Integrating Air Quality Management & Climate Change Mitigation:

Towards a Methodology for Stress-Testing Metrics

Air quality management and climate change mitigation have often been thought of overlapping but distinct policy domains. One is local, the other global; one has focused on reducing direct human health and agricultural impacts; the other on widespread environmental change leading to myriad effects including but not limited to health and agriculture; one is situated in international relations and treaties; the other in regional or domestic regulatory agencies.

The growing scientific evidence of the impact of a group of known air pollutants (tropospheric ozone, some of its precursors, and aerosols including organic carbon (OC), black carbon, and brown carbon) on climate change has forced these two policy domains into closer contact. The term “Short Lived Climate Pollutants” (SLCPs) has emerged as a kind of short-hand summary of the problem of climate-affecting air pollutants as well as a statement of an opportunity to have a relatively rapid impact on the trajectory of climate change. The emissions that it describes – aerosols, methane, tropospheric ozone and HFCs (not an air pollutant, but a powerful warming agent) – are all short-lived in the atmosphere. Reducing emissions affects concentrations within weeks to a decade and a half. The impact of such strategies on the longer-run trajectory of climate change is a matter of scientific debate, clearly SLCP reduction is no substitute for CO_2 mitigation.

The close integration of these policy domains has proven to be challenging. For one, mitigation and management have been addressed by separate agencies and, in the case of international collaboration, separate treaty and collaboration regimes. Second, there are complementarities but also trade-offs involved in emission reduction: policy efforts affect individual and group actions; these actions in turn affect a variety of emissions in different ways. Integrated assessments have been undertaken to assess the relationship between mitigation activities and a spectrum of emissions, but there is the further challenge of understanding how these emissions interact to affect climate. Third, there are also trade-offs as well as co-benefits between the various potential impacts of emissions reduction: environmental change, health, agriculture. Strategies designed with different sets of goals in mind may differ. Finally, emissions mitigation is a systemic challenge, requiring shifts in public investment, development finance, household behaviour, and other complex arenas as much as, if not more, than intense regulation or environmental policy. The governance “domain” for emissions mitigation is intertwined with other aspects of socio-economic policy.

The Interdisciplinary and Global Working Group (IG-WG) was established in 2012 to develop a roadmap toward an integrated approach to SLCPs. In its first meeting on 14 December in Potsdam at the IASS the group identified "metrics," or the ways in which emissions, concentrations, and climate and health impacts are characterized as a central point for consideration.

"Metrics" form a language by which various stakeholders communicate both about the problem and the efficacy of solutions. As summary measures of an underlying reality, metrics affect the stakeholder understanding of challenges, successes, failures, and opportunities for SLCP mitigation. The process of defining a metric is often seen as a technical matter, but it almost always involves meaningful decisions about what to measure and how; what parts of reality should be included and which removed as part of the simplification, hence containing a value judgment; and how the metric should be constructed.

These decisions have consequences. Metrics may strip away important dimensions of the phenomena that policymakers, investors, and society seek to measure. Global warming potential (GWP) figures commonly used in climate discussions, for example, do not provide insight into more specific climate-affecting impacts of emissions and the summary picture that they present depends on the time frame over which GWP is measured. Aspects of reality that do not get included in the metric become effectively invisible to stakeholders in their dialogue, strategy formation, and implementation of mitigation efforts.

The workshop entitled "Air Quality and Climate Impacts: Toward a methodology for stress-testing metrics" aims to elaborate key aspects to be included in an assessment method for anticipating the "stresses" that particular decisions about metrics may create for mitigation efforts and integration of air quality and climate change efforts. This assessment method or "stress-testing" shall test whether metrics that are applied in the SLCP / air quality / climate context are fit for the purposes that they are or are considered being used for. In particular, do they support the objectives of increasingly making use of co-benefits while avoiding trade-offs by accurately characterizing success, failure, and trade-offs.

We believe that this activity is especially important in today's policy arenas, since new metrics for characterizing SLCPs and their impacts are being developed even as the policy and regulatory approaches for mitigation are evolving. The opening session on October 3 thus discusses the "policy moment" that we are in by providing an overview of metrics under discussion.

The next sessions on October 3 focus on elaborating the concept of "metric stress" through discussion of a (recent) historic case as well as ways in which SLCPs are represented and incorporated (or not) in allied policy domains of urban planning, transport strategy, and solid waste management.

The final session closes with a re-integration of the day's lessons with the ongoing policy discussions surrounding SLCP mitigation.

The working group will also meet on October 4 to discuss methods for anticipating and quantifying the kinds of stresses raised in the discussion.

This background document provides

- a brief overview on the role of SLCPs in the air quality – climate interactions and different perceptions thereof;
- a review of a selection of existing air quality and climate metrics as well as currently proposed alternative metrics approaches highly relevant to SLCPs;
- a discussion of potential ways in which metrics interact with political, financial, and social processes of mitigation. It is meant to stimulate participants' thoughts rather than be an exhaustive catalogue.
- a brief introduction to some of the policy efforts emerging to adapt to available metrics.

I. Relevance of SLCPs for integrated approaches to air pollution and climate change mitigation strategies

Air quality (AQ) and climate change (CC) are strongly linked with regard to their causes, effects and mitigation options (Jacob and Winner, 2009), and the idea of integrating the two respective policy areas is no longer new (e.g. (Fiore et al., 2012;Williams, 2012;IGBP/IGAC, 2012). SLCPs, short-lived climate-forcing pollutants, are by their definition an important linking element between the two fields. Not only are they often emitted by the same sources as long-lived greenhouse gases (LL-GHG) such as power plants or traffic, but they also have simultaneous adverse effects on air quality and climate change. Hence, reducing SLCPs can only be executed and evaluated successfully in an environment where impacts on air quality and climate change are jointly considered.

While integrating AQ and CC policies is already partially accepted by policy makers (http://climpol.iass-potsdam.de/news/air-quality-and-climate-change-policies-separate-or-joint-challenges) the degree and "mode" of integration are open questions. "Mode" in this context means the general framing, or more specifically under which primary perspective (CC or AQ), the policy areas are integrated. From a climate change perspective, there are long-, medium- and short-lived forcers. SLCPs can hence be viewed as climate forcers and a tool to reduce global warming in the near-term. Currently, short-term climate forcing becomes more important as we proceed into the future. Model calculations show that BC, O_3 and CH_4 account for 57-60% of radiative forcing in next 20 years and their reduction might be necessary to achieve the 2° C temperature goal (Jackson, 2009). From an AQ perspective, SLCPs (without HFCs but including cooling agents such as sulfate aerosol) are traditional air pollutants that need to be reduced to protect human health and ecosystems regardless of their climatically cooling or warming characteristics. Air quality remains a significant concern for many countries, and may hence offer a better entry point for co-benefits than climate change (Zusman and Miyatsuka, 2013). Therefore, regardless of the viewpoint, reducing SLCPs in the near-term is attractive to both policy areas.

However, there are several more facets to the AQ and CC perspectives that are necessary to consider for the development of metrics that guide integrated policy making. It is highly likely that SLCPs need to be reduced to comply with the 2 degree target, especially when progressing into the future the near term mitigation will gain importance while little effort on CO_2 abatement is done (Jackson, 2009). This situation is challenging, because reducing SLCPs is technically easier than reducing CO_2 exacerbating the potential risk that CO_2 reduction is procrastinated too long into the future in favor of SLCP action. If only SLCPs are reduced, we end up with the same rate of global warming after a couple of years, however on a roughly 0.5 degree lower level. For policy decisions, the "right" mix between reducing SLCPs and LL GHG needs to be found to achieve short-term improvements and long-term mitigation. This is difficult because current climate metrics are mostly designed to describe the effects of LLGHG and not SLCPs. A prominent example is the 100-year global warming potential (GWP_{100}) applied in the Kyoto protocol. However, recently attempts are being made to introduce alternative metrics that are better suited, such as the global temperature change potential (GTP, more details in section II). In addition, alternative trading schemes are being proposed (more in section IV). These alternatives are a step forward to acknowledging multiple other impacts of SLCPs besides climate change. Different from medium and LL GHG, SLCPs have direct and local negative effects on human health and the environment, and they can also lead to climate cooling. This leads to another set of challenges because it introduces both co-benefits but also trade-offs to reducing SLCPs for climate, while from an air quality perspective, simply all SLCPs need to be reduced. Hence, impacts in both sectors need to be evaluated simultaneously for sound policies in order to take advantage of co-benefits and avoid trade-offs.

The question is how shall the effects in both sectors be weighed and what is the common denominator? In other words, what metrics can be applied to characterize SLCP effects in both sectors to facilitate comparison, collaboration, and overall recognition of potential trade-offs involved between pursuing air quality and climate change mitigation goals.

II. Metrics

The pillars of designing a useful metric are science, policy and value judgment considerations (Tanaka et al., 2010). Loosely defined for this context, metrics are a quantified measure or indicator of a status quo, effect or impact used to inform decision-making and to evaluate mitigation measures.

Climate emission metrics can be used to inform understanding of, and to communicate, the relative contribution to climate change of emissions (or reductions in emissions) of different gases or substances e.g., CO_2 versus non-CO_2 gas contributions, (Shine et al., 2007), or of emissions from different countries or sectors (IPCC Alternative Metrics Meeting Report, https://www.ipcc-wg1.unibe.ch/meetings/alternativemetrics/oslometrics.html). Air quality metrics, generally representing short-term ambient concentrations rather than emissions, are primarily used to assess the current state of air quality against regulatory prescriptions. In both cases, metrics are the "currency" of climate and air quality policy.

Example air quality metrics

- **Ambient concentrations**: A concentration guideline set to protect human health or ecosystems that is either recommended or legally binding. E.g., 50 ppb daily 8-hour mean for ozone (WHO guideline to protect human health).
- **SOMO35 (for ozone)**: The annual sum of daily maximum values over 35 ppbv (based on 8-hour running means), expressed in µg m^{-3} h. A human health-based guideline.
- **AOT40 (for ozone)**: Accumulated ozone over 40 ppbv from 8 am to 8 pm over May to July, expressed in µg m^{-3} h and based on hourly data. An ecosystems-based guideline.

Most of the air quality related metrics are legally binding limit or target values or thresholds.

Climate metrics

Climate metrics can be structured according to (1) how they consider emissions, i.e. pulse emissions or scenarios, (2) the indicator or impact parameters they use, such as radiative forcing, temperature change, price, sea-level rise etc., and (3) further characteristics including the time dimension (integrated or instantaneous), rate of change etc. (Tanaka et al., 2013;Shine, 2009). Climate metrics often attempt to place some kind of equivalence on different emissions to make them comparable across sectors, nations and different forcers. The following table from Tanaka et al. (2013) lists the most common climate metrics and alternatives.

Table 1 Approaches to the metric structure design. Metrics are classified according to the following three entities: i) emission, ii) indicator, and iii) time dimension. i) PUL and SCN indicate pulse emissions and emissions scenarios, respectively that are used to define the corresponding metrics. ii) FOR, TEM, and PRI denote radiative forcing, temperature change, and price, respectively, which are the indicators for the respective metrics. iii) INT and INS mean that a time-integrated and instantaneous indicator, respectively are used for the associated metrics. Note that the integration for the CETP accounts for discounting. A discounting of 0 % is implicitly assumed for other integrated metrics over the time horizon and an infinite discounting beyond the end of the time horizon

Type	Emission	Indicator	Time dimension	Description
Price ratio	SCN	PRI	INS	Price ratio (Manne and Richels 2001) (also called Global Cost Potential (GCP) (Tol et al. 2012)) allows one to achieve a stabilization target at the lowest possible cost theoretically. This metric is defined as the ratio of the *shadow prices* of relevant components. The price ratio can be calculated from a forward-looking optimization IAM, which produces not only a stabilization emissions scenario but also shadow prices (i.e., the level of which the emissions of each compound needs to be taxed or priced in a cap-and-trade system so that the emissions scenario can be realized).
GWP	PUL	FOR	INT	Global Warming Potential (GWP) (IPCC 2007) is used in the Kyoto Protocol and many other climate policies and assessments. It is defined as the *integrated radiative forcing* over the time horizon due to a pulse emission of the component in consideration divided by that of CO_2.
GTP	PUL	TEM	INS	Global Temperature change Potential (GTP) (Shine et al. 2007; Shine et al. 2005) is the most frequently-used alternative metric. This metric is formulated as the *temperature change* at the end of the time horizon due to a pulse emission of the component in consideration divided by that of CO_2. It has been proposed as a metric better designed in the context of climate stabilizations than GWP.
MGTP	PUL	TEM	INT	Mean Global Temperature change Potential (MGTP) (Gillett and Matthews 2010) (also called integrated Global Temperature change Potential (iGTP) (Peters et al. 2011) or (IGTP) (Azar and Johansson 2012)) is a hybrid of the GWP and the GTP—the MGTP is defined as the *integrated temperature change* over the time horizon due to a pulse emission of the component in consideration divided by that of CO_2.
CETP	PUL	TEM	INT	Cost-Effective Temperature Potential (CETP) (Johansson 2012) mimics the behavior of the GCP by using a simpler formulation. It accounts for the post-stabilization temperature change. The CETP is defined as the *integrated temperature change from the point of the stabilization year onward with discounting* due to a pulse emission of the component in consideration divided by that of CO_2.

FEI	SCN	FOR	INS	Forcing Equivalent Index (FEI) (Wigley 1998) is an instantaneous, time-varying index that produces an identical radiative forcing pathway over time. The FEI is computed for each time segment such that it exactly follows the original forcing pathway after the emission conversion (i.e., one could interpret that the time horizon is 1 year if computed every year).
TEMP	SCN	TEM	INT	TEMperature Proxy index (TEMP) (Tanaka et al. 2009a) is to ensure a *climatic equivalency* (Shine 2009). The TEMP is a numerical index that allows an emission exchange between two components over time such that the temperature pathway after the emission conversion is kept as close as possible with the original temperature pathway. The TEMP is, in contrast to the FEI, calculated over the entire time horizon. Unlike the FEI, the best-fitting temperature pathway after the emission conversion is not necessarily identical with the original pathway. However, the TEMP can be updated by re-fitting based on a revised time horizon, which makes the TEMP time-dependent. The TEMP presented here uses the forward-looking approach (in contrast to the backward-looking approach mainly shown in Tanaka et al. (2009a)), which is equivalent to the time-dependent time horizon (Table 2).

A significant difference between typical AQ and CC metrics is the spatial scale they are applied to. While AQ metrics often require point measurements at monitoring stations, hence reporting very local situations, climate metrics are commonly based on global averages. When integrating AQ and CC policies, metrics will have to provide information in higher spatial resolution for decision-support. Making use of co-benefits and avoiding trade-offs will be local to regional challenges. At the same time, however, smaller scale action needs to be in agreement with global climate change mitigation. Especially when considering short-lived species in general, or from an isolated emission sector (e.g., transport), that are not well mixed in the atmosphere and hence produce spatially very heterogeneous forcing (even of different signs), regional or local metrics can inform with much more details than global mean metrics that potentially average out small scale effects. To connect the regional information with the global picture, locally calculated metrics can be averaged globally. This captures a more complete and informative signal than global mean input. However, heterogeneous temperature response to forcing from emissions of isolated sectors is smaller than from CO_2 forcing. Hence, the importance of including regional climate impacts in global metrics depends on whether a sector shall be evaluated in isolation or as part of the overall climate change (Lund et al., 2012).

Also, the design of metrics can influence the willingness of regional or sectoral participation in collective climate change mitigation efforts, e.g. agriculture or energy-intensive sectors, depending on the weight that is put on a substance (e.g. CH_4 or CO_2). If, for example, a metric was applied that gave increasing weight over time to CH_4 it would increase abatement activities in the agricultural sector and take of burden from the energy-intensive sectors that emit large quantities of CO_2. Such weighting would also influence the burden that certain regions in the world would have to take on for climate change mitigation and this can then have large implications for regional food production and security (Reisinger and Ledgard, 2013).

III. Metrics and Mitigation

Metrics can be thought of as a kind of map that captures features of the system. The challenge is to ensure that metrics are as accurate and complete a map as possible, while at the same time parsimonious enough to support decision-making as well as feasible to actually measure. These trade-offs are assessed and metrics are often conceived with a particular type of decision in mind, but often become short-hand for describing a system for other groups of decision-makers as well as new decision problems. Metric error – or loosening of the correspondence between the map and the underlying reality – is likely to occur as policy, public discourse, public and private financial governance use the metric in more ways. This may become “stress” if the excluded dimensions play an important role in the system or outcomes that the decision-makers seek to influence.

Collective Delusions: Commonly understood definitions of a loosely used term – e.g. climate impact- and the precise definition of the metric differ. Evidence organized around a specific definition is then used in debates organized around different understandings.

Visibility and Invisibility: Metrics provide the map for policymakers, investors, and others to influence the system. What the metrics leave out of the map is thus invisible. Climate change mitigation efforts that are measured in terms of CO_2 and CO_{2e}, for example, do not take the impacts of their actions on SLCPs into account.

Administrative Mechanics: Metrics are often embedded in eligibility criteria for finance, cost-benefit analyses for statutory policy assessments (e.g. social cost of carbon as used in U.S. regulatory review), monitoring & evaluation systems, and other rule-based processes that mechanically affect outcomes.

IV. New institutional directions

While in the air quality sector little reason exists to develop new metrics or approaches due to the established regulatory frameworks, there are new developments with respect to climate metrics (see table 1) and policy approaches to using metrics. One of the reasons for this motivation is the critique (e.g., Tanaka et al., 2013;Shine, 2009;Fuglestvedt et al., 2010) of the usage of GWP_{100} in the Kyoto Protocol (KP). Next to the fact that the First Assessment Report (IPCC 1990) clearly states that there is no one single metric that can cover all the important factors, the GWP has not been designed to guide emissions towards any stabilization target and is hence largely irrelevant for policy making. It also contains a value judgment, because it leads to an underestimation of the relative potential impact of CH_4 in the near-term and of CO_2 in the long-term (Daniel et al., 2012).

Based on the success story of the Montreal Protocol (MP) which pursues a *multi-basket strategy* a similar approach has been called for for global climate change mitigation. A multi-basket approach assigns different substances or gases based on their different characteristics to different baskets, like the different ozone depleting substances in the MP. Trading within the baskets is allowed, while trading across the baskets is prohibited due to the non-unique relationships between controls (e.g. market control) and environmental impacts. This is currently one of the major caveats of the single basket KP approach where all gases can be traded. This is useful for finding e.g. economically optimized mitigation strategies. This flexibility, however, leads to the reduction of effectiveness of meeting policy goals.

A multi-basket approach moves responsibility of prescribing substance reductions to the policy design level, allowing for more direct control in addressing environmental risks, rather than allowing markets to guide the reductions (Daniel et al., 2012). If LL GHG and SLCPs were separated into different baskets, each basket would take care of emissions from different sectors using the mitigation potential to a much higher degree than at the moment. Only long-term focused mitigation would overlook emission from e.g., enteric fermentation, gas production, rice cultivation, coal production, wastewater treatment, landfills or residential biofuel combustion. These would be covered in a two basket approach (Jackson, 2009).

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