Information on SLCFs in “AR6 Climate Change 2022: Mitigation of Climate Change”

(The WGIII contribution to the Sixth Assessment Report approved/accepted at the IPCC-56/WGIII-14 session) based on the version released on 4 April 2022

TFI TSU

Introduction

- This file has been prepared by the IPCC TFI Technical Support Unit solely for the 3rd Expert Meeting on Short-lived Climate Forcers virtually held on 11-15 April 2022.
- The aim of this file is to help the meeting participants find most relevant information on SLCFs in the "AR6 Climate Change 2022: Mitigation of Climate Change" (the WGIII contribution to the Sixth Assessment Report approved/accepted at the IPCC-56/WGIII-14 session) that is of potential relevance to discussion at the Expert Meeting.
- "AR6 Climate Change 2022: Mitigation of Climate Change" (the version which is subject to final copy-edit and layout, released on 4 April 2022) is available at:
    - https://www.ipcc.ch/report/ar6/wg3/
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Metric

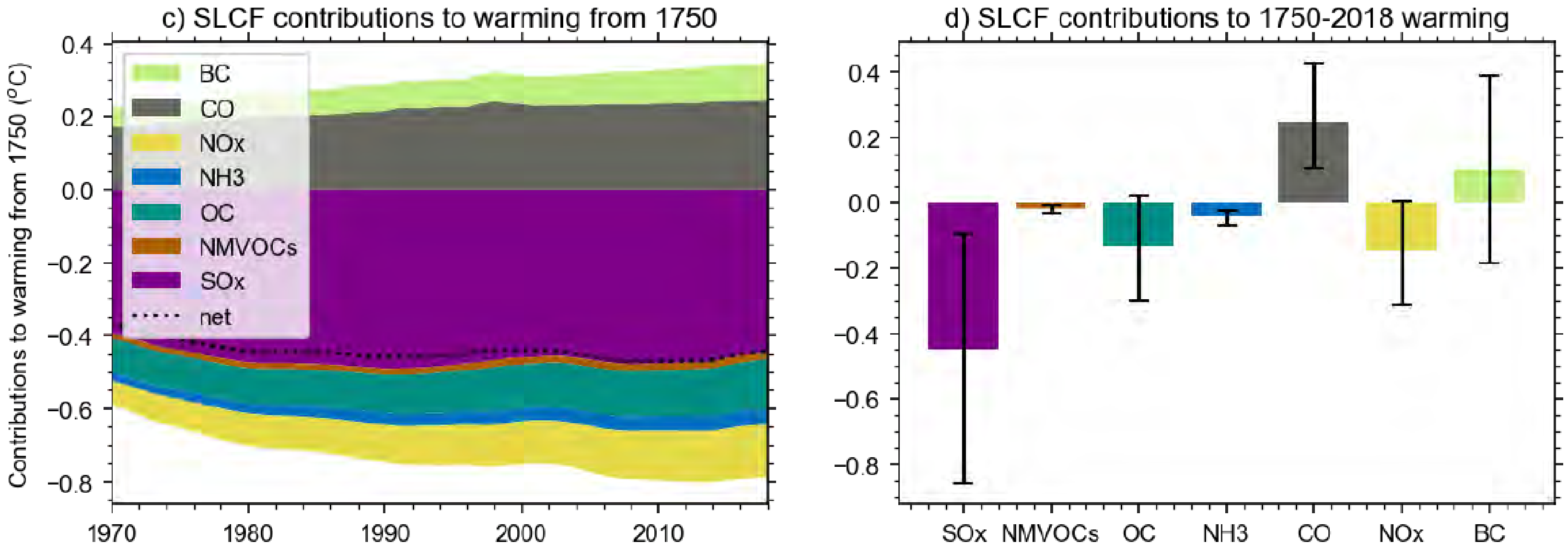
Chapter 2: Emissions Trend and Drivers

- Recently developed step/pulse metrics such as the CGTP (Combined Global Temperature Change Potential; Collins et al. 2019) and GWP* (referred to as GWP-star; Allen et al. 2018; Cain et al. 2019) recognise that a sustained increase/decrease in the rate of SLCF emissions has a similar effect on global surface temperature over multiple decades as a one-off pulse emission/removal of CO_2. [Ch2 p2-17]
- These metrics use this relationship to calculate the CO_2 emissions or removals that would result in roughly the same temperature change as a sustained change in the rate of SLCF emissions (CGTP) over a given time period, or as a varying time series of CH_4 emissions (GWP*). [Ch2 p2-17]
- The ability of these metrics to relate changes in emission rates of short-lived gases to cumulative CO_2 emissions makes them well-suited, in principle, to estimating the effect on the remaining carbon budget from more, or less, ambitious SLCF mitigation over multiple decades compared to a given reference scenario (*high confidence*; Collins et al. 2019; Forster et al. 2021). [Ch2 p2-17/18]

non-methane SLCFs

Chapter 2: Emissions Trend and Drivers

- There are other emissions with shorter atmospheric lifetimes that contribute to climate changes. Some of them like aerosols, sulphur emissions or organic carbon reduce forcing, while others like black carbon, carbon monoxide or non-methane organic compounds (NMVOC) contribute to warming (also see Figure 2.4) as assessed in Working Group I (Forster et al., 2021c; Naik et al., 2021a). [Ch2 p2-24]
- Many of these other short-lived climate forcers (SLCFs) are co-emitted during combustion processes in power plants, cars, trucks, airplanes, but also during wildfires and household activities such as traditional cooking with open biomass burning. [Ch2 p2-24]



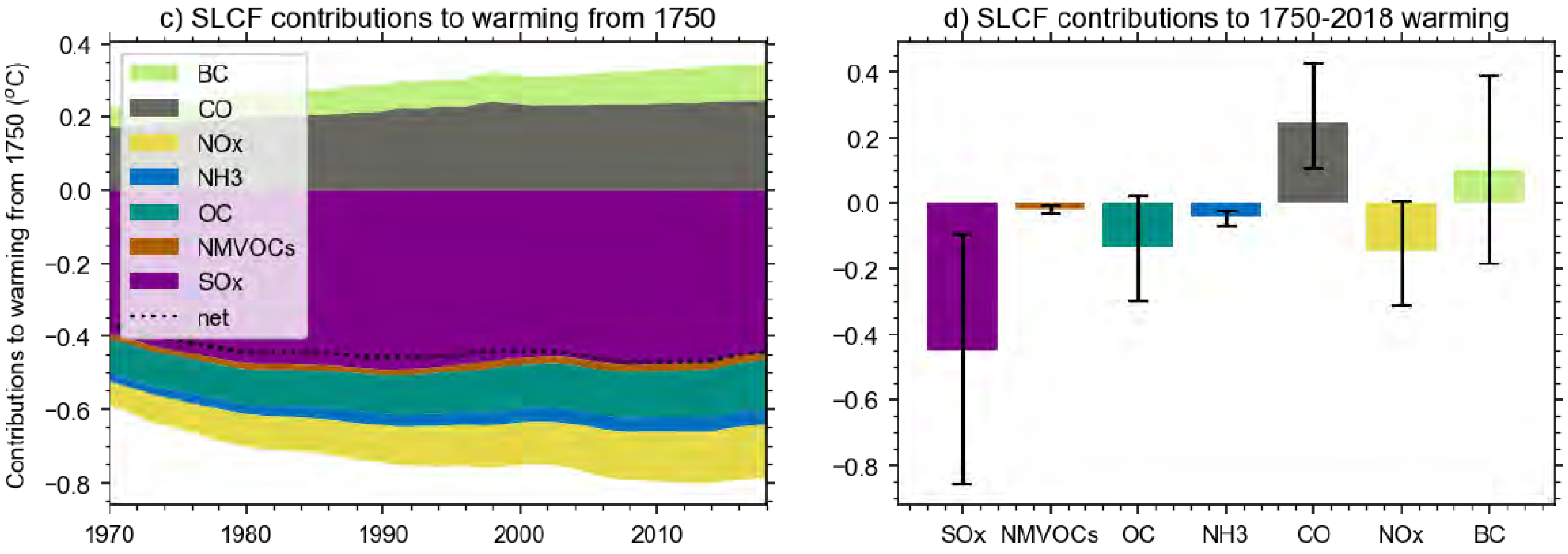
[Figure 2.4 - Ch2 p2-15]

Global Warming

Chapter 3: Mitigation Pathways compatible with long-term goals – [p 3-31]

- In the case of the first group, emission reduction thus leads to both air pollution and climate benefits.
- For the second, group there is a possible trade-off (Shindell and Smith 2019; Lund et al. 2020). As aerosol emissions are mostly associated with fossil fuel combustion, the benefits of reducing CO_2 could, in the short term, be reduced as a result of lower aerosol cooling. [Ch3 p3-31]

[Figure 2.4 - Ch2 p2-15]



Aviation

Chapter 10: Transport

- Aviation's net warming effect results from its historical and current emissions of CO_2, and non-CO_2 emissions of water vapour, soot, sulphur dioxide (from sulphur in the fuel), and nitrogen oxides (NO_X, = NO + NO_2) (Penner et al. 1999; Lee et al. 2021; Naik et al. 2021). [Ch10 p10-59]
- Emissions of NO_X currently result in net positive warming from the formation of short-term ozone (warming) and the destruction of ambient methane (cooling). If the conditions are suitable, emissions of soot and water vapour can trigger the formation of contrails (Kärcher 2018), which can spread to form extensive contrail-cirrus cloud coverage. [Ch10 p10-59]
- In total, the net ERF from aviation's non-CO_2 SLCFs is estimated to be approximately 66% of aviation's current total forcing. [Ch10 p10-59]
- For example, improved fuel efficiency has resulted from high overall pressure ratio engines with large bypass ratios. This improvement has increased pressure and temperature at the combustor inlet, with a resultant tendency to increase thermal NO_X formation in the combustor. Combustor technology aims to reduce this increase, but it represents a potential technology trade-off whereby NO_X control may be at the expense of extra fuel efficiency. [Ch10 p10-62]

ERF: Effective Radiative Forcing

Aviation (Liquid Hydrogen fuel [LH_2])

Chapter 10: Transport

- The non-CO_2 impacts of LH_2-powered aircrafts remain poorly understood. The emission index of water vapour would be much larger (estimated to be 2.6 times greater by Ström and Gierens (2002)) than for conventional fuels, and the occurrence of contrails may increase but have lower ERF because of the lower optical depth (Marquart et al. 2005). Moreover, contrails primarily form on soot particles from kerosene-powered aircraft, which would be absent from LH_2 exhaust (Kärcher 2018). The overall effect is currently unknown as there are no measurements. Potentially, NO_X emissions could be lower with combustor redesign (Khandelwal et al. 2013). [Ch10 p10-62]

Shipping

Chapter 10: Transport

- Like aviation, shipping is also a source of emissions of the SLCFs described in Section 10.5, including nitrogen oxides (NO_X), sulphur oxides (SO_2 and SO_4), carbon monoxide (CO), black carbon (BC), and non-methane volatile organic carbons (NMVOCs) (Naik et al. 2021). Though SLCF have a shorter lifetime than the associated CO_2 emissions, these can have both a cooling effect (e.g., SO_X) or a warming effect (e.g., ozone from NO_X). [Ch10 p10-68]
- Furthermore, increases in sulphur deposition on the oceans has also been shown to increase the flux of CO_2 from the oceans to the atmosphere (Hassellöv et al. 2013). [Ch10 p10-68]
- Changing the location of the emissions adds complexity to the assessment of the climatic impacts of Arctic shipping, as the local conditions are different and the SLCF may have a different impact on clouds, precipitation, albedo and local environment (Marelle et al. 2016; Fuglestvedt et al. 2014; Dalsøren et al. 2013). [Ch10 p10-69]

Ammonia as fuel

Chapter 10: Transport

- If produced from green hydrogen or coupled with CCS, ammonia could reduce short lived climate forcers and particulate matter precursors including black carbon and SO_2. However, the combustion of ammonia could lead to elevated levels of nitrogen oxides and ammonia emissions. [Ch10 p10-165]
- These fuels have their own unique transport and storage challenges as Ammonia requires a pilot fuel due to difficulty in combustion, and Ammonia combustion could lead to elevated levels of NO_X, N_2O, or NH_3 emissions depending on engine technology used (DNV GL 2020). [Ch10 p10-70]

Chapter 6: Energy Systems

- Ammonia can also be used in low and high temperature fuel cells (Lan and Tao 2014), whereby both electricity and hydrogen can be produced without any NO_X emissions. A key challenge in use of ammonia is related to significant amount of NO_X emissions, which is released from nitrogen and oxygen combustion, and unburned ammonia. [Ch6 p6-60]

Carbon Capture & Storage (CCS)

Chapter 17: Accelerating the Transition in the context of sustainable development

- CCS applied in industry is assessed as having synergies in terms of the control of non-CO_2 pollutants (such as sulphur dioxide), but increases in non-CO_2 pollutants (such as particulate matter, nitrogen oxide and ammonia). [Ch17 p17-54]

Chapter 11: Industry

- Methane based syngas (hydrogen and carbon monoxide) direct reduced iron (DRI) with CCS.

Most DRI facilities currently use a methane-based syngas of H_2 and CO as both reductant and fuel (some use coal). A syngas DRI-EAF steel making facility has been operating in Abu Dhabi since 2016 that captures carbon emitted from the DRI furnace (where it is a co-reductant with hydrogen) and sends it to a nearby oil field for enhanced oil recovery. [Ch11 p11-44]

EAF: Electric Arc Furnace

Solar Radiation Modification Schemes (SRM)

Stratospheric Aerosol Intervention (SAI)

Chapter 14: International Cooperation

- In addition, the effects of proposed SRM options would only last as long as a deployment is maintained— e.g. requiring ca. yearly injection of aerosols in the case of SAI as the lifetime of aerosols in the stratosphere is 1-3 years (Niemeier et al. 2011) or continuous spraying of sea salt in the case of MCB as the lifetime of sea salt aerosols in the atmosphere is only about 10 days—which contrasts with the long lifetime of CO_2 and its climate effects, with global warming resulting from CO_2 emissions likely remaining at a similar level for a hundred years or more (MacDougall et al. 2020) and long-term climate effects of emitted CO_2 remaining for several hundreds to thousands of years (Solomon et al. 2009). [Ch14 p14-56]
- SAI - Injection of reflective aerosol particles directly into the stratosphere or a gas which then converts to aerosols that reflect sunlight. [Ch14 p14-57]