

Chapter 2:

Short-lived Climate Forcers and their Impacts on Air Quality and Climate

Black carbon and tropospheric ozone cause health and climate impacts, while tropospheric ozone also causes damage to crop yields and ecosystem structure and function. Methane, a potent greenhouse gas, is also one of the most important precursors of tropospheric ozone and thus contributes to air pollution.

Black carbon and tropospheric ozone remain in the atmosphere for only days or weeks while the atmospheric lifetime for methane is about 12 years (Table 2.1). The critical point is that these substances have a positive radiative forcing and cause warming of the atmosphere through a number of different processes. The historical contribution of pre-industrial to present-day increases in black carbon, tropospheric ozone and methane to radiative forcing is about 1.1 W/m², 68 per cent of the forcing from carbon dioxide over the same time period (Forster *et al.*, 2007).

Some hydrofluorocarbons fall into the category of SLCFs but do not cause air-quality related impacts and therefore, are not considered in this report beyond the

information in Box 2.1. They are, however, covered in another UNEP report (UNEP, 2011a).

2.1 Methane

The increase of methane in the atmosphere has caused the largest radiative forcing by any greenhouse gas after carbon dioxide. Methane concentrations have grown as a result of human activities related to agriculture, including rice cultivation and the keeping of ruminant livestock, coal mining, oil and gas production and distribution, biomass burning and municipal waste landfills.

Methane has a direct influence on climate, but also has a number of indirect effects including its role as an important precursor to the formation of tropospheric ozone. For some methane sources, emission control measures also reduce other co-emitted substances such as the more reactive volatile organic compounds that contribute to the local formation of ozone, as well as air toxics, such as benzene, carbon tetrachloride and chloroform. Thus, some methane mitigation measures provide local air-quality benefits.

Table 2.1: Atmospheric lifetimes of short-lived climate forcers in comparison to the long-lived greenhouse gas CO₂

Substance	Lifetime	Description / Source
Carbon dioxide	Decades to centuries and about 20 per cent will persist for many millennia	No single lifetime can be defined for carbon dioxide because of the different rates of uptake by different removal processes (IPCC: http://www.ipcc.ch/ipccreports/tar/wg1/016.htm)
Ozone	4 – 18 days	http://www.grida.no/climate/ipcc_tar/wg1/pdf/TAR-04.pdf
Methane	12 years	http://www.ipcc.ch/publications_and_data/ar4/wg1/en/errataserrata-errata.html#table214
Black carbon	3-8 days	The mean residence time in the atmosphere for black carbon varies regionally and with the season. The range given here is based on an international evaluation of 16 models (Shindell <i>et al.</i> 2008). However, black carbon may also continue to warm the atmosphere after being deposited on snow and ice.

Box 2.1: Hydrofluorocarbons –climate forcing issues emerging from chemicals designed to replace ozone-depleting substances

Hydrofluorocarbons (HFCs) are intentionally made to replace stratospheric ozone depleting substances (ODS), in such applications as air conditioning, refrigeration, solvents, foam blowing and aerosols. Although, they do not deplete the ozone layer, they are potent greenhouse gases and a substantial fraction of hydrofluorocarbons have a lifetime of 29 years or less and can be considered short lived (Velders *et al.*, 2009; Forster *et al.*, 2007).

Although the abundance of hydrofluorocarbons in the atmosphere is currently small, recent scientific studies project substantial growth in their use in the coming decades as a result of increased demand for refrigeration

and air-conditioning, particularly in developing countries. If left unchecked, HFC consumption is projected to double by 2020, and their emissions could contribute substantially to radiative forcing in the atmosphere by the middle of the century (UNEP, 2011a; Velders *et al.*, 2009).

Currently, hydrofluorocarbons are included in the greenhouse gas emissions to be reduced under the Kyoto Protocol, thus there could be greater scope for collaboration between the Montreal Protocol, where proposals are being discussed to phase out production and consumption of HFCs, and the United Nations Framework Convention on Climate Change.

2.2 Tropospheric ozone

Ozone is a reactive gas that exists in two layers of the atmosphere: the stratosphere (the upper layer) and the troposphere (up to about 10–20 km above the ground). In the troposphere, ozone is a significant greenhouse gas. The threefold increase in ozone concentrations in the northern hemisphere during the past 100 years has made it the third most important contributor to the human enhancement of the global greenhouse effect, after carbon dioxide and methane (Royal Society, 2008). It is the main gaseous pollutant affecting the yield of many crops and also has impacts on the diversity and growth of plant communities. It also affects human health due to its action as a powerful oxidising gas causing, for example, oxidative stress in lungs once it has been inhaled (Romieu *et al.*, 2008).

Unlike many other air pollutants, ozone is not directly emitted. It is a secondary pollutant that is formed in the troposphere by sunlight-driven chemical reactions involving carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), methane and nitrogen oxides (NO_x). These precursors arise from both natural sources and a broad range of human activities. The breadth of sources of ozone precursors, the role of natural and physical processes in ozone distribution, production and destruction and its complex chemistry mean that controlling ozone requires responses that take these complexities into account. The only practical management strategy is to control the emissions of precursors from human activities and, based on the understanding of ozone formation and its impacts, determine which precursor reduction is most appropriate in order to minimise a particular ozone impact.

Reductions in both methane and carbon monoxide emissions have the potential to substantially reduce ozone concentrations and global warming. Methane contributes around 50 per cent of the increases in background ozone, with smaller contributions from non-methane volatile organic compounds and carbon monoxide (Royal Society, 2008). The ozone response to changes in methane emissions requires several decades to be fully realized, given the 12-year average atmospheric lifetime of methane. In contrast, reducing other ozone precursors, i.e. non-methane volatile organic compounds and nitrogen oxides, would only lead to limited global-scale climate benefits, but would play an important role in rapidly reducing peak ozone concentrations within a given region which will reduce air quality impacts on crops, vegetation and human health relatively close to the source of emission.

2.3 Black carbon

Black carbon, a major component of soot, exists in the atmosphere as particles. It is therefore not a greenhouse gas. Instead, black carbon particles absorb sunlight and then radiate energy to warm the atmosphere. Black carbon results from the incomplete combustion of fossil fuels, wood and other biomass. Although complete combustion would turn all the carbon contained in the fuel into carbon dioxide, in practice, combustion is never complete and always releases other gases including carbon monoxide, methane, non-methane volatile organic compounds, and particulate black carbon and organic carbon. Black carbon and other particles are emitted from many common sources, such as diesel cars and trucks,

residential stoves, forest fires, agricultural open burning and some industrial facilities.

There is a close relationship between emissions of black carbon, a warming agent, and organic carbon, a cooling agent as they are always co-emitted, but in different proportions depending on the source. Similarly, mitigation measures have varying effects on the black carbon/organic carbon mix, and on concentrations of other particles and ozone precursors. Therefore, the effectiveness of mitigation measures applied to different sources must take into account the changes in all emissions that influence warming.

Black carbon causes warming of the atmosphere by a number of different processes. These particles absorb visible light due to their dark colour. This absorption leads to a disturbance of the planetary radiation balance and eventually to warming. Another impact of black carbon is that when it is deposited on ice and snow it reduces the albedo of these surfaces, increasing both atmospheric warming and the melting rate caused by increased absorption of heat by the darker snow and ice. Black carbon particles also influence cloud formation. The limited level of knowledge of how some of these processes work also leads to a level of uncertainty of the overall effect of black carbon on global warming, that is higher than that, for example, of methane.

Black carbon aerosols have a large impact on regional circulation and rainfall patterns as they cause significant asymmetry in heating patterns over a region (Ramanathan *et al.*, 2005; Wang, 2004). Whilst not fully quantifiable, the impact of black carbon on regional weather patterns and regional warming is more certain than its impact on global warming. This is because, at the global scale, co-emitted species such as organic carbon may offset warming due to black carbon. At the regional scale, changes are more closely related to atmospheric heating which is dominated by black carbon, and co-emitted species have less of an impact.

Black carbon and organic carbon make up a substantial part of the fine particulate matter in air pollution that is the major environmental cause of ill health and premature deaths, globally (WHO, 2009). The health-damaging particulate matter is characterized as $PM_{2.5}$, particles with a diameter less than 2.5 micrometres – ‘fine’ or ‘small-sized’ particles which affect the respiratory and cardiovascular systems – and its impacts occur due to both outdoor and indoor exposure. The health benefits of reduced emissions from measures that focus on black carbon are mainly achieved by the overall reduction in this fine particulate matter. It should be kept in mind that all reductions of black carbon emissions reduce $PM_{2.5}$ concentrations but all reductions of $PM_{2.5}$ do not necessarily reduce black carbon.