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Effects of decarbonising international shipping and aviation on climate mitigation and air pollution

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ABSTRACT

This paper assesses the effects of a global emissions trading scheme (GETS) for international aviation and shipping as a way of reducing emissions of both greenhouse gases (GHG) and other atmospheric emissions that lead to air pollution. A prior assessment of such integration requires the coupling of energy–environment–economy (E3) global modelling of mitigation policies with the atmospheric modelling of pollution sources, mixing and deposition. We report the methodology and results of coupling of the E3MG model and the global atmospheric model, p-TOMCAT. We assess the effects of GETS on the concentrations of atmospheric gases and on the radiative forcing, comparing a GETS scenario to a reference BASE scenario with higher use of fossil fuels. The paper assesses the outcome of GETS for atmospheric composition and radiative forcing for 2050. GETS on international shipping and aviation reduces their CO_2 and non-CO_2 emissions up to 65%. As a consequence atmospheric concentrations are modified and the radiative forcing due to international transport is reduced by different amounts as a function of the pollutant studied (15% for CO_2, 35% for methane and up to 50% for ozone).

1. Introduction

International transport is the one of the most challenging of the main economic sectors for global decarbonisation because the international nature of the industry makes reaching any agreement difficult and also because the capital stock is exceptionally long-lived, so that radical shifts in technology require long-term horizons, making rapid change difficult.

Burning fossil fuel in engines produces gas and aerosol products such as CO_2 and water vapour (unavoidable products of combustion), NO_x, VOCs and carbon monoxide (engine performance related) and SO_2 (fuel composition dependent). Emissions from engines affect the composition and the radiative balance of the atmosphere, and therefore the climate system, through various mechanisms. These include the direct emission of the greenhouse gas carbon dioxide, CO_2, which has a long life time in the atmosphere and plays an

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mportant role in climate change. CO_2 is not directly involved in the atmospheric chemical system, and the so-called carbon cycle is relatively complex involving different timeframe mechanisms (Prentice et al., 2001). Emissions of NO_x influence atmospheric chemistry and result in changes of the abundance of ozone (O_3) and methane (CH_4), which are also igreenhouse gases. Fuel sulphur is converted to aerosol in the atmosphere, and direct emissions of particulates (black carbon) can both directly scatter and absorb incoming solar radiation and indirectly affect the microphysical and thus the optical properties of clouds. All these processes however exert their respective influence over different spatial and temporal scales particularly when considering shipping and aviation emissions (Lee et al., 2009; Eyring et al., 2010). Globally, international shipping and aviation contribute 5% of present-day anthropogenic CO_2 emissions with both sectors having a similar share. For other pollutants, the contribution for the year 2000 situation is different: for NO_x aviation reaches 2.6% when shipping is below 1.5%; for sulphur only shipping is one of the major emitters at 6% of the total anthropogenic amount. (Dessens et al., 2014).

International aviation and shipping are intrinsic to the success and efficiency of the global economy, despite trends towards a greater share of services in the economy and more use of information technology and telecommunications. In the last 15 years, many proposals to address international aviation and shipping CO_2 emissions have been discussed in the United Nations Framework Convention on Climate Change (UNFCCC), International Maritime Organisation (IMO) and International Civil Aviation Organisation (ICAO). However, apart from energy efficiency measures for ships, agreed by IMO in 2011, no measures have been agreed upon.

Substantial reductions of CO_2 emissions in the aviation and shipping industry will result in co-benefits in terms of reduced air pollution. The important co-benefits between climate control and reduction in air pollution have been recognised since the early economic assessments of the costs of climate control (Ekins, 1996). The co-benefits literature has been reviewed by successive IPCC reports (IPCC, 2001, 2007a; Bollen et al., 2009) with the conclusion that "integrating air pollution abatement and climate change mitigation policies offers potentially large cost reductions compared to treating those policies in isolation (IPCC, 2007b)." However in depth analysis of this integration has not generally taken place, either in the policy literature or in the modelling. Instead, the air pollution and other co-benefits have been treated as occasional added benefits for climate change policy (e.g. Stern, 2007, p. 314), or sometimes not mentioned at all (e.g. Nordhaus, 2007). An exception here to fill the gap is, for example, body of papers published on co-benefits of climate change policies where the analysis includes, in addition to modelling changes in atmospheric composition, the health impacts of such policies (for example, Barker et al., 2010; Woodcock et al., 2009). In contrast, the integration of non-GHG pollutants into climate modelling has long been standard practice, since pollutants such as NO_x have significant effects on radiative forcing by gases such as ozone and methane (e.g. Fuglestvedt et al., 1999; IPCC, 2007a; Myhre et al., 2011).

We apply the E3MG model to assess the impact of the Global Emissions Trading Scheme (GETS) on international shipping and aviation CO_2, NO_x, SO_2, VOC, CH_4 and CO emissions over the period from 2000 to 2050. Although there are substantial investment and behavioural costs in decarbonising international shipping and aviation, there are also very considerable benefits: less congestion than otherwise, improved air quality and human health, fewer pollution incidents, less noise, dirt, and less degradation of pristine environments (upper atmosphere, open seas and ice fields). The global chemistry-transport model (CTM) pTOMCAT is then used to examine the air pollution and climate effects of GETS for aviation and shipping. The results, given for emissions representative for the year 2050, show the effects on ozone and sulphate concentration at the surface (air pollution impact) as well as on radiative forcing due to CO_2, methane and ozone concentration changes in the troposphere (climate impact) compared to the reference scenario.

Section 2 gives an overview of existing literature in the study area and Section 3 describes the methodology. Thereafter Section 4 presents the modelling results and Section 5 draws some conclusions.

2. Climate control and air pollution for shipping and aviation.

One of the comprehensive reviews of the literature on co-benefits of climate change policies is that in the IPCC Report (Barker et al., 2007, section 11.8). The conclusion of the review is that "Mitigation strategies aimed at moderate reductions of carbon emissions in the next 10–20 years (typically involving CO_2 reductions between 10 and 20% compared to the baseline) also reduce SO_2 emissions by 10–20%, and NO_x and PM emissions by 5 to 10%. The associated health impacts are substantial." (p. 670).

The health impact from the international transport sectors has received considerable interest and discussion is on-going. Concerning aviation, the historical studies started with the impact of noise in the 1970s. The health impact of different emissions has also been studied. For aviation, the effects of NO_x and aerosols on air quality and heath are mostly recognised as important during the take-off and landing segment, representing regional pollutants in and around airports (Passchier et al., 2000). The effect of cruise altitude emissions moving from altitude to surface is more uncertain and may be of importance for aerosols formation (PM 2.5) since they have a relatively long life time in the atmosphere and as consequence can be transported downward to the surface (Barrett et al., 2010). 70% of shipping emission occurs in ports or coastal areas, and ozone and aerosols are causing air quality problems there (Derwent et al., 2005). Recent international legislations on low-sulphur emission zones (IMO, 2013) were set up in order to improve the outlook of the shipping emissions on human health.

In 1999, an assessment of the effects of aviation on the global atmosphere was undertaken within the IPCC in a special report "Aviation and the Global Atmosphere" (IPCC, 1999). Present effects of the transport sector emissions on global composition and climate have been calculated in Endresen et al. (2003) for shipping, in Stevenson et al. (2004) for aviation and in Fuglestvedt et al. (2008) for all transport modes. Future effects have been studied using pre-calculated