Concept Note

The linkages between air quality and climate policies: governance deficits and challenges

The effects of aerosols

international risk governance council

Preface

The International Risk Governance Council (IRGC) is an independent organisation whose purpose is to help the understanding and management of emerging global risks that have impacts on human health and safety, the environment, the economy and society at large. IRGC's work includes developing concepts of risk governance, anticipating major risk issues and their associated opportunities, and providing risk governance policy recommendations for key decision-makers.

In addition to ongoing work on the concept and practice of risk governance itself, IRGC's work programme encompasses all emerging, global risks of a systemic nature. IRGC is currently addressing the governance of a number of risks and opportunities posed by the mitigation of and adaptation to the effects of climate change, the security of energy supply, unconventional crises, and innovative technologies.

IRGC concept notes are intended to provide an overview of the particular topic being addressed and of its associated risks and opportunities. This is the objective of the following document, which is not intended to be a complete and in-depth description of the current state of knowledge of aerosols and their impacts on human health and the world's climate. Instead, the document provides a brief summary of scientific knowledge and of the issues it raises and suggests a number of questions relating to its risk governance. The document thus seeks to inform and guide any possible future work which IRGC may undertake on the subject.

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Introduction

Fine airborne particles, known as aerosols or particulate matter, have serious adverse effects on human health and have been estimated to be responsible for as many as 800,000 deaths worldwide each year, mostly in poor and developing countries. Additionally, aerosols are believed to be a significant climate forcing agent, with strong effects on climate at both regional and global scales. These effects are not uniform as some particles tend to offset global warming while others tend to reinforce it. Some aerosols can also contribute to the melting of polar and glacial ice and have a significant effect on the hydrological cycle and on rainfall which, in turn, can have a direct impact on the availability and quality of fresh water and on food production.

A wide range of human activities lead to the creation and emission of, mostly, fine aerosols with a diameter of a few microns or less. While these constitute only a small fraction of the total mass of aerosols in the Earth's atmosphere (the majority are naturally occurring from dust storms and sea spray), fine anthropogenic aerosols are of great concern for public health because they can travel deep into the lungs, where they can cause serious and adverse health effects. Cleaning the air of anthropogenic aerosols has thus become a top priority for air quality programmes throughout the world.

Due to the influence of aerosols on the world's climate, improvements in air quality can have unintended climatic effects of regional and global significance. Meanwhile, actions taken to mitigate global climate change may affect air quality and the objectives and costs of air quality policies. Although climate change and air quality policies have emerged and developed independently, there is an increasing recognition of the linkages between the two.

The impact of air quality on public health has been a major concern for centuries and an important policy priority for several decades. From the climate side, the attention of scientists – and then of policymakers – has focused first on the effects of greenhouse gases (GHGs) as they are the main drivers of anthropogenic climate change. While the scientific community has long understood that there is a link between local and regional control of particulate air pollution and climate policy, IRGC believes that this linkage deserves greater scientific and policy attention.

The purpose of this concept note is, primarily, to draw attention to the linkages between air quality policies and climate change policies resulting from the effects of aerosols. The concept note first provides background information on the health effects of air pollution caused by particulate matter and on current air quality regulation. It then describes the impacts of aerosols on climate and ecosystems at the international and global scales. It moves on to provide an overview of the governance context of air quality and climate change policies. Finally, the concept note provides a discussion of the risk governance deficits and challenges in this area.

1. Definition of aerosols and particulate matter

Aerosols are solid or liquid airborne particles that vary both in size (from a few nanometres to a hundred micrometres [µm] and in their chemical and physical properties [Seinfeld and Pandis, 1997]. Aerosols are also referred to as *particulate matter* (although, technically, particulate matter [PM] is the total mass of aerosols per unit of volume). In general, "particulate matter" is used in the context of air quality policy and science, while "aerosol" is used in the context of climate science.

Some aerosols occur naturally, originating from dust storms, sea spray, forest fires, living vegetation or volcanoes. Others, however, are the result of human activity such as transport, industry, forest and savannah burning as well as burning wood and coal for domestic heat and cooking.

Aerosols can be emitted directly into the atmosphere (such particles are called primary particles). Others (secondary particles) can be formed in the atmosphere by chemical reactions from precursors, as is the case with the conversion of sulphur dioxide (gas) to sulphate (aerosol). In many cases the formation of secondary particles is facilitated by sunlight.

Aerosols have effects on both health and climate. These effects depend on the size of the aerosol. One distinguishes between fine aerosols, with diameters of a few microns or less, and larger aerosols. The size distinction can also be denoted as $PM_{2.5}$ (the mass of particles with diameters less than 2.5 µm) and PM_{10} (the mass of particles with diameters less than 10 µm).[1]

Aerosols can remain in the atmosphere[2] from between a few minutes to a couple of weeks. The largest particles fall to the ground quickly due to their weight. The fine particles are in general those which persist up to a couple of weeks in the atmosphere and are eventually washed out with rainfall [Seinfeld and Pandis, 1997]. While they constitute only a small fraction of the total mass of atmospheric aerosols, fine aerosols are dangerous to human health. Human activities emit mostly fine aerosols [e.g., Ramanathan et al., 2001].

This concept note focuses on the following main anthropogenic aerosols:

- *Sulphate aerosol* – Coal-burning power plants and industrial activities contribute more than three-quarters of the emissions of sulphur dioxide (SO_2), the main precursor of sulphate, in Europe, the US and Asia. Global SO_2 emissions have decreased since the late 1970s due largely to emission controls in Europe and in the US (see for example, [Smith et al., 2004]), but they have nevertheless increased in Asia.[3]
- *Organic aerosol* – Emissions of organic aerosols are predominantly caused by forest and savannah burning but also at significant levels by

[1] "Fine" aerosols and $PM_{2.5}$ are roughly equivalent. PM_{10} includes both fine particles and larger particles with diameters up to 10 µm. However the term "large" aerosols can refer to particles with a diameter greater than 10 µm.
[2] This concept note will focus predominantly on the effect of aerosols in the troposphere (located between the Earth's surface and approximately 10 km in altitude).
[3] Between 1980 and 2000, emissions of sulphur dioxide were reduced from 18 to 4 megatonnes (Mt) per year in Europe, and from 12 to 8 Mt per year in the US. Emissions in Asia increased to approximately 17 Mt per year [IPCC, 2007].

fossil fuel and biofuel use. Emissions of organic aerosols increased by a factor of two to three between 1850 and 2000 [Bond et al., 2007].

- *Black carbon (BC) aerosol* (also referred to as soot or elemental carbon) – Black carbon is the result of incomplete combustion of fossil fuels, biofuels and forest and savannah burning. Globally, emissions have increased three-fold between 1950 and 2000, driven mostly by the rise of emissions in China and India and in spite of the gradual decrease in emissions in the US, Europe and countries of the former Soviet Union (see for example, [Novakov et al., 2003; Bond et al., 2007]).[4]
- *Mineral dust* [5] – Anthropogenic sources originate mainly from agricultural and industrial practices and changes in surface water and in vegetation cover. There are difficulties in determining the anthropogenic contribution to mineral dust. A best guess of between 0 and 20% has been used by the Intergovernmental Panel on Climate Change [IPCC, 2007].
- *Nitrate aerosol* – The main precursors of nitrate aerosol are ammonia and nitric acid, which derive from, for example, agriculture, soils, industrial processes, biomass and fossil fuel burning.

Fine particles, including those emitted by human activities, can remain in the air for enough time to reach high altitude currents. They can thus travel distances of thousands of kilometres and cross national borders and move between continents. Satellite observations have provided clear evidence of the long-range dispersal and transport of atmospheric aerosols (e.g., [Kaufman et al., 2002]).

These particles mix with other atmospheric materials and form large-scale hazes such as the atmospheric brown clouds found in the Indo-Asia region, making air pollution effectively an international issue. About three billion people live in regions influenced by these hazes, primarily in parts of south and south-east Asia, eastern China, sub-Saharan Africa, and Central and South America [Ramanathan and Carmichael, 2008].

In the Arctic, far from any anthropogenic sources of air pollution, the transport of aerosols and other atmospheric pollutants from North America, Europe and Asia has been known to cause the Arctic haze, which can have significant effects on the Arctic's regional climatic system as well as on ice-melt (e.g., [McConnell et al., 2007]).

[4] After the 1980s, the trends of BC emissions in the US and Europe are unclear, partly because of the proliferation of diesel cars.

[5] Mineral (natural) dust occurs when wind blows over arid areas and lifts particles up in the air. This is one of the main global sources of aerosols (from 1000 to 2000 Tg yr^{-1}) [IPCC, 2007].

2. Aerosols and air quality

Evidence of health effects

Among air pollutants, fine aerosols are particularly dangerous to human health because they are small enough to be inhaled deep into the lungs and can seriously affect the respiratory and cardiovascular systems.

Particulate matter contained in outdoor air pollution is currently estimated to be responsible for 800,000 premature deaths each year worldwide, 65% of which occur in poor and developing countries in Asia [Cohen et al., 2005; WHO, 2002] [6]. Indoor air pollution is responsible for an even larger number of deaths, also occurring predominantly in Asia, due to the inhalation of pollutants from the burning of solid fuels for cooking and heating.[7]

Particulate matter can cause severe health risks, even in Europe and North America where PM levels are considered relatively low in comparison to Asian or Latin American countries. Data on health effects (obtained from the American Cancer Society) combined with values of ambient air pollution (taken from US Environmental Protection Agency databases) show that ambient concentrations of $PM_{2.5}$ were associated with a significant mortality risk (much lower than the mortality risk associated with smoking, and less than that associated with obesity, but comparable with the estimated effect of being moderately overweight) [Pope et al., 2002]. Two elicitations of expert judgement studies confirm both the link between particulate matter and health risk and that the mortality risk is at least as large as found by Pope et al. American and European experts also believe that mortality occurs due to long-term rather than short-term exposures to particulate matter [Roman et al., 2008; Cooke et al., 2007].[8]

There is currently little evidence to recommend a concentration threshold below which adverse effects do not occur [WHO, 2006]. However, based on current knowledge, the World Health Organization (WHO) has provided specific guidelines for PM concentrations dependent on particle size and the duration of human exposure.[9]

There are still a large number of uncertainties regarding the adverse effects of particulate matter on health. Further research into and knowledge of the potential health effects of particulate matter may provide more opportunities to improve air quality. It is a priority for many governments to improve knowledge in this area and, for example, the US Environmental Protection Agency (EPA) has established a PM Research Program.[10]

[6] This figure of 800,000 represents 1.4% of the total number of annual premature deaths.
[7] Indoor air pollution is responsible for 1.6 million deaths due to the inhalation of air pollutants (including PM, carbon monoxide, nitrogen and sulphur oxides, and benzene) [Cohen et al., 2004].
[8] For short-term exposures to particulate matter, multi-city studies in Europe, the US, and Asia reported a very similar mortality effect of a daily concentration of approximately 0.5% per 10 $\mu g/m^3$ of PM_{10} [WHO, 2005].
[9] The WHO recommends, for $PM_{2.5}$:, an annual mean of 10 $\mu g/m^3$ and 25 $\mu g/m^3$ for the 24-hour mean, and, for PM_{10}:, 20 $\mu g/m^3$ for the annual mean and 50 $\mu g/m^3$ for the 24-hour mean.
[10] http://www.epa.gov/pmresearch/pm_research_accomplishments/

Two areas that are being given attention are:

- The relative toxicity of the different components of particulate matter. Cooke et al. show that "experts all identify primary combustion particles (i.e., elemental and organic carbon, traffic particles, or diesel particles) as the "most toxic" constituent of the ambient PM mixture (…); but acknowledge the limitations of available data and the large uncertainty in their answers" [Cooke et al., 2007].
- The impact of exposures to ultra-fine particles (with a diameter below 0.1 μm). There is evidence of potentially serious adverse effects on human health (e.g.,[Oberdörster, 2001]).

Background on the regulation of particulate matter

Concern about air pollution is not new. In the United Kingdom (UK), for instance, London has been regularly polluted by the burning of coal since medieval times when Royal Proclamations were already attempting to limit emissions of pollutants to protect the city's inhabitants. Centuries later, in 1952, a dramatic five-day episode of smog caused thousands of deaths in London, mostly from respiratory tract infections, and gave rise to a new awareness of air pollution and its effect on public health.

During the first part of the twentieth century, regulations were aimed mainly at controlling emissions from industry. In Europe and North America, the emphasis has subsequently shifted from the pollution problems caused by industry to those associated with emissions from motor vehicles and power plants.[11]

Policymakers have addressed the issue of regulating emissions in the transportation sector since the 1960s.[12] Regulations and voluntary programmes have led to technology advances in vehicle and engine design, as well as in cleaner and higher-quality fuels, that have considerably reduced vehicle emissions.[13] One of these design solutions has been to introduce diesel particulate filters in diesel engine exhausts to trap particles before they escape into the atmosphere. This technology has been used in automobiles since the 1990s and has proven to be particularly successful in reducing black carbon emissions by as much as 90%.[14] Another promising technology, available on the market since 2006, is ultra-low sulphur diesel with its substantially lowered sulphur content.

As a result of these and other measures, air quality has improved considerably over the past 30 years in developed countries without impeding economic growth. Between 1970 and 2006, US emissions of the six most common air pollutants have been reduced by 54% [Johnson, 2008] and many cities or

[11] http://www.ace.mmu.ac.uk/Resources/Fact_Sheets/Key_Stage_4/Air_Pollution/02.html
[12] http://www.dnrec.state.de.us/DNREC2000/Divisions/AWM/aqm/education/airqualityappx.pdf
[13] According to the EPA, these technological innovations have reduced emissions by as much as 75 to 90 percent per vehicle per mile as compared to emission levels in the 1970's. For more information, please see: http://www.epa.gov/oms/invntory/overview/solutions/vech_engines.htm
[14] See the Verified Technologies List of the EPA Diesel Retrofit Technology Verification Program, http://www.epa.gov/otaq/retrofit/verif-list.htm

states currently meet their ambient air standards (see for example [Charles, 2002]).

The US and the European Union (EU) have explicit standards for atmospheric concentrations of $PM_{2.5}$ and PM_{10}. The current US Clean Air Act was amended in 1990 and requires the EPA to set national ambient air quality standards for particulate matter. It is complemented by state and city-level regulations such as those of the Californian Air Resources Board, which have introduced more restrictive standards than the national standards. In the EU, a new Directive on ambient air quality and cleaner air was adopted in 2008 with the objective of lowering concentrations of $PM_{2.5}$ in all Member States.

These and other regulatory measures have led to significant reductions in PM concentrations in many developed countries, but air quality remains a concern and continues to cause severe health problems, even in these countries. According to the EPA, in 2007 more than 70 million people in the US were living in areas that did not meet the Federal $PM_{2.5}$ standards.[15] The APHEIS (Air Pollution and Health; a European Information System) programme concluded in 2005 that "air pollution continues to pose a significant threat to public health in urban environments in Europe". This statement was released following a number of health impact assessments on particulate pollution in 26 cities in 12 European countries [APHEIS, 2005].

Improving air quality is also a priority for developing countries. Air quality standards have been set for PM_{10} in several Asian countries (e.g., India)[16], but no standards to date aim at regulating $PM_{2.5}$. However, good air quality has not yet been achieved in Asia and some Asian cities have the world's highest recorded PM_{10} levels. For example, in Delhi and in Beijing, the annual mean level has been as high as 170 µg/m^3 (in 2003) and 160 µg/m^3 (from 1999 to 2002), respectively [HEI, 2004]. These figures are more than eight times higher than the WHO guidelines, although both cities have taken steps to alleviate the problem.

According to the WHO, "the standard-setting process needs to aim at achieving the lowest concentrations possible in the context of local constraints, capabilities and public health priorities" [WHO, 2006]. It is therefore possible that the PM standards may be further reduced over time.

The benefits to human health and the savings that come from improved air quality are considerable. The EPA has estimated that, due to the Clean Air Act and the control of particulate matter, more than 20,000 adult deaths, and approximately 100,000 hospitalisations and cases of chronic illness, will be avoided annually by 2010. This would represent a potential saving in the order of US$ 100 billion in health care costs [EPA, 1999].[17] The WHO has estimated that, within the EU, the implementation of current PM legislation will avoid more than 200,000 deaths by the year 2020, with an annual monetary benefit of between €58 and 161 billion. [18]

[15] http://www.epa.gov/air/airtrends/sixpoll.html
[16] In India, the government enacted the Air Pollution Act in 1981. Standards for PM_{10} (annual mean) exist and action plans are being considered for the control of pollution in cities that do not meet the ambient air quality standards [CAI-Asia, 2006].
[17] The monetary benefit from avoided mortality ranges between US$ 14 and 250 billion, with a central value of 100 billion. Values are in 1990 US dollars.
[18] http://www.euro.who.int/mediacentre/PR/2005/20050414_1

Reducing air pollution has also provided several ecological benefits, such as the reduction of water acidification. Successes in North America and Europe result, for example, from programmes that considerably reduce emissions of SO_2 and the environmental impacts associated with acid rain.

3. Aerosols and climate

Effects on global climate

The concept of *radiative forcing* (RF) is used widely to quantify the impact of a perturbation on climate. Radiative forcing is a measure of how much the Earth's energy balance (incoming minus outgoing energy) is modified. It is expressed in Watts per square metre (Wm^{-2}), where positive RF indicates a warming effect on climate and negative RF indicates a cooling effect [IPCC, 2007]. Use of the RF measure is convenient as a means of comparing different natural and anthropogenic drivers of climate change.

Aerosols affect the Earth's energy balance and its climate mainly through the reflection and absorption of sunlight (direct effect) and the modification of cloud properties (indirect effect).

Airborne particles reflect a portion of the sunlight, reducing the amount of solar radiation that reaches the Earth's surface and, thereby, leading to its cooling. In addition, some aerosol particles also absorb solar radiation, thus heating the atmosphere. In the case of absorbing particles, the balance between the negative surface forcing and the positive atmospheric forcing depends on several factors such as the properties of the particle, its altitude and the surface cover. Black carbon is the strongest sunlight-absorbing particle and has a net global warming effect on climate.

In addition to this direct effect, aerosols can modify cloud properties by acting as condensation nuclei on the surface of which cloud droplets can form. There are two main indirect effects of aerosols. First, the fine particles tend to produce brighter clouds that further cool the climate (referred to as the "cloud albedo effect" in Figure 1). Second, large numbers of fine particles may lead to droplet sizes that are too small to fall, which can decrease the probability of precipitation and may also increase cloud lifetime. These processes contribute to a net cooling effect on climate. However, note that, conversely, modest numbers of larger particles may increase the likelihood of precipitation.

Figure 1 provides the current estimates of radiative forcing [IPCC, 2007]. The anthropogenic forcing on climate is first and foremost driven by GHGs (+1.49 to +1.83 Wm^{-2} for CO_2, for example). Overall, aerosols have a net cooling effect on climate (-0.9 to -0.1 Wm^{-2} through their direct effect; -1.8 to -0.3 Wm^{-2} through the cloud albedo effect). However, black carbon particles have a net warming effect on climate (+0.2 ± 0.15 Wm^{-2} for black carbon from fossil fuel emissions; +0.2 Wm^{-2} for black carbon from biomass burning emissions; and +0.1 ± 0.1 Wm^{-2} due to black carbon deposited on snow and ice [IPCC, 2007]). It should be noted that there are large uncertainties associated with aerosol radiative forcing, and these uncertainties may be underestimated by the IPCC; for example, Morgan et al. suggest a somewhat wider range (of -0.25 to -2.1 Wm^{-2}) for the total aerosol radiative forcing [Morgan et al., 2006].

Effects on regional climate and the hydrological cycle

Aerosols have a much shorter lifetime in the atmosphere than GHGs. As a result, aerosol distribution is not globally uniform and, therefore, aerosol forcing on climate is highly variable, both spatially and temporally. In regions of high aerosol concentration, the impact of aerosols on climate can be much higher than the global and annual average (see Figure 1). Evidence of such regional impacts has been provided by field measurements and satellite observations. For example, the Indian Ocean Experiment INDOEX revealed a large negative surface forcing (-12 to -30 Wm^{-2}) over the tropical northern Indian Ocean during the 1998 and 1999 winters) [Satheesh and Ramanathan, 2000].[19] According to Ramanathan, a value of -14 Wm^{-2} is "typical of other polluted regions including the Atlantic, Eastern USA, the Amazon and Africa" [Ramanathan et al., 2001].

The fact that – unlike GHGs – aerosols act to strongly cool the surface and heat the atmosphere has significant implications for regional climate systems and the hydrological cycle (e.g., [Ramanathan et al., 2001]). In particular:

- Negative surface forcing results in a decrease of surface evaporation and rainfall. This is contrary to GHGs, which warm both the surface and the atmosphere, leading to an increase of surface evaporation and rainfall.

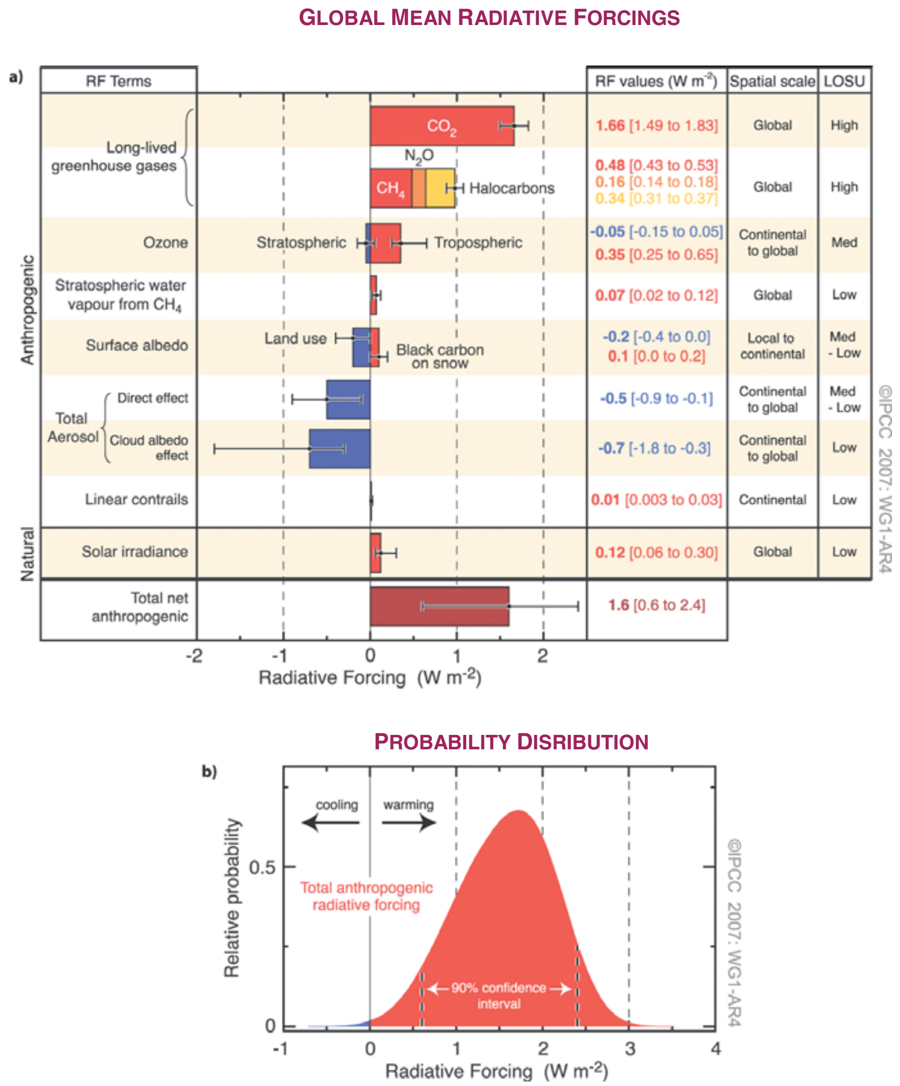
- Aerosols decrease sea surface temperatures but not in a uniform fashion (as aerosol distributions in the atmosphere are themselves not uniform). For example, rainfall in the tropics depends in part on latitudinal variations of sea surface temperature [Chung and Ramanathan, 2007]. Depending on the region of the world, changes to sea surface temperature can either increase or decrease rainfall.

- Aerosols reduce the dynamic motions of air currents in the lower atmosphere.[20] In the tropics this may reduce rainfall.

In regions with persistent atmospheric haze, particularly in tropical regions of Asia, South America and Africa, aerosols can contribute to regional climate change through the effects described above. There is a chain of complex and specific regional responses to aerosol forcing. These are currently not all fully understood, nor are the effects of aerosols *in combination* with GHGs.

[19] Measurements taken during INDOEX also revealed that, while there was a strong negative forcing at the surface of the sea, there was a strong *positiv*e forcing on the atmosphere due to the presence of absorbing aerosols (such as black carbon) [Satheesh and Ramanathan, 2000].
[20] In general, these reductions occur within the first 4 km [Ramanathan et al., 2005].

Figure 1: Global mean radiative forcings [IPCC, 2007]



(a) Global mean radiative forcings (RF) and their 90% confidence intervals in 2005 for various agents and mechanisms. Columns on the right-hand side specify best estimates and confidence intervals (RF values); typical geographical extent of the forcing (Spatial scale); and level of scientific understanding (LOSU) indicating the scientific confidence level (see [IPCC TS, 2007] for further details). Errors for CH_4, N_2O and halocarbons have been combined. The net anthropogenic radiative forcing and its range are also shown. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional form of natural forcing but are not included due to their episodic nature. The range for linear contrails does not include other possible effects of aviation on cloudiness. (b) Probability distribution of the global mean combined radiative forcing from all anthropogenic agents shown in (a). The distribution is calculated by combining the best estimates and uncertainties of each component. The spread in the distribution is increased significantly by the negative forcing terms, for which the uncertainties are larger than for the positive terms.

4. Governance context

Air quality and climate change policies

The United Nations Framework Convention on Climate Change (UNFCCC) entered into force in 1994 and has set an overall framework for intergovernmental efforts to tackle anthropogenic climate change. The role of the Convention is to encourage the stabilisation of GHG emissions. The UNFCCC is a success in terms of universality as it includes 192 countries. The Convention covers all GHGs not regulated by the Montreal Protocol on Substances that Deplete the Ozone Layer. The Kyoto Protocol to the UNFCCC, adopted in 1997 and signed to date by 84 countries, commits Annex I signatories[21] to meet prescribed targets in terms of GHG emission reductions through national measures and market-based mechanisms (emissions trading, Clean Development Mechanism (CDM) and Joint Implementation). The targets cover emissions of the six main GHGs, namely carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride. However, aerosols are not GHGs and are covered neither by the UNFCCC nor the Montreal Protocol.

With respect to air quality, policymakers are responsible for the implementation of national or state policies that are designed to protect human health. In support to governments, the WHO provides air quality guidelines that, while non-binding, are considered seriously by many governments. Aerosols are given full consideration by governments through their air quality policy (see Section 2). The international issues raised by the long-range transport of air pollution are addressed by the United Nations Economic Commission for Europe Convention on Long-Range Transboundary Air Pollution (LRTAP). LRTAP draws attention to the links between air pollution and climate, but it is not designed to address climate policies.

Air quality and climate change policies have developed independently. As such, climate policies do not effectively account for the climate impacts of aerosol emissions or control. Similarly, air quality policies regulate aerosols without consideration of their secondary climatic impacts. Because of complex and multiple scale (local, continental and global) interactions, decisions taken in one policy area can often affect other policy areas, either positively or negatively.

There is, however, an increasing awareness of the linkages between air quality and climate policies. In Europe, reports designed to support the UK government and the European Commission investigated the impacts of air quality policies on climate and *vice versa*. Both reports recommended that policymakers in the UK and in the EU use an integrated approach to address the linkages between air quality and climate [EEA, 2004; AQEG, 2007]. Experts in the UK have recently stated that "a potential risk of keeping research and

[21] Annex I parties include "the industrialized countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States", http://unfccc.int/parties_and_observers/items/2704.php

policy on CC and AQ separate is that abatement strategies may not recognise the synergies or trade-offs that may exist" [AQEG, 2007].[22]

The following section will investigate the impacts of climate (and climate policy) on air quality and vice versa.

Can climate policy have an impact on air quality?

- A report from the European Environment Agency (EEA) estimates that the EU's contribution to mitigating global warming will lead to a reduction of air pollutant emissions and their associated health effects and, thus, also reduce the costs of implementing existing air pollution abatement policies [EEA, 2006].[23] Similarly, the Organisation for Economic Co-operation and Development (OECD) suggests that GHG mitigation policies could deliver other significant benefits for air quality policy objectives (human health, environment) and also deliver important cost savings [OECD, 2008]. Such co-benefits resulting from the control of GHG emissions were also emphasised by researchers for China and other large developing countries [Aunan et al., 2006].

- Air pollutant levels (aerosols in particular) are influenced by meteorological conditions (such as wind and precipitation) which determine their transport and deposition. Aerosol levels are therefore expected to vary in response to climate change [IPCC WGII, 2007]. The UK's Air Quality Expert Group (AQEG) concluded that a change in air quality is expected in the future in the UK due to changes in winter and summer climate conditions [AQEG, 2007]. The AQEG also suggested a possible change in aerosol emissions from living vegetation resulting from changes in vegetation cover (due to climate change or to mitigation policies such as tree-planting) [AQEG, 2007]. However, those results rely on models which include large uncertainties and would require further development to influence the decision-making processes [e.g., AQEG, 2007].

Can air quality policy have an impact on climate?

- A report from the Massachussets Institute of Technology (MIT) examined the impacts on climate of caps on air pollutants (the study did not include aerosols other than sulphate and its emissions scenarios are "highly idealized but informative"). The MIT study suggests that "air pollution policies may have only a small influence, either positive or negative, on mitigation of global-scale climate change". This study, however, acknowledges that caps on other aerosols (in particular black carbon and organic aerosols) – if considered – could lead to "more substantial" impacts on global temperature, cloud and precipitation patterns [Prinn et al., 2005].

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[22] "CC" stands for climate change, "AQ" for air quality.
[23] A reduction of €10 billion per year, plus avoided health costs of between €16-46 billion per year, could be expected.

Worldwide improvements to air quality will lead to the reduction of global aerosol concentrations, and may therefore:

- Make more evident the global warming due to GHGs [e.g., Raes, 2004] as the reflection of sunlight by aerosols partially counterbalances the GHG warming effect. There is evidence that this may have occurred over the past few decades [Wild et al., 2005]. Additionally, models suggest that the contribution of aerosol reductions to temperature rise could be significant (see, for example, [Brasseur and Roeckner, 2005; Levy II et al., 2008]; note that the emissions scenarios in these two studies are idealised). According to Brasseur and Roeckner: "the globally averaged surface air temperature and amount of precipitation could increase in less than a decade by 0.8K and 3%, respectively, if the entire amount of anthropogenic sulfate aerosols were removed from the atmosphere" [Brasseur and Roeckner, 2005].

- Lower global warming, if the concentration of black carbon is reduced as suggested by several studies [see for example, Hansen et al., 2000; Jacobson, 2002; Bond, 2007; Ramanathan 2007; Ramanathan and Carmichael, 2008]. Black carbon absorbs strongly solar radiation and recent findings suggest it plays a significant role in current global warming [Jacobson, 2007; Ramanathan and Carmichael, 2008].

- Also if black carbon concentrations are reduced, slow the rate of ice-melt. Atmospheric warming due to black carbon may contribute significantly to the melting of snow packs and glaciers in the Himalayas [Ramanathan and Carmichael, 2008]. In addition, the deposition of black carbon on ice reduces the surface albedo, which results in a warming of the surface that accelerates ice-melt. Models suggest that the effect of black carbon on the reduction of sea-ice could be greater than that of CO_2 [Flanner et al., 2007].

- Perturb the hydrological cycle and regional climate, with possible implications for ecosystem services (such as water and food). Studies have suggested possible impacts on drought and floods in India and China [Menon et al., 2002]; drought in the Amazon Basin [Cox et al., 2008]; the strength of the Asian monsoon [Ramanathan and Carmichael, 2008]; the stabilisation of atmospheric dynamic motion [Ramanathan et al., 2005]; and, rice harvests in India [Aufhammer et al., 2006]. Model estimates of aerosol impacts on regional climates and the hydrological cycle are, however, highly uncertain, partially due to the difficulties related to cloud and precipitation modelling (e.g., [Randall et al., 2003]) and do not yet provide robust support for decision-makers.

5. Risk governance deficits and challenges

Scientists agree that aerosols have significant global impacts on climate. There is an increasing awareness of the linkages between air quality and climate policies. Current governance practices, however, ignore the global and regional effects of aerosols. This section of the concept note explores the risk governance deficits and challenges linked to current governance practices.

Governance deficits

Lack of scientific knowledge

There has been some recent progress in the modelling and observation of aerosols (and their effects on climate), in particular for black carbon aerosols [IPCC, 2007]. However, further specific research on aerosols is still needed, in particular to characterise aerosol sources, optical properties, distribution and transport, and interaction with clouds. The reduction of current uncertainties as well as the identification of remaining issues will require improvements in the tools used (models, satellite observation, ground-based measurements) [CCSP, 2008].

To best inform the decision-making process, an appropriate basis for comparison between the climate impacts of GHGs and aerosols is needed. So far comparisons rely on:

- Global warming potential (GWP). This is the means of comparison used by the Kyoto Protocol to compare the six regulated GHGs. GWP provides a measurement of how much a given mass of each GHG contributes to global warming, relative to the same mass of CO_2 (by definition the value for CO_2 is 1). GWP needs to be expressed as being over a specific time period and, under the Kyoto Protocol, the selected time horizon is 100 years. The GWP of black carbon can theoretically be estimated, but values vary enormously[24] and there is, as yet, no consensus in the scientific community regarding black carbon's GWP. For example, Boucher and Reddy argue that the metric of the GWP presents limitations when applied to aerosols such as black carbon because aerosol perturbations to the climate system do not occur uniformly over a 100-year period [Boucher and Reddy, 2008]. Global temperature change potential (GTP) accounts for the time profile of the radiative forcing and has been put forward as an alternative to GWP [Shine et al., 2005; Shine et al., 2007; Boucher and Reddy, 2008]. For example, Boucher and Reddy have shown the suitability of GTP for comparing short- and long-lived species and concluded that, in light of current uncertainties, there is a need for additional research to compare the effects of aerosols and long-lived GHGs on climate.

[24] There are a wide range of estimates for the GWP of BC as it varies according to several factors (e.g. regions, aerosol lifetimes). See, for example, the paper [Boucher and Reddy, 2008], which reported estimates (see references therein) from 374 to 1600 for a time horizon of 100 years.

- In the scientific literature, radiative forcing is widely used to compare the impacts of different agents on climate (see Section 3). It is generally given as a global mean at the top of the atmosphere. First, the uncertainty in the aerosol radiative forcing is large and needs to be reduced (see Section 3). Second, important limitations of the concept of radiative forcing with respect to aerosols have been identified by experts [NRC, 2005]. In particular, aerosols can have large regional impacts, much greater than is reflected by the global mean. In addition, aerosols can have climate impacts other than temperature change (for example, on clouds and precipitation), and this is not reflected by the concept of radiative forcing. Finally, aerosols have a different impact at the Earth's surface and at the top of the atmosphere and this difference is not reflected by the global mean at the top of the atmosphere [NRC, 2005].

Misunderstanding the dynamics of complex systems

Another element that impedes good risk governance is the multitude of different responses of, and feedbacks within, the climate system to aerosol forcing. These vary by region of the world and can be positive or negative. Bond argues, however, that this can be addressed by the definition of simple metrics to help the decision-making process [Bond, 2007].

Failure to respond to early warnings

There is a growing body of scientific evidence to suggest that aerosols have a significant impact on global warming, ice-melt, and the hydrological cycle in different regions of the world (e.g., Arctic haze, atmospheric brown cloud in south Asia). These constitute early warning signals that indicate a need to act.

No strategy or norms to deal with a commons problem

Many scientists recommend examining the issues of air quality and climate change together rather than separately. For example, Brasseur and Roeckner concluded that "strategies to limit climate warming below a specified threshold need to be reconciled with strategies to reduce air pollution" [Brasseur and Roeckner, 2005].

An assessment report by the United Nations Environment Programme (UNEP) on atmospheric brown clouds in Asia concludes that "aerosols and high level of ozone that result from rural and urban air pollution are part of the global warming issue. (…) Thus, there is a need to assess the impacts under one common framework" [UNEP, 2002].[25] However, this UNEP assessment does not focus on how to do so within current regional and international governance structures and processes.

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[25] A major new UNEP assessment report on atmospheric brown cloud impacts is expected in the coming months.

The control of aerosol emissions is currently not included in efforts encouraged within the UNFCCC to limit global warming, and aerosols are not recognised under the Kyoto Protocol. It has been argued that, as aerosols do not qualify for credits under the Kyoto Protocol, they are – accidentally or deliberately – not considered when GHG emission reductions are estimated or mitigation strategies planned [Bond, 2007]. Scientists recommend that the effects of aerosols on climate should be acknowledged at the international level. This is not to say that aerosols should be included in international regulatory frameworks such as the Kyoto Protocol as this would not be appropriate because of the large disparity of aerosol effects and the different characteristics of aerosols compared to GHGs.[26] Rather, there is a need to consider aerosol effects when climate policy is discussed. This is not in contradiction with the principles of the UNFCCC, which state in Article 3 (3): "The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects". [27]

Aerosols are definitely a significant driver of climate change, although not the primary driver. At the international level, attention can focus on whether there are key world regions or sectors that can be specifically addressed in order to efficiently reduce aerosol levels. There may also be some "conceptual barriers" to the consideration of aerosols in international efforts (see Box 1).

Dispersed responsibility between and within nations

The responsibilities for assessing the impacts of aerosols on health, climate and the environment, and for controlling their emission, are dispersed in several ways. For example, at the international level, whilst the UNFCCC and its Kyoto Protocol impose obligations on signatory governments to reduce GHG emissions and report on their progress in doing so, the WHO's air quality guidelines are non-binding.

A second difference is within countries. Those national governments that are signatories to the Kyoto Protocol are responsible at the national level for the implementation of the required measures and for the reporting of progress. Although national governments can set air quality policy (and many have done so, successfully), it is also possible for this to be done at regional (e.g., state) and local (e.g., city) levels.

BOX 1: Conceptual barriers to considering aerosols within climate mitigation strategies

Bond assessed four current "conceptual barriers" to the consideration of black carbon aerosols in global climate discussions, and made proposals for how to overcome them [Bond, 2007]. This concept note provides a brief summary of Bond's paper because of its relevance to the issues raised in this particular section.

[26] http://www.princeton.edu/~vnaik/agu_session_ppts/bond_DnP-AGU.pdf
[27] http://unfccc.int/resource/docs/convkp/conveng.pdf

According to Bond, one objection from policymakers to considering aerosols in global agreements is that local regulations would soon reduce the emissions that affect climate on a global scale. Bond argues that, among the five major sources of black carbon, at least three are not addressed by local regulations, namely: residential solid fuels, off-road diesel emissions, and open vegetative burning. That they are not addressed will prevent major decreases in global atmospheric concentrations of black carbon.

Second, it is argued that decision-makers understand aerosol particles to have primarily local effects concentrated on “hot spots” (areas near to the sources, where their concentrations are highest) and it is, therefore, considered inappropriate to consider them in global efforts to mitigate climate change. Bond shows that only 10 to 30% of the impact of black carbon occurs in hot spots and that most of it is generally spread over areas 40 times greater than the source region, despite the much lower concentrations with respect to the source areas [Bond, 2007] (see also Section 2).

Another argument for their exclusion is that aerosol impacts can be perceived as too complex to address in climate mitigation strategies. According to Bond, who described GWP as “not perfect” as a metric, scientists could describe their understanding of aerosols in simple metrics that are “not too complicated to communicate” [Bond, 2007].

Finally, it is argued that another objection from policymakers to considering actions is the high uncertainty of the climatic effects of aerosols. However, Bond states that controlling the sources of black carbon will result in a reduction of climate warming “with a very high probability” [Bond, 2007].

Challenges

Improve scientific knowledge

There is a need for additional research to improve scientific knowledge of, and reduce the uncertainties concerning, aerosols. More research is needed into both their health impacts (for example there is still almost no knowledge of the relative toxicity of the different species of particulate matter in air pollution) and their climate impacts, particularly to achieve a comprehensive characterisation of aerosol impacts on climate and to provide a proper basis to compare aerosol and GHG effects on climate.

Improve communication of complex issues between decision-makers and scientists

The science in the area of aerosols is complex and uncertain. To ensure the transfer of knowledge between the scientific and policymaking communities, there is a need for scientists to develop and use simple and appropriate concepts and metrics.

Address black carbon reduction with appropriate solutions

Despite the uncertainty of the magnitude of the radiative forcing of black carbon, American and European experts reporting to the US House of Representatives [Committee Hearings, 2007] and the European Commission [Raes, 2004], respectively, agree that reducing the concentration of black carbon in the atmosphere from fossil-fuel sources is “a non-regret policy” and will be beneficial both for human health and climate. Considering controls of black carbon in mitigation strategies was also recommended by an international panel of experts which reported to the United Nations Commission on Sustainable Development [SEG, 2007].

It is also widely acknowledged that the control of black carbon emissions cannot prevent other risks related to the increase of the atmospheric concentration of CO_2, such as ocean acidification. Furthermore “BC reduction can only help delay and not prevent unprecedented climate changes due to CO_2 emissions” [Ramanathan and Carmichael, 2008]. However, given the short lifetime of black carbon in the atmosphere and its strong potential for warming, reducing black carbon emissions can be an option to mitigate global warming and would, if successful, result in a rapid response from the climate system (which may occur within a few years, see for example [Jacobson, 2002]).

Because black carbon emissions derive from different sources and these sources and their intensity vary in different regions of the world, various control options exist and should be carefully evaluated. Some of the issues relative to black carbon reduction are discussed below.

Black carbon is always emitted together with other aerosols (in particular organic aerosols) which have a net cooling effect on climate. The most efficient solutions for mitigating global warming will be those which target the sources emitting a larger fraction of black carbon relative to organic or “cooling” aerosols (i.e. emissions from fossil-fuel combustion such as diesel engines and cooking stoves). Streets suggests that an analysis of black carbon together with organic and sulphate aerosol emissions can help identify the “key world regions and economic sectors that could be effectively targeted for aerosol reductions” and concludes that: (i) aerosol emission trends in east Asia and China will be decisive; and, (ii) transportation in developing countries is “the most worrisome sector” [Streets, 2007]. Similarly, in her testimony to the US House of Representatives, Bond suggests a “source-specific” approach rather than targeting species independently (i.e., consider in a comprehensive manner the effects of all species emitted by a given source rather than considering the emission of one component from all its different sources) when black carbon aerosols are involved [Committee Hearings, 2007].

As an example of a “win-win” solution, addressing cooker stove emissions has the potential to considerably reduce mortality in poor and developing Asian countries (it has been estimated that more than 1 million premature deaths per year occur due to indoor cooking in Asia [Cohen et al., 2005]). In addition to human health benefits, this may provide considerable global climate benefits. Introducing smoke-free cookers (solar, bio, or natural gas) in south Asia could lead to a 70-80% reduction in the regional warming due to black carbon [Ramanathan and Carmichael, 2008]. Furthermore, a significant fraction of the black carbon found in the Arctic is believed to originate from sources in south and east Asia [Koch and Hansen, 2005; Reddy and Boucher, 2007]. In 2006, the Clean Development Mechanism supported the introduction of solar cookers to Indonesia to replace the use of firewood for cooking.[28] Development agencies are also active in providing carbon-free cookers in developing countries (e.g., the "Cambodia Fuelwood Saving Project" established by Groupe Energies Renouvelables, Environnement et Solidarités in Cambodia [GERES Cambodia], winner of the 2007 "National Energy Globe Award Cambodia" [29]).

Emissions from transportation are an important policy concern in both developed and developing countries and different options for action are evolving rapidly, due to changes in both technology and regulation. Transport emissions involve different air pollutants (GHGs, aerosols, nitrogen oxides) and the benefits of any given strategy depend on the balance between their different effects on health and climate [AQEG, 2007]. This is another area for which there is a lack of robust information to support decision-makers, not least with regard to evaluating the effects on climate of a change in aerosol emissions relative to a change in CO_2 emissions. However, there is some information available to help in identifying options that are beneficial to both health and climate, to health or climate, or detrimental to both (although this cannot solve the trade-offs). Table 1 classifies some of the options that exist for reducing emissions from the transportation sector with respect to their effect on health and climate.

In Europe, diesel fuel is increasingly being used instead of petrol [AQEG, 2007]. Diesel fuel is generally perceived as beneficial for climate as it results in fewer CO_2 emissions than petrol. On the other hand, the use of diesel releases more aerosols and nitrous oxides (which have adverse effects on health) than petrol. Diesel particulate filters have been introduced to reduce aerosol emissions from diesel vehicles, but this option may indirectly result in additional emissions of CO_2 [AQEG, 2007; Jacobson, 2007; Boucher and Reddy, 2008] whilst still emitting some aerosol particles [Jacobson, 2007]. The climate benefit of diesel vehicles as compared to petrol vehicles has not been clearly assessed, especially because of the uncertainty related to the climate impacts of black carbon emissions [Jacobson, 2007] and, as a result, switching from petrol to diesel as a vehicle fuel is a "poor strategy" for addressing health and climate risks from transportation emissions [Jacobson, 2007].

An example of successful policy action in the transport sector in developing countries is that of public transport in India. In 2003, a policy that required public vehicles to switch to compressed natural gas fuel led to a reduction of black carbon emissions by buses and three-wheeled taxis and has resulted in considerable climate benefits (a 10 to 30% reduction in CO_2-equivalent emissions has been achieved) [Reynolds and Kandlikar, 2008]. The authors of this study concluded that "there is significant potential for emissions reductions through the UNFCCC Clean Development Mechanism for such fuel switching projects" [Reynolds and Kandlikar, 2008]. In addition, the study shows the importance of accounting for aerosols (both "warming" and "cooling" particles) in climate impact assessments. The fuel-switching policy results in a 30% increase in CO_2-equivalent emissions if the impact of aerosols on climate is not taken into account. Conversely, if the impact of aerosols on climate is taken into account, the net effect of the policy is a *decrease* in CO_2-equivalent

[28] http://www.carbonpositive.net/viewarticle.aspx?articleID=590
[29] http://www.energyglobe.com/en/energy-globe-award/winners-2007/national/

emissions ranging from 10 to 30%. These findings support the "source-specific" approach mentioned above.

In conclusion, options which lead to reducing both health risk and climate risk should be encouraged ("win-win" solutions), for example in the selection of certain types of CDM projects, through voluntary programmes, or in the continuous improvements of technology and regulation. When options that are beneficial for health and detrimental for climate are implemented, mitigation strategies should be developed alongside them (e.g., technology improvements). Overall, there is a need to account for aerosol effects in climate impact assessments, in addition to the climate effects of CO_2 and other air pollutants.

Table 1*: Examples of options to reduce emissions in the transportation sector and their related health and climate effects*

Option	*Effect*
Use of new vehicle technology: e.g., hybrid vehicles, electric and/or hydrogen fuel cell produced by a renewable energy source Fuel switching to natural gas Restricting road traffic in urban areas	Reduce health and climate risks (no or less emission of GHGs, particulate matter, and other pollutants) [AQEG, 2007; Jacobson, 2007] [Reynolds and Kandlikar, 2008]
Reduction of the sulphur content in fuel	Reduce health risks (reduce particulate matter), increase climate risks (increase CO_2 emissions due to extra fuel processing) [AQEG, 2007; Beer et al., 2001]
Retrofitting diesel particle filters	Reduce health risks (reduce particulate matter), can increase climate risks [AQEG, 2007; Jacobson, 2007; Boucher and Reddy, 2008]
Fuel switching from petrol to diesel	Increase health risks (increase particulate matter), climate risks not clearly assessed (impact on CO_2 emissions per km driven) [Jacobson, 2007]

Note that, in general, the impact of aerosols on climate is not accounted for when options are evaluated. As a result, in this Table an increase or a reduction of the "climate risk" refers to, respectively, an increase or a decrease of GHG emissions relative to the option (except in the study [Jacobson, 2007]. Similarly, an increase or a reduction of "health risks" refers to, respectively, an increase or a decrease of adverse air pollutant levels relative to the option. References are included in the right column. (Table adapted from [AQEG, 2007]).

Transfer appropriate technology

Given Asia's rapidly-growing economies, the atmospheric concentration of black carbon could also rapidly increase, risking an acceleration of the rate of global warming and ice-melt (emissions from China and India alone account for more than a third of global black carbon emissions [Ramanathan and Carmichael, 2008]). The technology for reducing black carbon emissions exists and can be transferred to developing countries and bring considerable benefits. In particular, emission cuts from households (heat and cooking) and transportation (diesel engines) can result in rapid climate benefits. According to experts, "the pace of diffusion of these technologies across the relevant sectors will be the limiting factor and deserves more attention" [SEG, 2007].

Encourage solutions that are positive for both air quality and climate

Most policies designed to improve air quality will have an impact on climate. Similarly, climate mitigation strategies will also have consequences for local air quality. The challenge for decision-makers here is to encourage "win-win" solutions and therefore to take actions that are positive for health, air quality and climate.

Consider the possible effects of air quality policy on climate; consider the possible effects of climate policy on air quality

Decisions taken in both policy areas would benefit from impact assessments acknowledging possible linkages with the other policy areas. Acknowledging aerosol effects on local and global scales should help: (i) to identify opportunities; and, (ii) to assess the net benefit of policy actions. National policies that affect air pollutants such as aerosols would benefit by being based on impact assessments that consider global climate effects (see, for example, [Reynolds and Kandlikar, 2008; Jacobson, 2007]).

Similarly, the text of the UNFCCC requires governments to evaluate the impacts on other areas of their actions aimed at mitigating climate change. Each party shall "take climate considerations into account, to the extent feasible, in their relevant social, economic and environmental policies and actions, and employ appropriate methods, for example impact assessments, formulated and determined nationally, with a view to minimizing adverse effects on the economy, on public health, and on the quality of the environment, of projects or measures, undertaken by them to mitigate or adapt to climate change" (Article 4 (1) (f)).[30]

[30] The text of the UNFCCC is available at http://unfccc.int/resource/docs/convkp/conveng.pdf

Conclusion and recommendations

This concept note has focused on the linkages between air quality and climate policies resulting from the effects of aerosols and has provided a basis for discussion of the risk governance deficits and challenges in this area.

As a result of successful air quality policies in developed countries, global levels of sulphate (cooling aerosols) have decreased in the last decade. At the same time, however, the global level of warming particles (black carbon) has increased, primarily due to the growth of newly industrialising economies in developing countries. This has created conditions that favour a more rapid increase of the rate of global warming.

Meanwhile, actions taken to mitigate climate change may in fact affect air quality in the future, as well as the effectiveness and costs of air quality policies.

Although there is increasing awareness of the linkages between air quality and climate policies, current governance practices consistently ignore the impact of aerosols on global and regional climate, in spite of the scientific consensus. To fill the gap between knowledge and governance, at this stage, IRGC recommends the following:

- Improving scientific knowledge of: (i) the health impacts of aerosols, specifically to increase knowledge of the relative toxicity of the different components of particulate matter as well as of ultra-fine particles; (ii) how to compare the effects on climate of short-lived aerosols and long-lived GHGs and define simple and appropriate metrics that will improve the communication between scientists and policymakers with respect to the complex aerosol issues; (iii) further characterisation of responses of the climate system to aerosol forcing; and, (iv) different aerosol sources, such as transport, and interactions of aerosols with clouds and the hydrological cycle.

- Specifically addressing black carbon emission reductions in key sectors (e.g., transport and household) by: (i) encouraging solutions which bring benefits to both human health and climate through technology improvements, voluntary programmes and regulation; and, (ii) in key world regions (e.g., developing countries in east and south Asia) using the Clean Development Mechanism to finance appropriate projects and enable technology transfer.

- Considering the impact of aerosols on climate when air quality strategies are evaluated and considering the impact of aerosol emission controls when international efforts to mitigate climate change are evaluated in impact assessments. In particular, when aerosols are involved, the use of a life-cycle approach and a "source-specific" approach would be appropriate (i.e., consideration in a comprehensive manner of the effects of all species emitted by a given source rather than the emission of one component from all its different sources).

Overall, there is a need to acknowledge the implications and impacts of aerosols for different policy areas (predominantly air quality and climate). Some of these implications may require international discussions.

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