

Shipping and aviation emissions in the context of a 2°C emission pathway

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Abstract

Shipping and aviation represented around 3.2% and 2.1% respectively of global CO₂ emissions in the mid-2000s. A wide range of projections and scenarios shows that both sectors are likely to grow over the coming decades with a resultant increase in CO₂ emissions by 2050, despite mitigation efforts through technology, operations, and usage of low-carbon fuels. Here, a typical emission pathway that will limit global mean surface temperatures to no more than a 2°C increase by 2100 over pre-industrial temperatures is taken from prior work. This 2°C emission pathway makes no assumptions over the contributions of either the shipping or aviation sectors or of any particular nations' efforts. It merely shows what the overall global emission reduction trend must be to reach the 2°C target. If current projections of emissions from shipping and aviation to 2050 are placed in the context of such an overall global 2°C emissions reduction pathway, then shipping might contribute between approximately 6% and 18% of median permissible total CO₂-equivalent emissions in 2050 to meet the pathway, and aviation might contribute between approximately 4% and 15% of median total CO₂-equivalent emissions, and the two sectors together might contribute between approximately 10% and 32% of total median CO₂-equivalent emissions in 2050.

1 Introduction

Shipping and aviation represent two important transport sectors for international business, leisure, and the transportation of goods. Shipping emissions of CO₂ at 0.96 Gtonnes CO₂ yr⁻¹ in 2007 represented 3.2% of global CO₂ emissions (Buhaug et al., 2009), whereas civil aviation emissions at 0.63 Gtonnes CO₂ Yr⁻¹ in 2006 represented 2.1% of global CO₂ emissions (Lee et al., 2011). The international fraction of total shipping CO₂ emissions is larger, at 83%, than that of aviation, which is 62%. The international portion of shipping and aviation emissions currently falls under Article 2.2 of the Kyoto Protocol for Annex I Parties to “...pursue limitation or reductions of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.” Domestic emissions from shipping and aviation fall to the Parties of the United Nations Framework Convention on Climate Change (UNFCCC) for inclusion in national inventories and are subject to national goals.

The concept of a ‘2°C emission pathway’ refers to the desire to limit an increase of global mean surface temperature warming by no more than 2°C over pre-industrial temperatures by 2100. This concept has been widely discussed in the scientific literature and has now entered into the international climate policy context within the UNFCCC negotiations and discussions.

The concept of aviation within a 2°C framework has been briefly discussed by Lee et al. (2013a), who described the scientific framework of CO₂ emissions and how they need to

be limited quantitatively, without making judgments on *by whom* they should be limited in terms of sectors or countries. The key concept to be understood is the nature of CO₂ in the atmosphere in that it accumulates, since it has different timescales of removal, according to 'sinks', or removal processes. According to the IPCC (2007, Chapter 7):

"About 50% of a CO₂ increase will be removed from the atmosphere within 30 years, and a further 30% will be removed within a few centuries. The remaining 20% may stay in the atmosphere for many thousands of years."

Thus, with this underlying science in mind, it then becomes clearer as to why emissions of CO₂ need to be reduced, and very dramatically so, if the 2°C target is not to be exceeded by the end of this century. Currently, emissions continue to increase, but the time by which they start to be reduced is becoming critical. The United Nations Environment Programme (UNEP) has produced three reports charting progress on pledged emissions reductions by nations and whether there is an 'emissions gap' between the pledges and the shorter-term emission pathway in terms of what is required to reduce the CO₂ emissions (UNEP, 2010; 2011; 2012). The UNEP reports have identified a projected 'emissions gap' of 8 to 13 Gtonnes CO₂-e¹ between that required and that projected in 2020, and that this gap is increasing (UNEP, 2012).

In this paper, some of the data underlying the assessment of available aviation and shipping emission projections for the UNEP (2011) report are re-visited and expanded to illustrate how shipping and aviation emissions might fit into a particular 2°C emission pathway.

2 Data and Methods

In the UNEP (2011) report, Lee et al. (2011) reviewed projections of aviation and shipping CO₂ emission projections available in the literature and from specialist sources (e.g. work undertaken by states under the *aegis* of the International Civil Aviation Organization's Committee on Aviation Environment Protection, ICAO-CAEP).

The emission projections and their data sources are shown in Figures 1 and 2.

¹ Emissions are in giga tonnes (10⁹) CO₂ equivalents, the 100 year Global Warming Potential-weighted sum of the greenhouse gases covered by the Kyoto Protocol, that is CO₂, CH₄, N₂O, HFCs, PFCs and SF₆, and include emissions from land use, land-use change and forestry (LULUCF).

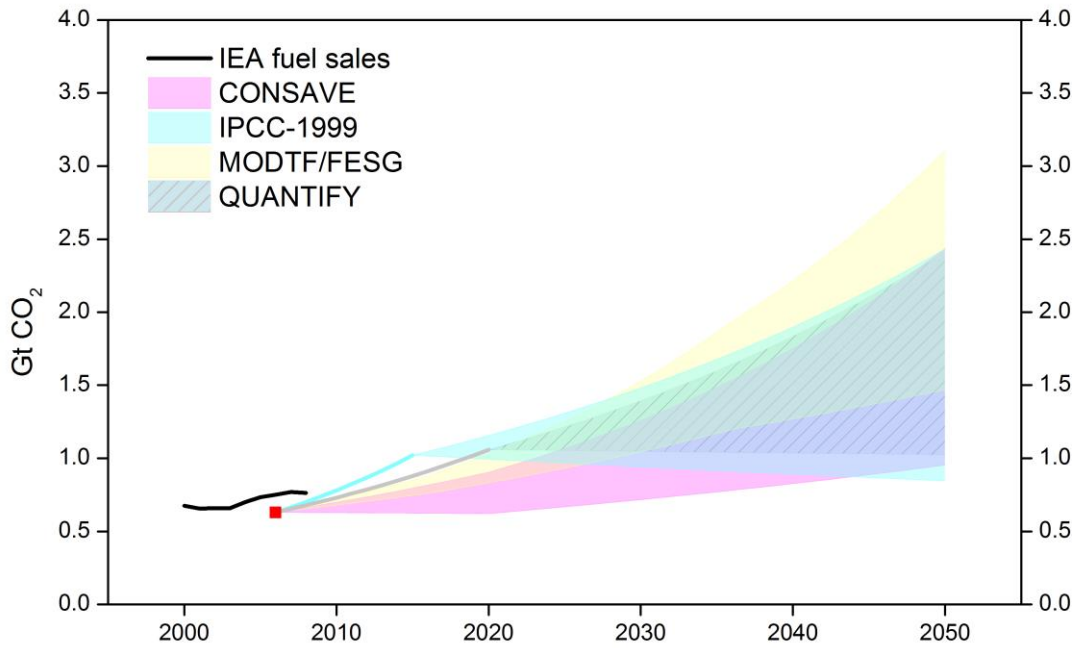


Figure 1. Emissions of CO₂ from aviation from 2000, and projections through to 2050. Data from 2000 to 2009 based on IEA fuel sales data. Projections from: MODTF/FESG (2009); QUANTIFY project (Owen *et al.*, 2010); IPCC aviation special report (IPCC, 1999); CONSAVE project (Berghof *et al.*, 2005). Data are interpolated from the red dot, which represents a best estimate of civil aviation emissions in 2006 at 0.63 GtCO₂e to forecast/scenario data points. The solid line (IEA fuel sales) refers to *total* aviation as compared to the rest of the data, which refer to civil aviation only (figure taken from Lee *et al.*, 2011).

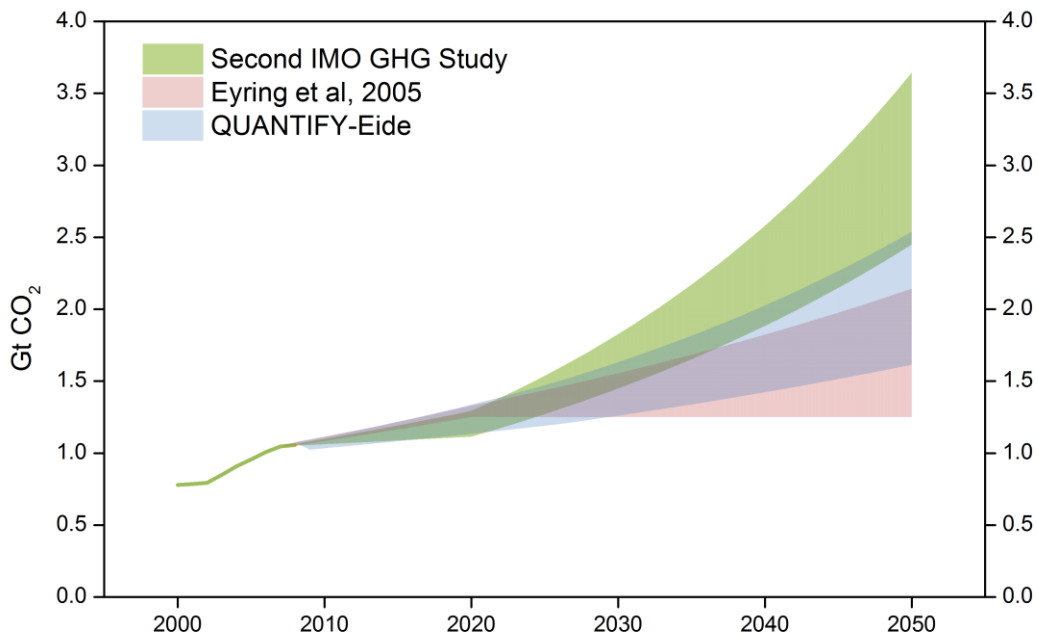


Figure 2. Emissions of CO₂ from shipping from 2000 to 2007, and projections through to 2050. Data from 2000 to 2007, IMO Second GHG Study (Buhaug *et al.*, 2009). Projections from Buhaug *et al.* (2009), Eyring *et al.* (2005), Eide *et al.* (2007). Note that projections from Eyring and Eide have been adjusted upwards to calibrate against the 2007 estimate reported by (Buhaug *et al.*, 2009). Data are interpolated between 2007 and forecast/scenario data points (taken from Lee *et al.*, 2011).

The aviation emissions shown in Figure 1 are taken from a number of sources (see figure legend). The International Energy Agency (e.g. IEA, 2009) is a definitive source used for current kerosene usage. The CO₂ emissions from aviation implied are generally larger than calculated with 'bottom-up' inventories and this is a well-known phenomenon, largely arising from military usage of kerosene and small amounts of non-aviation usage of kerosene. There are inherent uncertainties in the civil aviation emissions inventories that may cause systematic under-estimates but a datum of 630 Mtonnes of CO₂ in 2006 is a consensus best estimate (0.63 Gtonnes CO₂) from a range of models contributing to ICAO-CAEP activities (ICAO, 2010).

In terms of the aviation projections to 2050, the Intergovernmental Panel on Climate Change (IPCC) published a range of emission projections to 2050, and the European projects 'QUANTIFY' and 'CONSAVE' have published projections that consider a range of demand and technology forecasts (Owen et al., 2010; Berghof et al., 2005). Also shown in Figure 1 is the full range of projections from ICAO-CAEP activities reported in ICAO (2010) and in detail by MODTF/FESG (2009). The projections and scenarios are mixed in what they consider in terms of underlying demand forecasts, technological and operational improvements, and uptake of lower carbon fuels (biofuels etc.) but represent a reasonable range of possibilities given the inherent uncertainties involved in making projections out some 40 years or so.

The shipping emissions shown in Figure 2 are similarly taken from a range of project and literature sources, and also have a consensus 'best estimate' of emissions for 2007, based upon a project undertaken under the auspices of the International Maritime Organization's (IMO) Greenhouse Gas Study (Buhaug et al., 2009). In this case, the other studies have been calibrated to have a base year start of the 2007 IMO emissions (see Lee et al., 2011). As with the aviation emission projections, the shipping CO₂ emissions projections consider a range of demand, technological and fuel type scenarios.

The background emissions required for a 2 degrees pathway are taken from the UNEP (2011) report and Rogelj et al. (2011). These have been calculated with a range of integrated assessment models but all rely on a technique termed 'inverse modelling' whereby an 'outcome' is modeled iteratively with a range of inputs until that outcome (in this case, 2°C by 2100) is reached with some statistical uncertainty from a knowledge of the modeling process.

It should be understood that there is no unique solution to 2°C by 2100 but the models give a broad agreement as to an emission pathway, based upon a peak in emissions between approximately 2010 and 2020, and a decline thereafter, without the median value necessitating 'negative emissions', i.e. physical removal of CO₂ from the atmosphere (for the 2°C emission pathway only). In this analysis, the background emissions are only considered as far as 2050, since aviation and shipping emission projections are only available on this timeframe. The emissions trajectories that give a variety of temperature outcomes are shown in Figure 3.

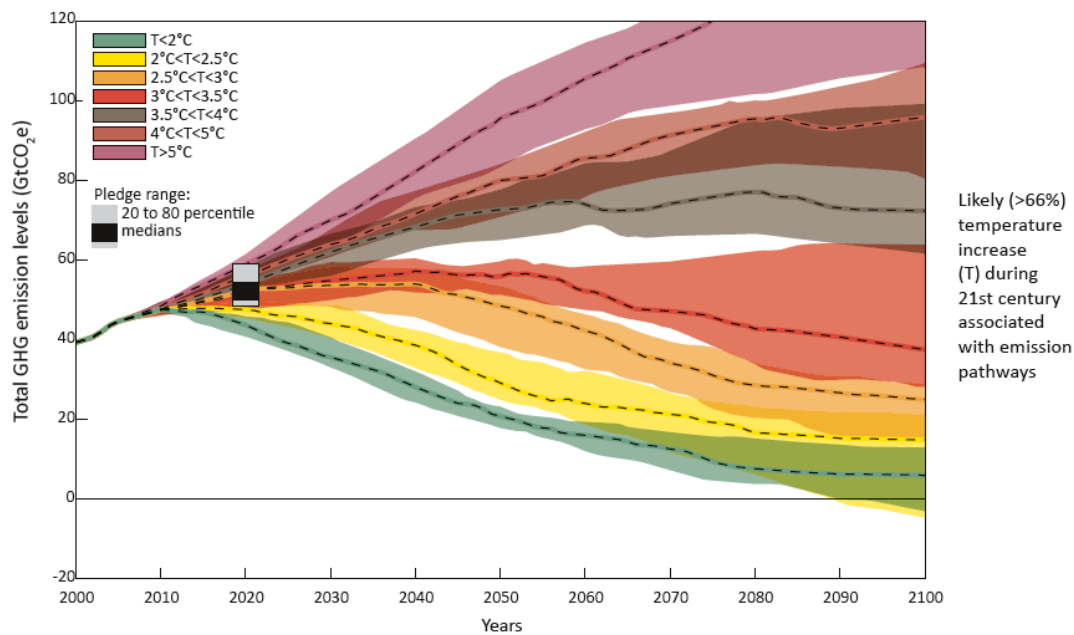


Figure 3. Temperature increases associated with emission pathways as a function of the transient shapes of emission pathways. The coloured ranges show the 20 to 80th percentile ranges of the sets if integrated assessment model emission pathways that have approximately the same “likely” avoided temperature increase in the 21st century. Dashed lines show the median transient emission pathways for each temperature level, respectively (taken from UNEP, 2011, its Figure 2). The ‘pledge range’ is that as described in Chapter 2 of UNEP (2011).

3 Results and Discussion

The aviation emissions projections (maximum and minimum), shown in Figure 1, are shown against a background of the required overall 2°C emission pathway (as far as 2050) in Figure 4. In Figure 4, the total ‘allowable’ emissions for 2°C by 2100 are shown out as far as 2050 in terms of Gtonnes CO₂-e (see Chapter 2, UNEP, 2011). The shipping emissions projections (maximum and minimum) are shown against the 2°C emission pathway in Figure 5, and the combined shipping and aviation CO₂ emissions (minimum and maximum) similarly shown in Figure 6.

In each of Figures 4, 5, 6, the blue line is the median emissions required for a 2°C emission pathway showing 20 and 80 percentile values as the extremities of the blue band (dashed=20 percentile, dotted =80 percentile).

In each of the figures, the red band (with solid, dashed, dotted lines = median, 20 percentile, 80 percentile, respectively) represents the total allowable emissions less the *maximum* aviation/shipping (or combined) emissions, and the green band (with solid, dashed, dotted lines = median, 20 percentile, 80 percentile, respectively) the *minimum* aviation/shipping (or combined) emissions.

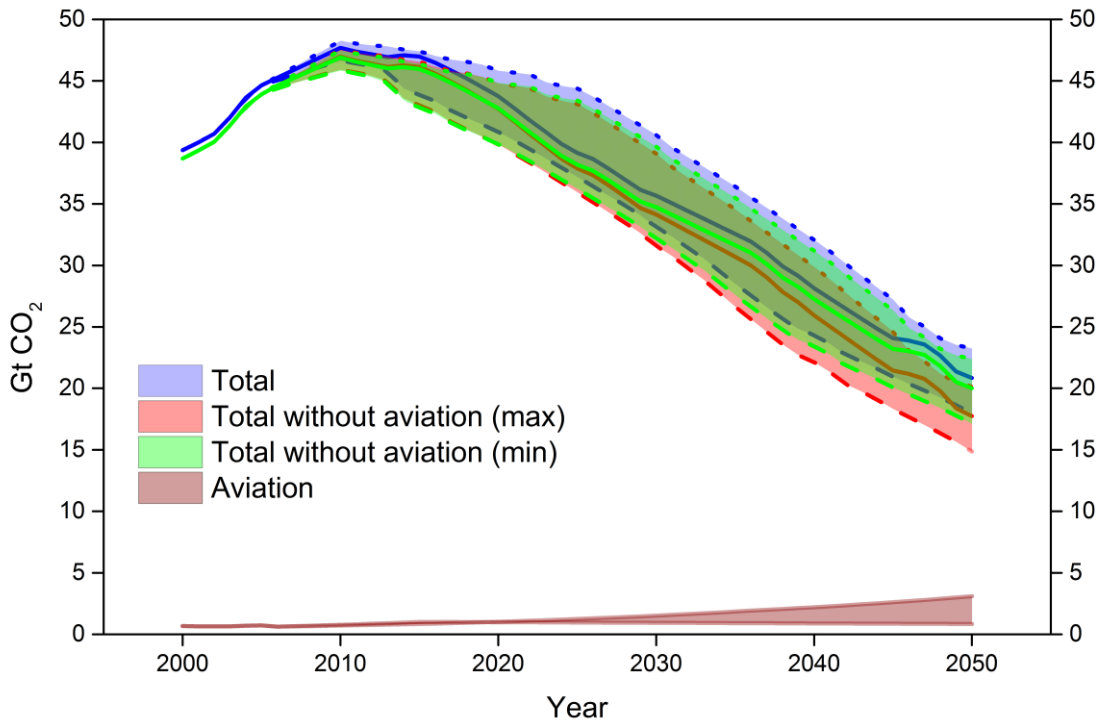


Figure 4. Two degrees emission pathway (blue band) and aviation emissions (minimum, maximum from Figure 1, brown band) and total emissions less minimum aviation emissions (green band) and total emissions less maximum aviation emissions (red band). For 'total', 'total without aviation (max)', 'total without aviation (min)', the solid line of the coloured band is the median, the dotted line the 80 percentile value, the dashed line the 20 percentile value.

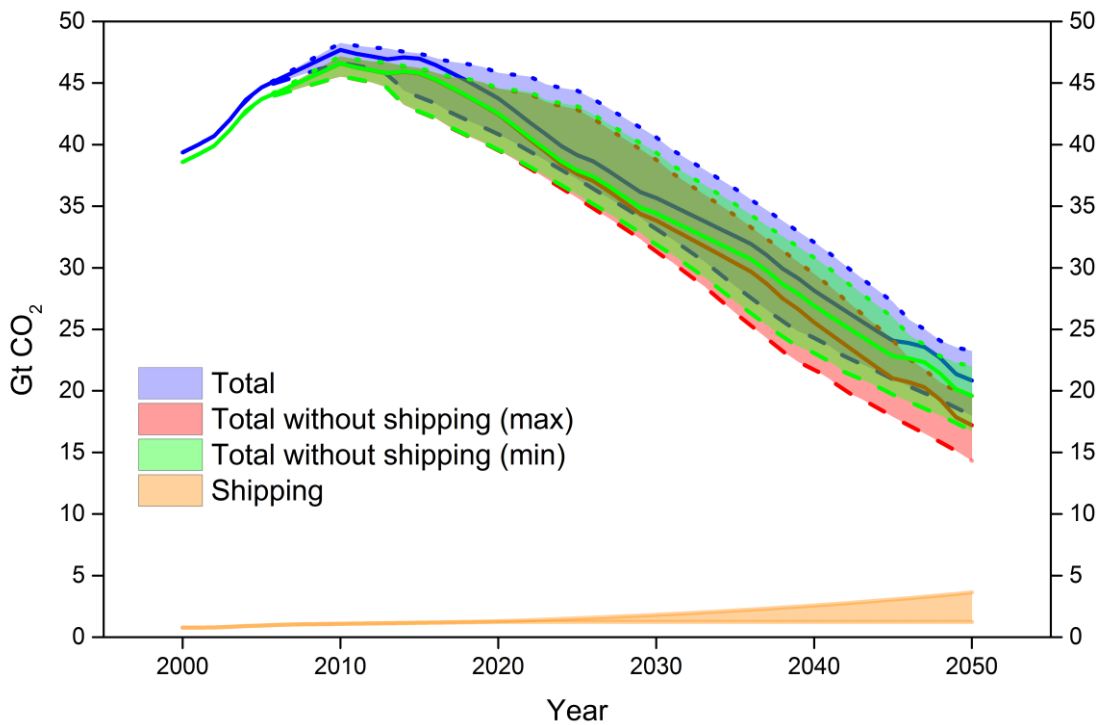


Figure 5. Two degrees emission pathway (blue band) and shipping emissions (minimum, maximum from Figure 1, orange band) and total emissions less minimum shipping emissions (green band) and total emissions less maximum shipping emissions (red band). For 'total', 'total without shipping (max)', 'total without shipping (min)', the solid line of the coloured band is the median, the dotted line the 80 percentile value, the dashed line the 20 percentile value.

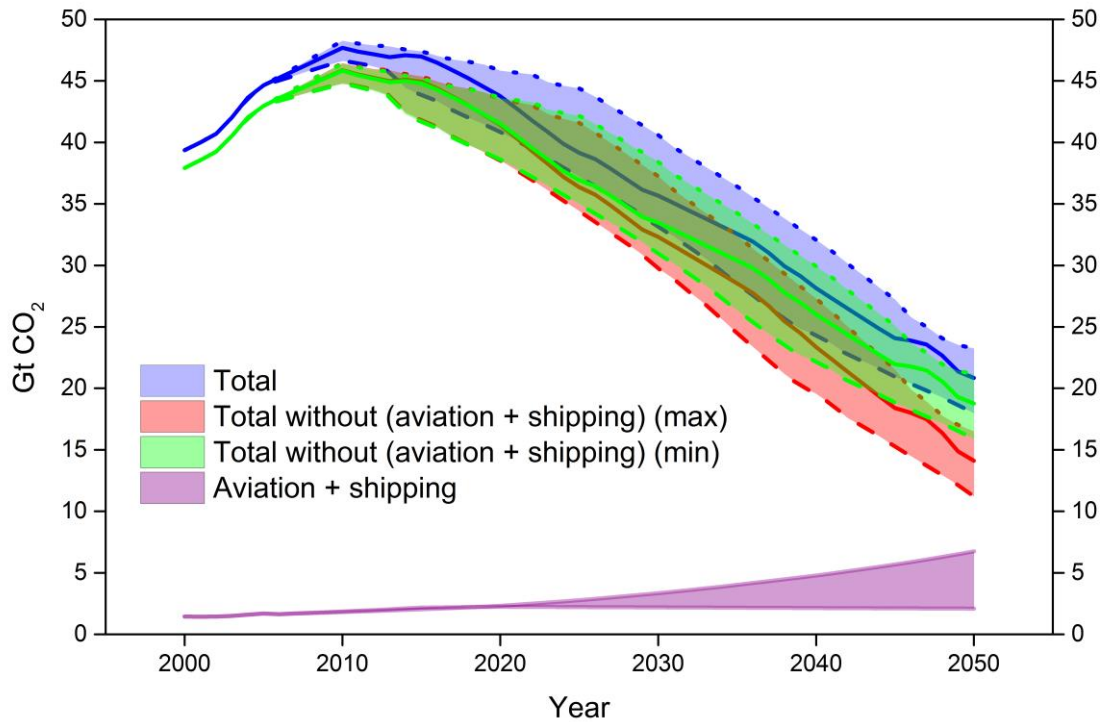


Figure 6. Two degrees emission pathway (blue band) and aviation plus shipping emissions (minimum, maximum from Figure 1, purple band) and total emissions less minimum aviation plus shipping emissions (green band) and maximum aviation plus shipping emissions (red band). For 'total', 'total without aviation + shipping (max)', 'total without aviation + shipping (min)', the solid line of the coloured band is the median, the dotted line the 80 percentile value, the dashed line the 20 percentile value.

It is important to understand what is shown in in Figures 4, 5, and 6; the emissions underlying the 2°C emission pathway (blue band in all cases) *make no assumptions about mitigation from particular sectors*. The emissions are simply those in CO₂-e that result in a particular emission pathway.

The point of assuming a variety of projections of aviation and shipping emissions out to 2050 is simply to illustrate that such emissions under a variety of conditions of forecasted growth and technological mitigation etc. could be a significant fraction of total emissions in 2050. In the case of aviation, the 'gap' between various potential mitigation options and the sector's own targets has been illustrated by Lee et al. (2013b); however, such emission targets do not explicitly consider what role aviation might have within a 2°C emission pathway.

Table 1. Emissions in Gt CO₂ (total) in 2050 for 2°C emission pathway (20 percentile, median, 80 percentile), first line. Emissions (Gt CO₂) in 2050 available to other sectors; aviation projections (min/max), shipping projections (min/max), aviation plus shipping projections (min/max).

Case	20 percentile/20 percentile-case	Median/med-case	80 percentile/80 percentile-case
<i>Total</i>	18.0	20.9	23.2
Aviation maximum	14.9	17.8	20.1
Aviation minimum	17.1	20.0	22.4
Shipping maximum	14.3	17.2	19.6
Shipping minimum	16.7	19.6	22.0
Av'n + ship'g max	11.2	14.1	16.5
Av'n + ship'g min	15.9	18.8	21.1

Table 2. Percentages of global emissions in 2050 for 2°C emission pathway (20 percentile, median, 80 percentile) for aviation (min/max), shipping (min/max), aviation plus shipping (min/max).

Case	Percentage contribution to total, 20 percentile	Percentage contribution to total, median	Percentage contribution to total, 80 percentile
Aviation maximum	17.3	14.9	13.4
Aviation minimum	4.7	4.1	3.6
Shipping maximum	20.3	17.5	15.7
Shipping minimum	7.0	6.0	5.4
Av'n + ship'g max	37.6	32.4	29.0
Av'n + ship'g min	11.7	10.0	9.0

Table 1 gives the absolute amounts of total global CO₂ emissions in 2050 under the 2°C emission pathway, and also the differences for the various cases (min/max aviation; min/max shipping; min/max aviation plus shipping), i.e. the CO₂ emissions available to *other* sectors. Table 2 gives the percentages of total emissions that the various cases represent in 2050. So for example, the minimum aviation CO₂ emissions represent 4.1% of median emissions (4.7%, 3.6% as 20 and 80 percentiles); the maximum of aviation plus shipping CO₂ emissions represents 32.4% of total median emissions in 2050 (37.6%, 29.0% as 20 and 80 percentiles).

It should be noted that the total emissions listed in Table 1 are Kyoto CO₂-e gas emissions. Thus, the comparison with aviation and shipping emissions is accurate in using CO₂ only under this particular definition. However, it is understood that aviation has a total radiative forcing response that exceeds that from its CO₂ emissions alone (Lee *et al.*, 2009; 2010) and shipping has one that produces an overall negative radiative forcing response (Eyring *et al.*, 2010). The overall negative radiative forcing effect of shipping is driven by S emissions, which under International Maritime Organization (IMO) regulations are expected to be reduced on air quality/public health grounds. IMO's Marine Environment Protection Committee (MEPC) revised the MARPOL Annex VI regulations by reducing the global sulphur limit of marine fuels from 4.5% to 3.5% in 2012, and to 0.5% in 2020 or 2025, pending a review of fuel availability. The CO₂ radiative forcing response from shipping, however, remains and Fuglestedt *et al.* (2009, 2010) have shown that at some point the accumulating CO₂ global and long-term positive response will overwhelm the regional and short-term (reducing) negative response from S emissions, such that the overall response will change sign. Accounting for these complex responses could be done by usage of a variety of potential climate metrics such as the Global Warming Potential (GWP) or Global temperature Change Potential (Shine *et al.*, 2005), but the underlying non-CO₂ radiative forcings are uncertain and would also require value judgements over user choices in these candidate metrics such as time horizon, on which the GWP and GTP values are strongly dependent (Fuglestedt *et al.*, 2010).

Conclusions

A 2°C emission pathway has been taken from the UNEP (2011) analysis, and shows that total 'allowable' emissions in 2050 (on this pathway) would be between 18.0 and 23.2 Gtonnes of CO₂-e. This estimate makes no assumptions over contributions of sectors or countries, it is simply an estimate of global CO₂-e emissions that would result in a typical 2°C emission pathway (by 2100), at 2050.

Taking available estimates of CO₂ emissions projections from the literature to 2050 for aviation and shipping, aviation might represent between approximately 4% and 15% of

median total CO₂-e emissions in 2050; shipping might represent between approximately 6% and 18% of total CO₂-e emissions. Taken together, shipping plus aviation emissions might represent between approximately 10% and 32% of total median CO₂-e emissions in 2050 under a typical 2°C emission pathway.

The emissions of aviation and shipping in these scenarios from the literature represent a variety of growth and technological scenarios, but no specific climate mitigation responses.

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