include impacts on agricultural

[1] 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)

productivity, and therefore also affect human health (e.g. via food supply, and associated food access, and undernutrition).

- Surface temperature metrics are comparatively well developed for methane and HFCs; the above-mentioned AGTP and ARTP are recommended for these gases. However, there is more ambiguity for black carbon as its interactions with climate have greater uncertainties. It typically has many co-emissions such as organic carbon, sulphates, nitrogen oxides, carbon monoxide, and non-methane volatile organic compounds, some of which have cooling effects, and its short lifetime makes metrics sensitive to the timing and location of emissions.
- The recently developed methodology for black carbon by the Gold Standard[2] considers only emissions (not impacts, and hence is only a portion of a climate metric) and transform all co-emissions into black carbon-equivalents using the global warming potential, a metric not recommended by the SAP.
- For the AGTP and ARTP to be used for black carbon-related emissions reduction strategies, it is important that estimation of impacts take into account the effects of the co-emitted species. This means that all co-emitted species would need to be reported and included in the estimations.

Health Benefit Metrics

- The methodology for the evaluation of the health effects of air quality is relatively advanced compared with methodology for evaluation of the health effects of climate change. The latter is typically assumed to be accounted for within climate metrics (explicitly in the case of social costs, implicitly in the case of temperature change that is assumed to be reflective of impacts), although there are considerable challenges in attributing health changes to climate change as a result of the indirect pathways linking health and climate change. Climate change influences air quality, however, so that these processes are not fully separable.
- Hereafter, we discuss health benefits as those arising from air quality changes related to the direct effects of emissions (e.g. $PM_{2.5}$ concentration changes associated with implementing measures to reduce black carbon emissions) or indirect effects via atmospheric chemistry (e.g. methane leading to ozone formation) and excluding changes in air quality due to climate change or other impacts of climate change on health (e.g. spread of tropical diseases, malnutrition due to crop yield decreases). Not because they are not important, but because they are difficult to quantify.
- As health impacts are highly sensitive to the timing and location of emissions, simple emission metrics analogous to those developed for global climate change have seldom been used for health benefits (except in the case of methane). Metrics for health thus refer to quantification of impacts using sophisticated atmospheric modelling or atmospheric measurements for $PM_{2.5}$ and ozone concentrations, linked with concentration-response functions, population data and baseline mortality rates.
- There are a number of different health metrics used to characterise the benefits of emission reductions, and these have different strengths and weaknesses related to the confidence in the estimated values and their transferability from one region to another.
- The most widely used metric, which is also recommended for use by the SAP, is attributable mortality that measures the number of deaths over a specified time period which are attributed to exposure to $PM_{2.5}$ and ozone. For $PM_{2.5}$ in particular uncertainty in this metric becomes large at high exposure levels as data for these conditions is limited. Nonetheless, the underlying exposure-response relationship rests upon many peer-reviewed independent studies using a wide variety of methods, leading to high confidence in the quantitative impacts and their associated uncertainties.

[2] See: http://www.goldstandard.org/sites/default/files/bc-quantification-methodology-27032015.pdf

- Other metrics may also be used with some confidence including years of life lost (YLL) (which can also be expressed in terms of average reduced longevity), years of life lived with disability (YLD), and disability adjusted life-years (DALYs) which combine YLL and YLD.
- Other health impacts metrics include chronic, non-lethal illnesses, as well as effects of short-term changes due to exposure such as lost work days, lost school days, hospital admissions, and emergency room visits related to $PM_{2.5}$ and ozone exposure.

Agricultural Benefit Metrics

- As with health, emissions of climate altering pollutants can affect ecosystems via multiple pathways. For example, ecosystem structure and function (e.g. species composition and crop yield or forest productivity) can be affected by changes in ground-level ozone concentrations (which is toxic to plants), by changes in aerosol optical depth (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.
- Ecosystem impacts that occur as a result of climate change are generally assumed to be captured within climate metrics (as in the case of health), explicitly within social costs and implicitly in the case of temperature change that is assumed to be reflective of impacts. SLCP strategies, however, will lead to changes in regional temperature, rainfall as well as other meteorological conditions (e.g. the influence of aerosol on radiation quantity and quality) that are not necessarily proportional to their effect on global mean temperatures. These will in turn affect ecosystems; thus the climate metrics may not fully capture impacts (see climate metrics section). In this section, we focus on benefits related to emissions-driven air quality changes (in the knowledge that the climate related impacts can be considerable).
- Again as with health impacts, ecosystem benefits associated with changes in ozone concentrations and aerosols are sensitive to the timing and location of emissions, and hence simple emission metrics analogous to those developed for global climate change have not been used for benefits for most SLCPs. The exception is well-mixed methane, for which agriculture metrics have been developed based on atmospheric modelling of ozone concentrations, linked with concentration-response functions and crop distribution datasets. Therefore, similar to health metrics described above, we here discuss ecosystem benefits as those arising from air quality changes related to the direct effects of emissions on air quality (e.g. BC contributing to aerosol) or indirect effects via atmospheric chemistry (e.g. methane leading to ozone formation) and excluding changes in air quality due to climate change (or other impacts of climate change or enhanced [CO_2] on ecosystems).
- A number of concentration-based indices have been developed for ozone that either average daylight ozone concentrations over the growing season (e.g. M7, M12, W126) or accumulate daylight ozone concentrations over a growing season (e.g. AOT40, SUM06). All these metrics include, to greater or lesser degrees, additional weighting to higher ozone concentrations since it is considered that higher ozone concentrations will have a disproportionately greater crop damage impact. These metrics have been used to develop dose-response relationships including:
    - *yield losses* or *losses in grain quality* for some crop species (the latter only for wheat);
    - *biomass losses* for a number of forest species
    - *productive grasslands* describing shifts in species composition (i.e. the enhancement of grass species at the expense of legumes which can have important consequences for grassland forage quality and hence livestock productivity.

- These dose-response relationships can be used in conjunction with ozone concentration and crop, forest or grassland distribution and productivity data to quantify the benefits of reducing ozone concentrations over a particular region.
- In Europe, there has been a move towards characterizing ozone using flux-based metrics rather than concentration based metrics. These metrics account for the fact that ozone damage is more directly related to ozone uptake (via the leaf pores) than ozone concentration, since environmental conditions (such as water or temperature stress) can reduce ozone uptake and hence ozone induced damage. Flux-response relationships now exist for a number of crop species (wheat, potato and tomato); temperate and boreal forest species (beech, birch, oak, Norway spruce and Aleppo pine) and productive grasslands and can be used in the same way as concentration based metrics to quantify damage.
- Currently, no metrics exist that can readily quantify the influence of aerosol (e.g. Aerosol Optical Depth) on radiation quantity and quality and consequent plant photosynthesis, growth and productivity.
- Ozone, aerosol, [CO_2] and climate will interact to impact ecosystem and agriculture. For example, elevated CO_2 may reduce ozone uptake limiting the ozone induced damage. These interacting effects cannot be easily incorporate in metrics that have to date focussed on individual pollutants (though the flux based ozone metric does go some way to incorporating these interactions at least in relation to uptake).

Economic Valuation of Impacts

- Metrics to estimate the monetary costs of the impacts of SLCP emissions to society have also been developed. Standard methods exist for deriving relevant direct market cost estimates, for example, the direct market costs of air pollution on the health sector, for different countries. It can be contentious to transfer estimates to countries and regions where costs have not been estimated, however.
- Indirect costs due to higher order effects, for example a shifts 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.
- For crop yields, only direct costs based on the market value of crops tend to be estimated. 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, health, suffering, and other non-market impacts. These assessments will also not capture the influence of changes in, for example, grain quality on nutrition.
- Social (or welfare) cost emission metrics attempt to incorporate monetized market and non-market impacts over time. These have most often included impacts of climate change alone. Hence they account for climate, human health and agricultural impacts, but only when these occur via climate change and not via air quality changes resulting directly from emissions (or indirectly via atmospheric chemistry). Other metrics such as the global damage potential, global cost potential, and cost-effective temperature potential that combine physical and economic factors have been examined in scientific literature but have not yet made substantial inroads into policy.
- There is a large body of literature on social cost emission metrics, and these have been put into use or considered by multiple governments, but studies have been almost entirely focused on carbon dioxide. Recently, several studies have however addressed the social cost of methane, incorporating climate change-related effects alone or all the effects considered here.
- As with health and agriculture, for SCLPs and air quality in general, many analyses have been done of social costs using sophisticated modelling and such tools provide valuable results for the specific emissions scenarios considered.

Recommendations

We recommend that the CCAC emphasize the potential benefits from SLCP emission control measures and strategies for near-term climate, human health, agriculture and ecosystems rather than the contribution of historical SLCP emissions to current warming.

Recognizing that decision-makers around the world will have varying perspectives, the UNEP/WMO Integrated Assessment strove to include climate and air quality benefits on an equal footing rather than characterizing one as a co-benefit of the other. As evident in its very name, and reflected in its framework of impact indicators, the CCAC is likewise concerned with more than just climate impacts. Hence as multiple SLCP impacts are of interest, we also recommend that the CCAC continue to utilize multiple metrics, each suitable for characterizing various end-points of interest. Metrics for near-term climate, long-term climate, human health and agriculture could all be utilized.

Best practices, including for data collection under the CCAC impacts indicators, should include specifying emissions changes of all pollutants (not aggregating) whenever possible to facilitate the use of metrics related to whichever end-point is of greatest interest to the user. Hence, within countries Nationally Determined Contributions for example, countries would ideally report both their estimated changes in CO_2 and other Kyoto gases and individual SLCPs.

The use of multiple metrics will allow the achievements of the CCAC and SLCP reductions in general to be related to multiple goals, including very broad ones such as the SDGs in addition to the UNFCCC's twin goals of keeping warming far below 2 degree Celsius and the often overlooked goal or keeping the rate of change from becoming too fast for human and natural systems to adapt. The SDGs in particular address a much broader swath of issues affecting societal well-being, and hence impacts and the beneficial effects of SLCP mitigation actions on the achievement of the SDGs need to be assessed in multiple areas (beyond purely emission-based metrics in some cases). Economic analyses are also overly narrow if they focus on a single impact of SLCPs, and hence economic metrics will ideally include all impacts that can be readily characterized. Note that virtually all economic indicators include a time-weighting giving greater value to near-term impacts in line with basic economics principles, and hence a metric such as GWP is particularly unsuitable to relate to economics. Best practice for economic indicators, as with emissions, is reporting disaggregated as well as total values so that users can effectively analyse market vs non-market costs, health costs, agricultural costs, etc.