OZONE AND AEROSOLS IN FUTURE CLIMATE AGREEMENTS OR GREENHOUSE GASES IN AIR POLLUTION AGREEMENTS?: SCIENTIFIC AND POLITICAL CHALLENGES

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Abstract
In addition to the six greenhouse gases included in the Kyoto Protocol, the ozone precursors CO, NMVOC and NO_x and the aerosols/aerosol precursors black carbon, organic carbon and SO_2 also play significant roles in climate change. These compounds differ from the Kyoto gases for several reasons: their climate effects are dependent on the geographical location of emissions; aerosols and NO_x can contribute with a negative forcing (cooling); uncertainty about their climate impacts is higher (in particular for aerosols); and they affect health, vegetation and materials in addition to climate. Because of these differences, these compounds, in particular the aerosols and NO_x, are less suitable to be included in the Kyoto basket of gases as part of a global protocol. Instead, they may be regulated more appropriately in regional agreements. Such agreements could be a part of a future climate regime or air pollution agreements that could address the climate effects as well as other environmental effects. There are several important challenges, among others: to increase the knowledge of atmospheric transport and regional climate effects, to assess the institutional basis for an agreement with respect to the UNFCCC and air quality agreements (for example the Convention on Long-Range Transboundary Air Pollution), and to get a better understanding of the cost-effectiveness (abatement costs and functioning of the flexibility mechanisms). An important question is whether the complexity and fairness issues introduced by addressing ozone precursors and aerosols might negatively affect the political feasibility of a future agreement.

1. Introduction
The Kyoto Protocol sets targets for reducing the emissions of the main greenhouse gases (GHGs), inter alia, CO_2, CH_4, N_2O. However, because the United States, Australia and Russia have not ratified the Protocol and the initial emission reduction target was only 5.2%, the impact of the protocol on climate change will be very small – if it ever enters into force. There is an increasing call for post-Kyoto climate treaties, whether they be global or regional, to widen the scope to include ozone precursors (NO_x, NMVOC and CO) and aerosols/aerosol precursors (black carbon (BC) and organic carbon (OC)) (hereafter called OAPs). There are two main reasons for this: First and foremost, there is increasing evidence that these air pollutants play an important role in the climate system. Second, reducing GHGs that are also significant air pollutants can have an added beneficial effect on human health and the environment, which may increase the attractiveness of the agreement and thus increase participation, which will be a prerequisite for future treaties to be effective.

Because of the natural links between OAPs and the other GHGs in the Kyoto Protocol, it has been suggested that there should be a closer link between air quality and climate policies (Akimoto, 2003). The design of such an agreement, however, is far from obvious. One of the most important design elements for an integrated agreement is the degree to which it is globally or regionally based. Holloway (2003) argues that a hemispheric treaty covering OAPs for both climate and air quality purposes could be politically attractive for the USA and possibly open up for a willingness to also accept targets for the direct greenhouse gases. The argument is that, while climate issues cannot garner enough political interest in the United States, air pollution concerns are high. On the other hand, Rypdal et al. (2004) point out that a regional treaty may be complex because it is difficult to weight the various concerns and because there are at present large uncertainties connected to the climate effects of OAPs. Neither the scientific nor the political basis for agreements to regulate emissions of OAPs is in place on a worldwide basis. In this paper we will briefly summarize the knowledge of the climate effects of OAPs and give an overview of concerns that might influence policy makers. We will finally discuss whether the current knowledge can be used to conclude whether OAPs should be included in a global climate agreement or whether greenhouse gas concerns should be integrated into air pollution agreements.

2. A brief summary of the climate effects OAP emissions

Most of the gases included in the Kyoto Protocol have sufficiently long life-times to be considered well-mixed in the atmosphere. This implies that the climate effect is independent of the location of the emissions. In contrast, the climate effect of OAPs can depend on location (Fuglestvedt et al., 1999; Wild et al., 2001; Berntsen et al., 2004). This is because:

i) Ozone and many aerosols are not emitted directly, but are rather formed from other substances: *e.g.* CO, NMVOC and NO_x form ozone; and sulphate and OC form aerosols. These formation processes are non-linear (depending on the background concentration of other species which due to short life-time are not evenly distributed) and there are regional differences in removal times
ii) The radiative forcing resulting from a change in concentration of ozone or an aerosol depends on the physical properties of the earth/atmosphere system which are regionally dependent. Aerosols may also have an indirect climate effect through the modification of clouds which is regionally inhomogeneous
iii) The spatially heterogeneous radiative forcing means that the spatial pattern of heating and cooling of the atmosphere is changed. This may give different regional patterns of climate change, for example, changes in precipitation patterns. Studies indicate that the emissions of SO_2 and BC may have specific regional climate effects (Lelieveld et al., 2002; Menon et al., 2002).

The uncertainties associated with the estimated radiative forcing, and in particular the climate effects, are larger for tropospheric ozone and aerosols than for the gases included in the Kyoto Protocol. Furthermore, the forcing of some aerosols and NO_x can be negative, implying that the emissions lead to cooling. A key question is whether and to which extent negative forcing of these substances counteracts the positive forcing from others.

The Global Warming Potentials (GWPs) concept constitutes the foundation for the principle of comprehensiveness of the Kyoto Protocol. GWPs for CO and NO_x have been calculated for some main regions (Berntsen et al., 2003 and 2004), illustrating the much larger spatial dependence for NO_x and a both positive and negative component. Furthermore, the short life-times of OAPs are not compatible with the 100 year integration applied for the implementation of GWP in the Kyoto Protocol. For CO the regional difference in GWP is much smaller and there is only a positive component. In general it is difficult to expand the GWP concept to gases (NO_x and aerosols) with a negative forcing (Rypdal et al., 2004).

3. Political attractiveness

There are a number of policy-related concerns that affect the political attractiveness of an agreement that includes OAPs.

Cost-effectiveness: By expanding the comprehensiveness of a global climate agreement, states will be able to expand the portfolio of abatement options, which means that they will be able to choose the option that represents the lowest cost. For this kind of cost-effectiveness to be realized, two requirements must be met: First, that reducing ozone precursors and aerosols is comparable to that of reducing the other Kyoto gases in terms of both costs and amount. The second requirement is that measures and investments which are least expensive per tonne of CO_2 equivalent are carried out first. According to Rypdal et al. (2004) including NO_x and NMVOC in the Kyoto basket for Norway will improve cost-effectiveness, but the potential is limited because the GWP contribution is small and Norway has already implemented many of the cheapest measures due to concerns about local and regional air pollution. This conclusion may be different in countries with other marginal abatement costs and source/pollutant compositions.

Measures: Measures to reduce emissions of GHGs also often lead to reductions in emissions of OAPs, therefore the cost of reducing air pollution will be lowered if climate measures are implemented (van Harmelen et al., 2002; van Vuuren et al., 2004).

Co-benefits: Political attractiveness is enhanced when an agreement meets multiple goals simultaneously. Reducing emissions of OAPs not only leads to a more stable climate, but there are also other benefits (so-called co-benefits). Ozone causes agricultural damage and affects human health adversely. Aerosols affect health adversely and influence plant growth directly and indirectly.

Regime linkage: The most comprehensive air quality regime, both with respect to geographical and pollutant coverage is the UN Economic Commission for Europe (UNECE) Convention on Long Range Transboundary Air Pollution (LRTAP). The LRTAP Convention aims to directly reduce emissions of ozone precursors and indirectly reduce aerosols by reducing emissions of heavy metals and persistent organic pollutants (POPs) (which are emitted primarily on particles) and the aerosol precursor SO_2. The Gothenburg Protocol under this convention is a multi-effect protocol, addressing tropospheric ozone formation, eutrophication and acidification. There are also ongoing negotiations to include the health effects of aerosols directly. The emission targets under the Gothenburg Protocol are individual for each country, negotiated on the basis of pollution effects (health, crop and nature) and abatement options. The multi-effect approach taken under the LRTAP Convention opens up for also including climate considerations in the framework. Although national policies are in place in non-European Annex I and in non-Annex I countries, regional cooperation is weaker than in Europe and North America. Consequently, existing regional cooperation might not at present be strong enough to deal with climate issues on a worldwide basis.

Verification and compliance: Any agreement covering more pollutants will be more difficult to enforce as ensuring accurate reporting and assessing compliance will become more challenging. Furthermore, emissions of aerosols (except SO_2) are poorly known. However, there are potentially large synergies when producing joint GHG and OAP inventories.

4. Discussion

Ozone precursors can be regulated through a *global climate agreement* (for example in a subsequent commitment period of the Kyoto Protocol), through *regional agreements,* or simply by leaving regulation to *national policy*. It seems unlikely that local or national policies alone will be able to deal with the complex concerns related to optimal reduction strategies for OAPs, taking into account all the local, regional and global effects. The issues related to regulating ozone precursors and aerosols in a global climate agreement are summarised for each gas in Table 1. Of the OAPs, CO, and to some extent NMVOC, have atmospheric behaviour closest to the Kyoto gases in that it is possible to define an average climate effect, the forcing is positive and the uncertainties are not extremely high (Rypdal et al., 2004), although the current metric (GWP) has methodological problems when applied to the emissions of these ozone precursors.

Black carbon (which contributes with a positive forcing) may be suited for inclusion in a global climate agreement if uncertainties with respect to emission inventories and the climate effects could be reduced, but it can be difficult to define an average climate effect. NO_x is also complicated because it contributes with both a positive and negative forcing. Due to the variations in regional effects, it may not be appropriate to assume that the climate effect of a negative forcing counteracts the effect of a positive forcing of the same magnitude. With the present knowledge, OC and SO_2 are not suitable to include in a global climate agreement in a basket with the Kyoto gases. Although negative forcing technically can be handled within the comprehensive approach, it would most likely be politically difficult to negotiate an agreement that could encourage increases in emissions of SO_2 and OC.

Table 1. Overview of gains and obstacles when regulating ozone precursors and aerosols in a global climate agreement (from Rypdal et al., 2004)

	CO	NMVOC	NO_x	SO_2	BC	OC
Sign of forcing	Positive	Positive	Positive or negative	Negative	Positive	Negative
Possibility to apply an average climate effect	Fair	Fair	Fair	Complicated	Complicated	Complicated
Knowledge of GWP values	Fair	Poor-Good*	Fair/poor	Poor	Poor	Poor
Knowledge of emission data	Fair	Fair	Good	Good	Poor	Poor
Co-benefits with air quality problems	Yes	Yes	Yes	Yes, but negative forcing complicates the issue	Yes	Yes, but negative forcing complicates the issue
Increased cost-effectiveness	Yes	Yes	Yes, to some extent	Negative forcing complicates the issue	Yes	Negative forcing complicates the issue
Conclusion	**Well suited**	**Well suited**	**Maybe suited**	**Not suited**	**Maybe suited**	**Not suited**

* Depending on species

The regionally confined climate effects of the ozone precursors and aerosols may mean that it will be more appropriate to regulate them in *regional agreements* (see Holloway *et al.*, 2003). The advantages and drawbacks of a regional vs. global regulations are shown in Table 2.

If aerosols and NO_x are to be better integrated into climate policy there are many advantages to addressing them in regional agreements rather than in a global agreement. Regional agreements would make it easier to account for negative forcing because the climate effects are more confined to the regions where the emissions occur. One could foresee a more advanced modelling-based metric that could account for smaller scale regional effects and changes in wind and precipitation in addition to temperature. Regional agreements would also be well suited for NMVOC and CO. In principle, the Kyoto gases could also be regulated in regional agreements. However, the pure global effects of these gases provide few arguments supporting a regional approach. The main argument against separate regulation of the OAPs and the Kyoto Protocol GHGs is the loss in cost-effectiveness compared to having one basket covering all gases. This could to some extent be handled through having a close link between targets and trading mechanisms in the global and regional agreements.

Table 2. Ozone precursors and BC in global or regional climate agreements (from Rypdal et al., 2004)

Issue	**Global**	**Regional**
Negative forcing	Difficult to handle	Less difficult to handle
Possibility to apply an average climate effect	Fair approximation for the ozone precursors, difficult for BC	Less difficult
Cost-effectiveness	High	Less cost-effective if the direct GHGs are regulated in a global agreement
Co-benefits with respect to reducing air quality problems	Policies will often not be integrated	Policies can be integrated. Different concerns can be included in an agreement.

One advantage of regional agreements is the possibility of better integrating air quality and climate concerns. This should build on existing institutions like the UNECE LRTAP Convention and the UNFCCC. The UNECE's strength lies in its multi-pollutant target setting while the UNFCCC's strength is *i.a.* its flexibility mechanisms and broad participation. Integration of air quality and climate concerns in one agreement could, however, be complicated because of the need to weight the different concerns in order to set targets. Holloway *et al.* (2003) suggest that an agreement with a larger focus on ozone precursors and aerosols might be more acceptable to the USA and China, among others, because the co-benefits with respect to improvements in air quality are large. Furthermore, they argue that the air quality problems are transboundary, so that national policies alone are inadequate. The co-benefits of reducing ozone and aerosols, however, vary significantly between global regions. Many Western European countries have already implemented the cheapest measures to reduce emissions of ozone precursors and aerosols to improve air quality. Thus, the co-benefit of climate policies in terms of reduced damage from air pollution is limited. In countries where air quality improvements have *not* been undertaken, however, it seems clear that implementing climate measures would entail large environmental co-benefits. Many developing countries may, however, object to changing the focus from CO_2 and the other direct GHGs emitted in the industrialised countries to ozone precursors and aerosols, where developing countries have a larger share of global emissions.

The main argument against a broad regional agreement is that making links to a global climate agreement as well as to various air quality concerns may be too complex to negotiate. Furthermore, integrating OAPs into the flexible mechanisms is not straightforward. The LRTAP area is Europe and North America, however, if this type of arrangement were extended, there could be one hemispheric treaty (as suggested by Holloway et al., 2003) or several (e.g. Pacific, Atlantic and Euro-Asian), depending on the complexity and interrelationships between problems.

Further study on the political feasibility of including ozone precursors and aerosols in a future climate agreement can thus be seen as a fruitful and important area of inquiry. Of particular interest will be studies of how domestic actors, constellations of political majority, and interest groups perceive the political attractiveness of expanded agreements. An increased understanding of the climate effects of OAPs, source-receptor relationships and costs of integrated policies are needed as background for further policy development.

5. Conclusions

From a scientific point of view, NMVOC and CO could with minor difficulties be included in a *global* climate agreement together with the basket of direct GHGs, but regional climate agreements covering ozone precursors and aerosols will be better able to handle the regionally confined climate effects and negative forcing. Such regional agreements could also take into account air quality concerns and should, where possible, build on existing air quality agreements, for example the LRTAP Convention. Separate regulation of ozone precursors and aerosols from the GHG of the Kyoto Protocol would, however, imply a loss in cost-effectiveness compared to a fully integrated regulation. To increase the cost-effectiveness, regional climate agreements have to be linked to the global Kyoto Protocol. Including ozone precursors and aerosols in regional or global climate agreements may be attractive in political terms due to the possible savings from cost-effectiveness, synergy effects from regime linkage, and co-benefits with respect to improved air quality. However, developing countries might see this as an attempt to change the focus from CO_2, which is not only the main GHG, but is primarily caused by activities in the industrialized world. Moreover, the heterogeneous nature of the radiative forcing from the short-lived gases may well affect the political feasibility of an agreement that includes them in terms of added complexity.

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References

Akimoto, H., 2003. Global air quality and pollution. Science vol. 302, 1716-1719.

Berntsen T., Fuglestvedt, J.S., Myhre, G., Stordal, F. and Berglen, T.F., 2003. Abatement effectiveness of simultaneous reductions of several GHGs and aerosols: Does location matter, Accepted in Climatic Change.

Berntsen T., Fuglestvedt, J. S., Joshi, M., Shine, K.P., Ponater, M., Sausen, R. and Hauglustaine, D.A., 2004. Climate response to regional emissions of ozone precursors. Manuscript in preparation.

Fuglestvedt, J.S., Berntsen, T.K., Isaksen, I.S.A., Mao, H., Liang, X.-Z., and Wang, W.-C., 1999. Climatic effects of NO_x emissions through changes in tropospheric O3 and CH4 - A global 3-D model study, Atmos. Environ., Vol. 33, No. 6, 961-977.

Holloway, T., Fiore, A., Hastings, M.G., 2003. Intercontinental Transport of Air Pollution: Will emerging science lead to a new hemispheric treaty? Environ. Sci. Technol. 2003, 37, 4535-4542.

Lelieveld, J., Crutzen, P.J. and Brühl, C., 1993. Climate Effects of Atmospheric Methane, Chemosphere, Vol. 26, No. 1-4, 739-768.

Menon S., J. Hansen, L. Nazarenco, Y. Lao, 2002. Climate effects of black carbon aerosols in India and China, Science, 297, 2250-2253.

Rypdal, K., Berntsen, T., Fuglestvedt, J.S., Aunan, K., Torvanger, A., Stordal, F., Pacyna, J.M. and Nygaard, L.P. Ozone and aerosols in future climate agreements: scientific and political challenges. Submitted to Environmental Science & Policy.

Van Harmelen, T., Bakker, J., de Vries, B., van Vuuren, D., den Elzen, M. and Mayerhofer, P., 2002. Long-term reduction in costs of controlling regional air pollution in Europe due to climate policy. Environmental Science & Policy 5 (2002), 349-365.

van Vuuren, D.P, Cofala, J., Eerens, H., Oostenrijk, R., Heyes, C., Klimont, Z., den Elzen, M., and Amann, M., 2004. Exploring the ancillary benefits of the Kyoto Protocol for air pollution in Europe. Technical report 93. European Environmental Agency.

Wild, O., Prather, M.J., Akimoto, H., 2001. Indirect long-term global radiative cooling from NO_x emissions, Geophys. Res. Lett., Vol. 28, No. 9, 1719.