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Climate-neutrality versus carbon-neutrality for aviation biofuel policy

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ABSTRACT

We model global aviation biofuel uptake under a future emissions trading policy, and compare aviation CO_2 emission reductions with climate impact reductions (CO_2 and non-CO_2). We find that climate impacts in terms of global warming potential are less favourable than CO_2 climate impacts for biofuel use, dependent on the time horizon of the chosen output climate metric. Results indicate that widespread use of aviation biofuel may lead to a scenario in which aviation growth is accompanied by flat or decreasing carbon emissions but an increasing total climate impact.

1. Introduction

In response to concerns over the global environmental impacts of aviation, stakeholders have committed to strategies of mitigation. For example, the International Air Transport Association (2009) set out goals aimed at achieving stable carbon emissions from 2020 onwards despite further growth in air traffic, to be achieved by a combination of fleet renewal, operational and infrastructure measures, retrofits, offset mechanisms and the use of alternative fuels.

One option for reducing aviation's climate impact is the use of aviation biofuels. The lifecycle CO_2 emissions impact, including all emissions from fuel production, distribution and combustion, of biofuels can be significantly lower than that of Jet A, because of the CO_2 absorbed from the atmosphere during feedstock growth. Direct substitution of Jet A by biofuel in existing aircraft is possible ('drop-in' biofuels), without any major technical modifications. Future biofuel use may also be motivated by the EU emissions trading scheme (ETS) if carbon prices contribute to biofuels becoming economically attractive. Because the EU ETS considers only CO_2 emissions from aircraft engines in-flight, rather than lifecycle CO_2 emissions, it does not account for reduced lifecycle emissions when using biofuels. Instead, biofuel is to be exempt from emissions trading, i.e. its emissions are assumed to be zero. Exempting biofuel from emissions trading completely adds a strong incentive for airlines to make use of it, regardless of the amount of lifecycle emissions reduction achievable.

2. The AIM aviation systems model

We use the model developed by the Aviation Integrated Modelling (AIM) project (Reynolds et al., 2007) to simulate the response of the global aviation system to changes in costs and available technologies. AIM consists of seven interconnected modules. The air transport demand module projects true origin-ultimate destination demand for air travel for a set of 700 cities using future scenario variables such as population and GDP. The airport activity module assigns routing, aircraft types and a schedule based on this demand and regressions on historical data, and calculates delays and airport capacity

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requirements. The aircraft technology and cost module computes costs, fuel burn and fleet turnover by aircraft type and simulates airline decisions to invest in new technology. The aircraft movement module calculates global emission locations and accounts for flight routing inefficiencies. These modules are run iteratively until a partial equilibrium between demand and supply is reached. The output is then passed to the global climate module, which calculates a range of climate metrics; the air quality and noise module, which calculates regional and local impacts for selected airports; and the regional economics module, which calculates the economic impact of the obtained system equilibrium. We omit the local environment and regional economic modules.

AIM estimates biofuel uptake based on the associated fuel and carbon costs compared to those of Jet A, in combination with any biofuel production limits that may be applied. We assume airlines have emission-reducing technology options other than biofuel which they may choose to adopt based on the associated costs, including retrofits and new aircraft models with open rotor engines. Reductions over time in air traffic management inefficiencies via schemes such as SESAR and NextGEN are also assumed. Absent these specific measures, it is assumed that the fuel use of new aircraft models will decrease by 1% per year and that the NO_x emissions index ($EINO_x$) of new conventional aircraft engines will remain roughly constant (Faber et al., 2008); for open rotor engines we use $EINO_x$ values given by Guynn et al. (2011).

2.1. Emission species

The climate-relevant non-CO_2 emissions include NO_x, sulphur compounds and unburnt hydrocarbons which alter the abundance of chemically active greenhouse gases ozone (O_3) and methane (CH_4). They further include particulate matter (e.g. soot), and cloud-related phenomena such as linear contrails and aircraft-induced cirrus (Burkhardt and Kärcher, 2011) which affect the Earth–atmosphere radiation balance. Emissions of CO_2 are linearly linked to fuel burn. Emissions of NO_x are dependent on engine settings, flight altitude and the type of technology used and their impact on greenhouse gas concentrations is dependent on emissions location and local atmospheric composition (e.g. Köhler et al., 2013).

CO_2, NO_x and its impact on O_3 and CH_4, contrails and the impact of contrails on the formation of aircraft-induced 'natural' cirrus cloud are considered. We omit aviation induced cirrus cloudiness triggered by emission particles due to the very low level of scientific understanding and large uncertainty associated with current estimates of climate impact (Lee et al., 2010). Emissions of water vapour (warming effect), sulphate aerosol (cooling effect) and soot aerosol (warming effect) are also omitted because their RF magnitude is small in comparison to RFs from other emitted species.[1]

2.2. Emissions inventory

The commercial aircraft fleet in AIM is represented by six sample aircraft types that in turn represent three size and two technology categories (Dray et al., 2010). Performance parameters and emission indices for each aircraft type are specified individually and based on data calculated in the aircraft performance and design model Piano-X (Lissys Ltd., 2010) for departure, cruise and approach and on International Civil Aviation Organization (2011) data for taxiing, take-off, climb, descent and landing. Emissions are modified on the basis of age, year of manufacture and the technology composition of the fleet via the AIM fleet turnover model. Absolute emissions are obtained by summing emissions from each flight segment, and include the effects of taxi and terminal delays and route-specific ATM inefficiencies.

The distribution of cruise altitudes by flight distance is derived from the AERO2k global aviation inventory for 2002 (Eyers et al., 2005), which is based to a large extent on radar tracked flight data. For flights under 400 nm we assume that peak altitude scales linearly to distance flown between 18 kft and 25 kft altitude. Emissions from step climbs during long-range cruise flights are neglected, as are the impacts of variation in load factor, payload and fuel masses.

Significant differences between global emission inventories are common, and result from the different scopes and the varying methodologies used (e.g. whether they are based on fuel-uplift or flight tracks). We find that the present-day emission values and emissions distributions by altitude generated by AIM fall within the range of variability shown by other contemporary emission inventories (Table 1).

2.3. The AIM climate module

The climate module determines the global change in a range of CO_2 and non-CO_2 climate impacts relative to present-day aviation, including radiative forcing (RF), global warming potential (GWP) and global temperature change potential (GTP) (Fuglestvedt et al., 2010). We concentrate on GWP. We use Absolute Pulsed GWPs (APGWPs), for which the GWP values are not normalised by pulse emissions of CO_2.[2] APGWPs are calculated as a function of distance flown per flight level with global values obtained through integration over distance and altitude. For non-CO_2 climate impacts, 16 flight levels between about 5–15 km altitude (16.5–48.5 kft) are considered based on the climate impact calculations provided in Köhler et al. (2008) and Rädel and Shine (2008); for CO_2 impacts, we consider the entire altitude range.

[1] Fischer–Tropsch jet fuels from biomass, such as the one assumed in this study, are likely to have reduced sulphur aerosol emissions compared to conventional jet fuel. We have not included these effects.

[2] A pulse of emissions here is the emissions attributable to aviation in 1 year.