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synthesis article

All adrift: aviation, shipping, and climate change policy

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All sectors face decarbonization for a 2 °C temperature increase to be avoided. Nevertheless, meaningful policy measures that address rising CO_2 from international aviation and shipping remain woefully inadequate. Treated with a similar approach within the United Nations Framework Convention on Climate Change (UNFCCC), they are often debated as if facing comparable challenges, and even influence each others' mitigation policies. Yet their strengths and weaknesses have important distinctions. This article sheds light on these differences so that they can be built upon to improve the quality of debate and ensuing policy development. The article quantifies '2 °C' pathways for these sectors, highlighting the need for mitigation measures to be urgently accelerated. It reviews recent developments, drawing attention to one example where a change in aviation mitigation policy had a direct impact on measures to cut CO_2 from shipping. Finally, the article contrasts opportunities and barriers towards mitigation. The article concludes that there is a portfolio of opportunities for short- to medium-term decarbonization for shipping, but its complexity is its greatest barrier to change. In contrast, the more simply structured aviation sector is pinning too much hope on emissions trading to deliver CO_2 cuts in line with 2 °C. Instead, the solution remains controversial and unpopular – avoiding 2 °C requires demand management.

Policy relevance

The governance arrangements around the CO_2 produced by international aviation and shipping are different from other sectors because their emissions are released in international airspace and waters. Instead, through the Kyoto Protocol, the International Civil Aviation Authority (ICAO) and the International Maritime Organization (IMO) were charged with developing policies towards mitigating their emissions. Slow progress to date, coupled with strong connections with rapidly growing economies, has led to the CO_2 from international transport growing at a higher rate than the average rate from all other sectors. This article considers this rapid growth, and the potential for future CO_2 growth in the context of avoiding a 2 °C temperature rise above pre-industrial levels. It explores similarities and differences between these two sectors, highlighting that a reliance on global market-based measures to deliver required CO_2 cuts will likely leave both at odds with the over-arching climate goal.

Keywords: aviation emissions; carbon emissions trading; climate change mitigation; CO_2 reductions; stakeholder participation/engagement; transport policy

1. Introduction

The international community continues to negotiate about how to limit the global temperature rise to 2 °C above pre-industrial levels. Taking this target as a meaningful goal, as opposed to a political anchor point (Jordan et al., 2013), it can be translated into emission budgets and pathways to explore the scale

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of policy intervention required to remain within given constraints. This translation requires at least two further assumptions, namely (1) the choice of probability of exceeding 2 °C and (2) the year when global emissions reach a peak. The first assumption relies upon assessments of likely impacts at 2 °C, as well as political and economic decisions reflecting the level of risk of exceeding 2 °C considered reasonable for society. This leads to a constraint on 21st-century cumulative emissions (Meinshausen et al., 2009). The second assumption draws attention to inertia within energy systems, given their large contribution to total CO_2 emissions, and how rapidly these systems can feasibly start down a pathway of decarbonization (Anderson & Bows, 2011). It also highlights the influence on global CO_2 of large and rapidly growing sources of emissions, such as those from energy systems in populous non-Annex I nations, where rising income to improve standards of living remains closely coupled with levels of CO_2 (Lamb et al., 2014).

Interpreting quantitatively the 2 °C goal into constrained emission budgets and pathways delivers the scale of the mitigation effort needed globally and for all sectors. However, allocating or apportioning responsibility to regions, nations, or sectors for the production of emissions is where the debate becomes more subjective. It involves one of many allocation regimes (Den Elzen & Hohne, 2011) and, for individual sectors specifically, can be further disaggregated using marginal abatement cost curves (Kesicki & Ekins, 2012) to identify sectors with more or less scope to cut emissions. Leaving aside national emission apportionment, a topic well documented in the past (Berk & Den Elzen, 2001; den Elzen, Lucas, & Vuuren, 2005; Ringius, Torvanger, & Underdal, 2002), for aviation and shipping a complication arises over the allocation of responsibility for emissions released into international airspace and waters.

For all sectors other than international aviation and shipping, national emission targets dictate mitigation policies through the United Nations Framework Convention on Climate Change (UNFCCC). International aviation and shipping are excluding from national obligations as a consequence of where their emissions are released. Between 1990 and 2010, CO_2 from international aviation and shipping grew by around 80%, compared with growth closer to 40% from the rest of the global economy (CDIAC, 2013a, 2013b; IEA, 2013; UNFCCC, 2013). While this is in part driven by rapidly growing emerging economies, it is also a consequence of these sectors being without national CO_2 policies within Annex I nations.

Two broad approaches can be taken to manage the mitigation effort for these outliers. One is to apportion their emissions to regions or nations, assuming sub-global responsibility for policy implementation. The other is to consider international aviation and shipping as sovereign nations, treating them in a similar way to other nations. The former idea is unpopular with industry stakeholders, who, certainly in aviation, tend to support a global trading system above all other measures (ATAG, 2013). They consider global trading to be more efficient and less economically damaging than the first approach, as aviation (and shipping) could trade emissions permits with other nations. Such a policy was endorsed in October 2013 at the International Civil Aviation Authority (ICAO) Assembly.

Although the view within aviation is clearly expressed, the debate within the shipping sector's equivalent body, the International Maritime Organization (IMO) is ongoing (Psaraftis, 2012). There is a preference within the industry for the IMO to avoid national apportionment of responsibility, but topics such as a global framework for reporting ship fuel consumption are at present receiving greater attention than proposals for market-based measures (MEPC, 2014).

With regard to a target as challenging as 2 °C, there are at least two key sticking points linked to relying on a global mechanism such as trading. First, can emissions trading in general deliver a satisfactory outcome as far as the Copenhagen Accord is concerned? That is, one that is consistent with:

> deep cuts in global emissions . . . with a view to reduce global emissions so as to *hold* the increase in global temperature below 2 degrees Celsius, and take action to meet this objective consistent with *science* and on the basis of *equity*. (UNFCCC, 2009)

In other words, the mechanism should be able to produce short-term emission reductions consistent with a reasonable to high probability of avoiding a 2 °C temperature rise (Anderson & Bows, 2011; Rogelj, McCollum, O'Neill, & Riahi, 2013). Second, many industry stakeholders make the presumption that emissions trading can provide space for international transport to grow as much as demand for these services requires. This article will explore the second of these two points quantitatively in Section 3.

Regarding the first, emissions trading may have had a pivotal role to play if it had been comprehensively implemented when mechanisms for addressing rising emissions were first identified in the 1990s. Now, the scale of the 2 °C challenge raises questions around the ability of this type of mechanism to deliver the required rapid and urgent cuts in CO_2. For instance, the EU's Emissions Trading Scheme (EU ETS) is a useful example of how to implement a large-scale mechanism in a 'short' period of time, but to date it is argued to have delivered more institutional learning than it has a meaningful contribution to emissions cuts commensurate with avoiding 2 °C (van Renssen, 2012; Wråke, Burtraw, Löfgren, & Zetterberg, 2012). Furthermore, questions remain over the equivalence of emissions released in one country when exchanged through the Clean Development Mechanism (CDM) for a Certified Emission Reduction (CER) credit in another. A CER is not a permit or emission allowance, but a value given to a project that cuts emissions to below a business-as-usual baseline. Yet some governments have purchased CERs to offset emissions within the EU ETS (MacKenzie, 2009). Possible outcomes are that these exchanges do not lead to the equivalent cut in emissions or, worse still, provide revenue to be spent on other CO_2-producing projects or lead to rebound effects through making 'dirty technology' cheaper, thereby potentially increasing global emissions (Anderson, 2012; Millard-Ball & Ortolano, 2010). Any increases in emissions in the short term need to be compensated by more rapid and deep reductions in the longer term when constrained by a carbon budget.

Conversely, if international negotiations were to secure a strict global carbon cap, then including international aviation and shipping within a cross-sectoral global scheme could be both practical (Haites, 2009) and an attractive and workable solution. However, no such cap is likely to be implemented much before 2020, given that the next set of carbon reduction commitments will not be agreed until the 2015 Paris UNFCCC Conference of the Parties (COP).

Given that emissions trading schemes with a stringency commensurate with a reasonable chance of avoiding 2 °C are currently not forthcoming, the scale of the mitigation challenge for the aviation and shipping sectors without trading is quantified and discussed in this paper, in light of current policy debates. Through this simple quantification, the scale of the challenge demonstrates why, even if trading were as effective as theory suggests, additional CO_2 cuts from international transport would be necessary. This challenges a view that international transportation services can grow to meet required demand. The level of CO_2 reduction commensurate with 2 °C is then compared with opportunities for mitigation over the coming decades, as well as barriers to implementation. Finally, this article specifically compares these two sectors, arguing that greater separation is needed between their mitigation debates if progress in line with 2 °C is to be made.

2. Methodology

Papers exploring how CO_2 from international aviation and shipping may evolve in the future are generally prospective, using the Special Report on Emission Scenarios (SRES) (Nakicenovic et al., 2000) from the Intergovernmental Panel on Climate Change (IPCC) to underpin trends. Through gross domestic product (GDP) growth rates and assumptions around technology and operational change, they determine future levels of emissions (Eyring, Kohler, Lauer, & Lemper, 2005; Lee et al., 2009; Owen & Lee, 2010). Others focus more on CO_2 cost abatement potential relative to a business-as-usual scenario (Eide, Longva, Hoffmann, Oyvind, & Dalsoen, 2011; McCollum, Gould, & Greene, 2009), while some go beyond using SRES to estimate levels of future CO_2 by taking into account industry-specific demand assumptions (Macintosh & Wallace, 2009). In general, all these studies compare future levels of CO_2 against global projections, but do not compare results with scenarios specifically aiming to curb emissions in line with 2 °C (Bows, 2010). Only one other study can be found that attempts to meaningfully compare a 2 °C global trajectory with projections for international transport (Lee & Owen, 2013). Their 2 °C scenarios assume a peak year for global emissions prior to 2015 with low growth rates towards this peak. Assuming that global CO_2 emissions continue to grow at over 2% per year (CDIAC, 2014), with no binding global CO_2 cap expected prior to 2020, such 2 °C trajectories tend to underestimate the rate of cuts ultimately needed to keep emissions within the constraints of a 2 °C budget. The author is unaware of other studies that explicitly explore what a 2 °C pathway would look like if applied specifically to international aviation and shipping.

Here, the starting point for translating 2 °C into CO_2 pathways for international aviation and shipping is to choose a constraining global carbon budget. Assessments using climate models with different uncertainties, parameters, and starting conditions lead to a range of budgets commensurate with a global temperature rise of 2 °C. Meinshausen et al. (2009) provide a thorough analysis of carbon budgets with associated probabilities. Using their work, a constraining budget for a 50% chance of exceeding 2 °C is chosen (1578 $GtCO_2$) – assumption (i) in the analysis presented here.

Suites of scenarios aiming to remain within the 2 °C goal are often developed through the use of Integrated Assessment Models (IAMs). However, on close inspection of many of the outputs, the global peak dates assumed tend to be prior to 2015. Given that the results from IAMs are used extensively within the policy process, arguably, decision makers are being informed by overly optimistic, or unrealistic (past), peaking dates (Hansen et al., 2008; Nordhaus, 2010; Raskin, Electris, & Rosen, 2010) and low growth rates to the peak year (Baer & Mastrandrea, 2006; King, Richard, & Tyldesley, 2011; Ranger, Gohar, Lowe, Bowen, & Ward, 2010; Stern et al., 2006). If more consideration is given to how soon emissions can feasibly peak, a different quantitative analysis arises.

For a given carbon budget, the later that emissions reach a peak, the greater the rate of reduction needed after the peak year. There is a temptation when considering emission budgets to aim to avoid the rapid reductions implied after the peak date by assuming earlier mitigation is feasible. However, taking that more mathematical approach ignores the physical reality of the changes required in energy systems, overlooking infrastructural lock-in and inertia. Instead, it is assumed here that an appropriate peak year is determined by considering energy system developments around the world.

Furthermore, the larger share of global GHG emissions (both under territorial and consumption-based accounting approaches) from non-Annex I nations results in them having a greater influence over global CO_2 (Bows & Barrett, 2010). To demonstrate the implications of this for international aviation and shipping, peak years are here based on a study where such lock-in, inertia, and influence from non-Annex I nations were considered: Anderson and Bows (2011) – assumption (ii) in this analysis. Peak years of 2015 and 2020 are derived using short-term projections of Annex I and non-Annex I CO_2 emissions, taking data from the Carbon Dioxide Data Analysis Centre and the Global Carbon Project to assess the historical trend (CDIAC, 2013a). For more details on the methods and assumptions, see Anderson and Bows (2011). It should be noted that even these peaking dates are optimistic given the current direction of travel, and the time now passed since these pathways were published.

Aviation and shipping stakeholders prefer emissions to be unapportioned and treated under a global regime (Bows, Anderson, & Mander, 2009; Gilbert & Bows, 2012). Although the present author and others have explored apportionment of both aviation and shipping emissions to nations (Gilbert & Bows, 2012; Wood, Bows, & Anderson, 2010), the practical short-term challenges identified (Heitmann & Khalilian, 2011; Owen & Lee, 2006) support taking a global perspective for this analysis. To translate 2 °C into CO_2 pathways for international aviation and shipping, these two sectors are treated as 'sovereign states' taking a path proportionally in line with an appropriate global average rate of mitigation derived from assumptions (i) and (ii). These sectors are treated as typical average nations, rather than typical Annex I or non-Annex I nations. Accordingly, they do not need to make the greater level of cuts required of Annex I nations. It is also not appropriate to consider them as non-Annex I nations, given that a large proportion of their CO_2 emissions is directly associated with Annex I citizens.

Avoiding 2 °C with reasonable probability significantly constrains the emission budget, so for any sector to do less than the average places considerable pressure on others to mitigate more (Calverley, 2012). Assessing which sectors could deliver greater cuts than the average is beyond the scope of this article. Instead, it addresses the feasibility of international aviation and shipping following these mitigation pathways, without relying on emissions trading.

In the literature, forecasting scenario development, and road-mapping are used to explore future expected or desired socio-technical developments across sectors. Some deliver forecasts underpinned by economic projections (e.g., Eyring, Kohler, Lauer, & Lemper, 2005). Others start with where future emissions 'need' to be to meet specific carbon objectives, in other words, backcasting (Mander et al., 2008). Here, the 2 °C emission pathway constraints, when applied to international aviation and shipping, are compared with anticipated levels of CO_2 from these sectors, using the academic literature to illustrate the gap between meeting mitigation objectives and projected expectations. To drill down into the range of options available to close this gap, participatory (involving expert stakeholders) backcasting and road-mapping processes are drawn upon (Bows et al., 2009; Bows-Larkin et al., 2014; High Seas, 2013). Backcasting identifies opportunities and barriers to change to articulate alternative futures.

3. Analysis and results

3.1. Global trends

Aviation and shipping CO_2 data taken from the International Energy Agency (IEA, 2013), supplemented with newer IMO analysis (Buhaug et al., 2009) between 1990 and 2010, are presented in Figure 1. This shows growth of 78–83% by 2010 from 1990, a period when global CO_2 from the aggregate of other sectors grew by closer to 40% according to data from the Carbon Dioxide Information Analysis Centre (CDIAC, 2013a). By 2010, CO_2 emissions from aviation and shipping combined were of a similar magnitude to CO_2 emissions from the entire continents of either Africa or South America. This is also approximately equivalent to the sixth largest emitter if compared with world nations (Haites, 2009). As climate impact is dictated by cumulative emissions, Figure 1 shows that international aviation and shipping have had a larger climate impact between 1990 and 2010 than if they had followed the average trajectory of all other sectors.

Using the global emission pathways from Anderson and Bows (2011) indexed to 1990 (designated C + 4 and C + 5 to remain consistent with that analysis), then translated for international aviation

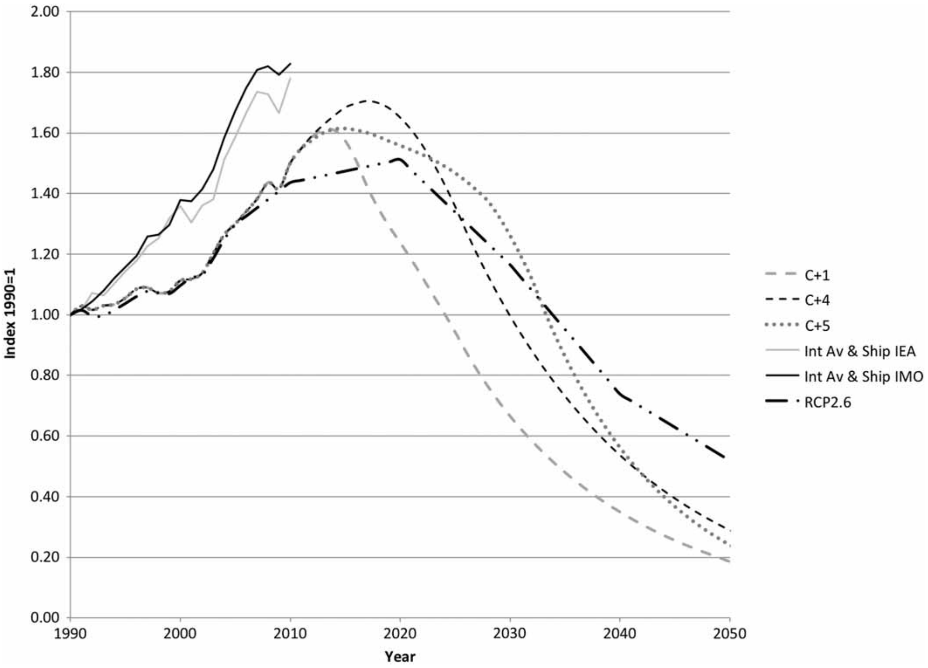

Figure 1 International aviation and shipping emissions indexed to 1990 for three 2 °C pathways taken from Anderson and Bows (2011) and Anderson and Bows (2012) (C + 1, C + 4, and C + 5), one RCP pathway in addition to international aviation and shipping CO_2 estimates for 1990–2010 using IEA data (grey solid line) and IEA data supplemented with IMO shipping data (black solid line). C + 1 is a pathway with a high chance of avoiding 2 °C (grey dashed line), C + 4 is a pathway assuming a gradual peak by 2020 with rapid emission reductions to 2050 (black dashed line), and C + 5 assumes a continuation of the depressed world economy following the 2008 economic downturn, with a more gradual emission reduction until 2030 (grey dotted line). RCP2.6 is the Representative Concentration Pathway (Meinshausen, Smith, Riahi, & Van Vuuren, 2010) most closely aligned with 2 °C (black dash-dotted line). Both C + 4 and C + 5 are constrained by a cumulative budget of 1578 $GtCO_2$ with a 50% chance of exceeding a 2 °C temperature rise above pre-industrial levels.

and shipping using the 1990 starting point (Figure 1), provides two illustrative example pathways for aviation and shipping when constrained to a 50% chance of avoiding 2 °C. As their emissions are already growing more rapidly than the global average, the additional climate impact from the CO_2 released between 1990 and 2010 could be removed from the remaining budget. This reduces the budget by ~35% between 1990 and 2049. However, given that the issue of historical responsibility is unresolved in general, here the pathways shown provide a lower threshold for mitigation commensurate with a 50% chance of avoiding 2 °C. Note the emission reduction rate from five years after the peak year for C + 4 is 6% per year. The much lower growth to the earlier peak year in C + 5 results in a lower annual reduction rate of 1–2% until about 2030, reducing at 8% thereafter. For comparison, a scenario with a higher probability of remaining within the 2 °C threshold, C + 1, is also presented. C + 1 requires an immediate and steeper cut in emissions. Finally, the Representative Concentration Pathway RCP2.6 is also shown. This is the RCP pathway most closely aligned with a 2 °C level of warming, although global CO_2 emissions have in reality risen more rapidly than this by 2010 due to the low growth rate to the peak date assumed in RCP2.6.

3.2. Comparison with futures studies

Using the literature to benchmark the pathways presented in Figure 1 reveals a huge gap between 2 °C-type pathways and expectations (Figure 2). For instance, in IMO projections, emissions are anticipated to increase by 180% to 305% relative to 1990 levels by 2050 (102–193% for a 2000 baseline) (Bazari & Longva, 2011). For aviation, Gudmundsson and Anger (2012) summarize a range of scenarios showing how international aviation CO_2 is assumed to rise by up to 515% between 2000 and 2050, although more typical figures are around 220%. This compares with the 71–76% cut needed to remain commensurate with a 50% chance of avoiding 2 °C. Other key indicators from Figure 1 include the CO_2 from international aviation and shipping either returning to 1990 levels or being less than 25% higher by 2030; the rate of emission reduction from around 2030 onwards being around 6–8% per year; and emissions reaching a peak between 2015 and 2020.

3.3. Global policy landscape

ICAO was given responsibility for developing mitigation policy for emissions released within international airspace within the Kyoto Protocol. By the end of the Protocol's target period, however, there was little progress towards establishing the necessary mechanisms, although ICAO had put in place a voluntary 2% annual efficiency improvement target up to 2050 and an aim for 'carbon neutral growth' from 2020 through economic instruments, improvements to technologies and operations, and the use of alternative fuels. During this time, the EU pushed for sub-global policy measures, ultimately including aviation within the EU ETS. Since the Kyoto Protocol targets ended in 2012, there has been progress by ICAO in the development of a global trading scheme for aviation emissions after assessing the feasibility of market-based measures. By October 2013, policy development was under way, with plans for the derived revenue to be used to mitigate the environmental impact of aircraft engine emissions. ICAO considers that sustainable alternative fuels for aviation offer one of the most promising technical solutions for reducing CO_2 emissions, a solution supported and encouraged by the UNFCCC. Other global mitigation measures include an international CO_2 standard for aircraft by 2016.

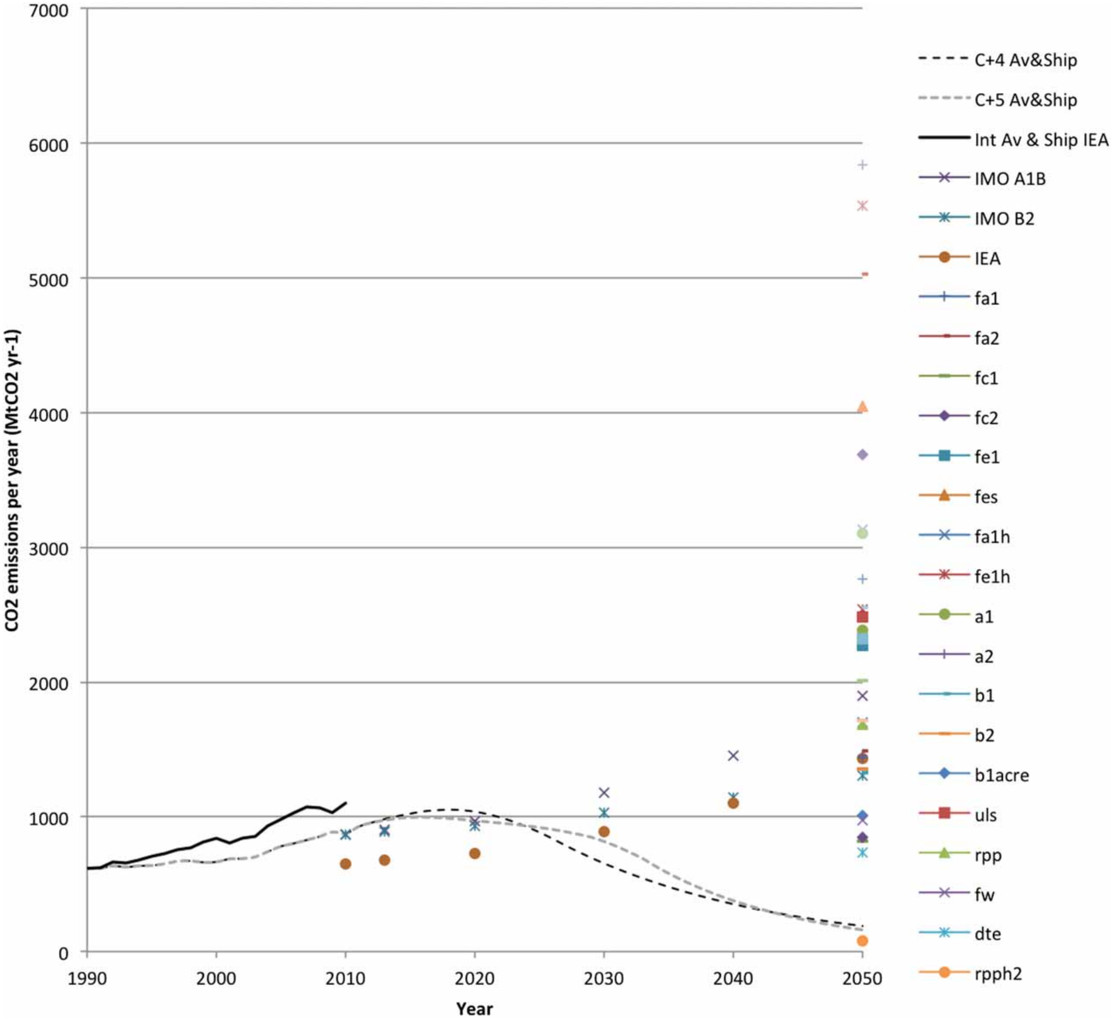

Figure 2 Comparison of the 50% Anderson and Bows trajectories from Figure 1 and the IEA bunker estimates (black solid line) with scenario studies for CO_2 from international shipping (IMO A1B, IMO B2 and IEA) taken from Bazari and Longva (2011) and CO_2 from international aviation (the rest of the designations are taken from the review by Gudmundsson & Anger, 2012).

Complementing ICAO's efforts, airlines represented by the Air Transport Association (IATA) have targets for improving annual fuel efficiency at a rate of 1.5% to 2020 as well as to cap net emissions from 2020 and cut net emissions by 50% by 2050 compared with 2005 levels. 'Net emissions' or the term 'carbon neutral growth' assumes that emissions cuts will not necessarily come from the industry directly, but through emissions permits traded with other sectors. In other words, aviation emissions in absolute terms can rise, or fall by a lower amount, through the industry purchasing emissions rights from elsewhere, while at the same time net emissions plateau or fall. If emissions from international transport are to be dealt with through global, rather than national/regional policy instruments, these policies must be commensurate with the global climate policy regime. So, as long as existing trading schemes continue to be at odds with the 2 °C goal, this amounts to the current ambition for mitigating aviation emissions being incompatible with the 2 °C constraints assumed in (i) and (ii) previously.

The body charged with controlling shipping emissions within the Kyoto Protocol is the IMO. Again, progress towards implementing mitigation policies commensurate with the scale of the challenge has been absent. Similar to aviation, the EU began to place pressure on the sector, particularly towards the end of the Kyoto period. Discussions of potential mechanisms did not gain momentum until after the 1990s, when bringing the shipping sector into an emissions trading scheme received attention, including the potential creation of an international sectoral trading scheme (Australian Shipowners' Association, Royal Belgian Shipowners' Association, Norwegian Shipowners' Association, The Swedish Shipowners' Association, & British Shipping, 2009). However, unlike aviation, there is an additional barrier when seeking to secure policy movement through the IMO: conflict between the UNFCCC's principle of 'common but differentiated responsibility' (CBDR) and the maritime principle of 'no more favourable treatment' (NMFT) (Kågeson, 2007). The first assumes differentiated effort to mitigate emissions based on the stage of economic development, with the other seeking fair and consistent treatment across all shipping nations. This apparent contradiction has presented a barrier during discussions within the Marine Environment Protection Committee (MEPC) at the IMO, delaying progress on agreeing fleet-wide measures to tackle CO_2. Indeed, some of the largest and most influential non-Annex I maritime nations, including China and Brazil, have voted against measures considered to contravene the UNFCCC's principle (MEPC, 2011).

Despite these additional challenges, by July 2011 the first global measure aiming to curb CO_2 from international shipping was agreed. This is a mandate on minimum efficiency levels for new ships implemented through an Energy Efficiency Design Index (EEDI). It aims to cut emissions from new ships by 30% by 2025, with overall efficiency gains dependent on fleet turnover. Complementary measures agreed to date include the Ship Energy Efficiency Management Plan (SEEMP) and the Energy Efficiency Operational Indicator (EEOI) to monitor the progress of the SEEMP. Debate around market-based measures and a climate levy is ongoing but making little progress due to the perceived conflict between CBDR and NMFT. A Market Based Measure Expert Group (MBM-EG) set up by the IMO conducted a feasibility study in 2010 of the relative merits of the available options (IMO, 2010). As no firm conclusion on the most appropriate measure to employ was drawn at the time, the subsequent focus has been on implementing the EEDI and SEEMP. Only light reference to market-based measures is made in documentation published following recent MEPC sessions, although the topic continues to be on the agenda to complement technical and operational measures already in place (MEPC, 2012). In 2014, discussions focused on technology transfer aiming to improve energy efficiency, updating the global estimate for GHG emissions from shipping, and establishing a framework for collecting and reporting ship fuel consumption (MEPC, 2013, 2014).

3.4. EU and UK policy landscape

During the 1990s and in response to slow progress by ICAO, EU policy makers agreed a strategy to tackle aviation CO_2 with two core strands: improving airspace use through the Single European Sky programme (Eurocontrol, 2014) and the inclusion of aviation in the EU ETS. The Single European Sky initiative aims to improve the management, design, and regulation of EU airspace by altering how it is divided by national borders using more efficient ‘functional airspace blocks’ (FABs).

In the last year of the Kyoto Protocol targets, the EU included aviation within its ETS, setting out a framework to include all flights departing or arriving at EU Member States. However, analysis at the time concluded that costs associated with its inclusion could be readily passed onto the consumer, with a limited impact on demand and CO_2 emissions expected (Anger & Köhler, 2010; Bows & Anderson, 2008; Scheelhaase & Grimme, 2007). By November 2012, before the policy began operation, the EU suspended plans to include non-EU nations’ flights within the scheme (European Commission, 2012). The delay was in response to moves by ICAO towards developing its global trading scheme, as it was anticipated that only one scheme would be needed. While the suspension was described as a gesture of goodwill to support an international solution, it coincided with legal challenges from nations outside the EU who were concerned that costs would rise as a result of including all flights.

Bringing international shipping into the EU ETS has also been on the agenda over the past 10 years, but it became clear that the more complex nature of the shipping system posed greater challenges over how to allocate emissions for trading than for aviation (Gilbert & Bows, 2012; Kågeson, 2007). Instead, the EU in 2013 proposed legislation requiring owners of large ships (>5000 gross tonnes) arriving and departing from EU ports to monitor and report ships’ annual CO_2 emissions (European Commission, 2013). The apparent absence of data transparency in the shipping sector has led to studies developing a range of methods for estimating its CO_2 (Corbett & Koehler, 2004; Endresen, Sorgard, Behrens, Brett, & Isaksen, 2007; Traut, 2014). Academics and stakeholders engaged in this issue consider robust monitoring, reporting, and verification of emissions to be an essential prerequisite for informed discussions on targets globally and at an EU scale. The new EU legislation is set to apply from January 2018.

With its legally binding Climate Change Act to cut the UK’s emissions and active debate around the inclusion of international aviation and shipping, the UK is an interesting national policy case to consider. As the Act commits to avoiding the 2 °C rise, it by default assumes that all sectors’ emissions are covered. To this end, there is a target to cut CO_2 by 80% by 2050 as well as shorter-term carbon budgets. However, there is an ongoing and unresolved debate around the formal inclusion of international emissions into these targets. Recent UK policy documents describe a preference for global action through ICAO for mitigating international aviation emissions. They also support the EU in including aviation in the EU ETS over unilateral policies given the ‘risk of putting UK businesses at a competitive disadvantage’ (Secretary of State for Transport, 2013).

In April 2012, the UK’s Committee on Climate Change (CCC) recommended that international emissions should be formally included in the Act’s targets (Committee on Climate Change, 2012a). However, the CCC altered its position by December 2012, arguing that the EU’s decision to suspend full inclusion of aviation in the EU ETS made its formal inclusion impossible (Committee on Climate Change, 2012b). There are plans to revisit the issue once uncertainties surrounding the EU ETS are resolved, with further guidance given when advice on the UK’s fifth carbon budget is presented in 2015. An interesting point to note is that the developments around global trading for aviation have had an impact on shipping mitigation efforts, with debate concerned with formally including shipping emissions into UK budgets and targets now suspended until 2015. Thus, although it has been argued that there are measures that nations could implement unilaterally or in tandem with other EU nations to influence shipping CO_2 (Doudnikoff, 2013; Gilbert & Bows, 2012), the global negotiations around a trading scheme for aviation have helped to put UK shipping mitigation efforts on hold.

3.5. Policy summary

Debate around how to deal with emissions from international aviation and shipping maintains its focus on seeking global mechanisms underpinned by goals set at the Paris COP in 2015. This leaves both sectors without binding carbon targets at present, and certainly until after 2015. At the same time, expected growth will increase absolute levels of CO_2, consuming more of the available budget, unless substantial efficiency gains or a large-scale shift to alternative fuels occurs in the meantime. Looking further ahead, even the planned 50% reduction in net emissions from aviation by 2050 from 2005 levels falls short of the 80% cut necessary to remain commensurate with 2 °C. This means that additional mitigation effort is required to push net emission reductions closer to an 80% reduction, assuming others are able to cut emissions in excess of 80% to have emissions rights to sell. Climate policy directed at aviation and shipping is currently woefully inadequate considering the scale and urgency of the 2 °C goal. To explore the practical feasibility of these sectors being able to follow a 2 °C pathway similar to the one presented in Figure 1, opportunities from technical, operational, and demand perspectives are presented in Section 4.

4. Opportunities for decarbonizing aviation

The decarbonization debate across all sectors often starts with technology. Yet taking a technology-focused view, with its long time horizon, ignores the science underpinning 2 °C; curbing emissions in the short term is essential. The absence of meaningful policies that go beyond pursuing efficiency gains through technology has influenced recent aviation emissions growth rates. Incremental technology change and minor adjustments to operations, coupled with a buoyant market, uphold the aviation sector's CO_2 growth at between 3% and 6% per annum (p.a.). Even where international aviation is considered 'mature', for instance in the US, CO_2 emissions have risen at 2.5% since 1990, an increase of 64% in 20 years (IEA, 2013). The available technology, operational and demand-side measures that could feasibly mitigate rising levels of CO_2 are now considered.

4.1. Technology

Energy costs are important given the fuel-intensive nature of flight (Williams, 2007). As a result, extremely efficient, high-bypass, high-pressure-ratio gas turbine engines have been developed and are now common across the fleet. Nevertheless, opportunities for ongoing improvements are in decline (Peeters, Middle, & Hoolhorst, 2005), and are around 1% per year in terms of fuel combusted per passenger-km at present. To push efficiency further, a fundamental shift in design is required. Open-rotor engines or propfans offer scope for up to a 50% cut in fuel intensity per aircraft (Akerman, 2005), but at present have limited application given their high noise and vibration levels. Geared turbo fans offer major efficiency improvements and have low noise levels (Szodruch, Grimme, Blurich, & Schmid, 2011), but the rate of diffusion across the fleet is key to their role in mitigating emissions.

New aircraft construction materials can deliver better fuel efficiency. Recent designs from both Boeing and Airbus replace 50% of the aluminium used with composites. Although important, it is only as the fleet renews, and older aircraft fully retire, that real benefits will materialize. As suggested by the industry's own targets in Section 3.3, the combined technological developments offer a 1–2% improvement in fuel efficiency per year.

There are more radical options, including alternative fuels or airframe designs such as the Blended Wing Body aircraft or aircraft powered by hydrogen propulsion (Lee et al., 2009). For aircraft to combust hydrogen they need a larger fuel tank to take into account hydrogen's lower energy density. Compounding the hindrance of slow fleet turnover, any radical changes also require alterations to the supporting fuel and airport infrastructure. Thus, these options are considered viable only in the long term. Instead, it is more attractive to research technologies to retrofit into existing aircraft and infrastructure. Deriving kerosene-grade fuel from biomass is one option. Research is under way (Kivits, Charles, & Ryan, 2010), and well supported by industry, but needs to address concerns over the demands from other industries for the same sustainably produced biomass (Bows-Larkin & Anderson, 2013). Given the constraints faced, it is understandable why industry goals are conservative, in addition to relying heavily on trading to reduce net CO_2. To fit with the challenge posed in Figure 1, other non-technical options require consideration.

4.2. Operations

The 'Single European Sky' initiative was put forward around 2000 with full deployment expected by 2020. Although better operations will improve fuel efficiency over the coming years, such initiatives offer only a one-time saving. Moreover, reducing congestion facilitates throughput, ultimately supporting aviation growth, in other words a rebound effect. More efficient use of airspace and increases in airport capacity can reduce fuel consumed per passenger-km, but serve to maintain or raise growth rates, increasing absolute energy consumption. To stabilize and then cut CO_2, rates of operational change, when coupled with technical efficiency or carbon intensity improvements, need to be greater than growth in activity. The industry target set for 'net' emissions to plateau by 2020 illustrates an expectation that absolute CO_2 emissions will rise, to be offset by permits purchased through trading.

4.3. Demand-side

It is useful to consider what typical growth rates are 'allowable' within the constraints of a 2 °C target. Assuming an optimistic 2% annual fuel efficiency improvement, for the $C + 4$ scenario (Figure 1), passenger-km growth rates would need to be cut to zero from 2020, with a 4% p.a. reduction from 2025. $C + 5$ requires zero growth to 2025, then reductions of 6% p.a. from 2033. Constraining demand for flying is unpopular, with little reference to it as a viable policy option in industry and government literature. Nevertheless, it can be argued that a gradual reduction from the typical 3% p.a. growth seen since 1990, to zero by 2020 to 2025, is no more challenging to achieve than a large-scale and rapid fleet-wide role-out of new technologies, or emissions trading implemented globally and commensurate with 2 °C. A personal carbon quota scheme for CO_2 that includes international flights is one mechanism that could lead to such a radical change in levels of per capita flying (Fawcett, 2010). Administratively, this type of policy could build upon existing credit-card-type technology (Starkey & Anderson, 2005). It is difficult to imagine how a policy could physically drive a rapid technological overhaul of the global aircraft fleet in a similar timeframe. It is highly desirable therefore that there is more research analysing where absolute cuts in passenger-km through the provision of alternatives such as virtual communications or long-distance, low-carbon rail travel, to add to existing literature (e.g. Coroama, Hilty, & Birtel, 2012; Guldbrandsson & Malmodin, 2010).

5. Opportunities for decarbonizing shipping

Voices capturing the sentiments of both sectors argue that shipping and aviation play pivotal roles in economic growth, and should be protected from policies that could damage their industries, the national economy, and global trade networks. Although aviation plays an important role in investment and business development in some sectors, it continues to be largely servicing leisure passengers, with shipping serving trade and freight. As flying is closer to the public consciousness than the shipping of goods, managing demand for aviation is particularly sensitive (Randles & Mander, 2009). On the other hand, there will likely be big shifts in the demand for international shipping due to change in other sectors, as discussed in Section 5.3.

5.1. Technology

Improving fuel efficiency has historically been less of a driver within shipping than aviation, despite constituting a higher proportion of operating costs, depending on service type (Cranfield, 2009; Mazraati, 2011). As well as the energy required to ship a freight-tonne being considerably lower than the equivalent energy required for flight, the elasticity of demand for shipping is low (Mazraati, 2011). Moreover, the relatively high number of actors within the shipping system leads to varying fuel ownership. Where to incentivize fuel-saving measures is challenging to pinpoint. However, very high oil prices have lately drawn greater attention to ship efficiency (Mazraati, 2011) and the potential benefits of slow-steaming (Cariou, 2011; Psaraftis & Kontovas, 2013). With or without slow-steaming, ship engines are very efficient, and shipping goods is a low-carbon method for moving freight. Nevertheless, the wide range of incremental technologies, many of which could be retrofitted to existing ships, are yet to be widely exploited throughout the sector (Buhaug et al., 2009).

In addition to incremental technologies, there are others offering more significant emission savings (Crist, 2009). Pioneering technologies for exploiting wind power are gaining traction, with the potential to offer fuel savings of up to 50% (Traut et al., 2014). Technologies include Flettner rotors, kites, and fixed or rigid sails (Lockley & Jarabo-Martin, 2011). Flettner rotors can be retrofitted to vessels, overcoming the problem of slow fleet turnover, although the availability of deck space for different ship types is important to consider. Sails have had a demonstrable impact on a bulk carrier run by the Modern Merchant Sailing Vessel (Schwarz, 2014), with other examples including sail-assisted cargo ships. Kites attach to the bows of vessels, are controlled from the deck, and operate at high altitudes to maximize wind speeds (Fernández Soto et al., 2010). An advantage of wind-power technologies is that they are low-carbon, low-sulphur, and offer the chance for short-term emissions savings (Gilbert, 2013).

There are also a range of feasible options for alternative fuels, with some already used. Liquefied natural gas (LNG) cuts the CO_2 emissions intensity of operations in the short term, but as a fossil fuel, a fleet-wide switch to LNG is insufficient to deliver 2 °C-type decarbonization (Bengtsson, Fridell, & Andersson, 2011), risking further carbon lock-in (Gilbert, 2013). Biogas, biofuels, and micro-algae are subject to sustainability concerns, as in other sectors (Bengtsson Fridell, & Andersson, 2012). Nuclear-powered ships present an interesting alternative. Opportunities for decarbonizing the shipping sector through technological intervention are manifold, but choosing the appropriate portfolio of solutions depends on a particular end-use (Bows-Larkin et al., 2014). Moreover, options such as wind-propulsion have more scope for cutting emissions in some sort of hybrid model, and if ship speed is cut.

5.2. Operations

A measure to reduce fuel costs that has gained in popularity since the global economic downturn is slow-steaming. With fuel consumption's cubed relationship with ship speed, slow-steaming can provide cuts in consumption of up to 50% per voyage (estimated using data from Buhaug et al., 2009). However, for the volume of cargo transport to be maintained, slow-steaming is less attractive without compensation from an increase in ship size or numbers to maintain freight flows. Regardless, slow-steaming, and optimizing ships for slower speeds reduces power requirements, improving the proportion of power that could be provided by renewable technologies. Slow-steaming also offers a route to delivering immediate cuts in CO_2 (Cariou, 2011; IMO, 2014; Psaraftis & Kontovas, 2013).

5.3. Demand-side

Despite strong potential for decarbonization, there are few incentives to encourage the uptake of low-carbon options. Unlike aircraft, most ship construction occurs in nations without climate targets, with many diverse manufacturers, charterers, owners, operators, and other stakeholders worldwide. Directly influencing change in this sector is extremely challenging, and arguably most effectively encouraged by combining global IMO-led policies with measures implemented at the port-state level (Doudnikoff, 2013; Gilbert & Bows, 2012). Thus, influences on the demand-side of shipping warrant further consideration.

One topical issue in 2014 relates to how nations decarbonize their energy systems. Taking the UK as an example, in 2010 around 50% of the tonnes of goods imported into the UK were fossil fuels. Changes to the levels of fossil fuel consumption and the growth in biomass/biofuels impact heavily on shipping under the UK Government's own energy scenarios (Mander, Walsh, Gilbert, Traut, & Bows, 2012). For instance, the success of carbon capture and storage technology determines whether there will be any coal imports into the UK by 2050. Similarly, cutting CO_2 associated with land-based transport will mean a sector-wide shift away from petrol, again impacting on fossil fuel trade. A general strain on global resources, as well as climate impacts on agriculture, raise the debate around the levels and types of consumption, with the potential to alter typical patterns of trade. So, although managing demand for shipping is rarely discussed, realizing the decarbonization agenda will, by definition, lead to a substantial reduction in the demand for trading fossil fuel. Notably, the view from many stakeholders is that the maritime industry serves demands in other sectors, an argument made for dismissing the idea of directly attempting to manage the demand for shipping.

6. Discussion and policy implications

It is not uncommon to couple international aviation and shipping within the climate mitigation debate. There are even examples where shifts in policy aimed at aviation have had a material impact on mitigation policy for shipping (Section 3.4). As with all sectors, both ultimately face a significant challenge in achieving decarbonization at a level commensurate with 2 °C. What sets them apart, and has led to their omission from stringent policy measures targeted at all other sectors, is that their climate governance arrangements differ, leaving them outside Annex I nations' CO_2 targets. Their international nature and close ties to globalization maintain above-average global growth rates – with further substantial growth expected to 2050. Nevertheless, a majority of the activity within these sectors, and particularly in the aviation sector, stems from Annex I nations, supporting an argument for the urgent implementation of meaningful emission mitigation policies on a level playing field with other sectors. Although international governance is a reason for considering aviation and shipping together, there are many differences between them that call for a more sophisticated and targeted approach.

The aviation industry's structure, with its two main manufacturers, nationally based airlines, and its mode of operation (where flights typically operate between two points), opens up the option of apportioning international aviation emissions to nations (even regions) (Wood et al., 2010). There are much more significant challenges if apportionment is applied to shipping (Gilbert & Bows, 2012), given the complexity of its structure and the fact that voyages often include many ports of call en route. This has been recognized through aviation being brought into the EU ETS, while the EU's approach for shipping instead focuses on measuring, monitoring, and verifying fuel consumption. Although options for influencing change in the short term in shipping are open to port-states, there is little appetite from within the industry to explore this avenue, as the establishment of further global market-based policy instruments is anticipated and for many considered preferable.

This article started out by highlighting two key sticking points in relying on global market-based mechanisms such as trading to enable international aviation and shipping to play their fair part in delivering on 2 °C: (1) that emissions trading in general can deliver a satisfactory outcome and (2) that emissions trading can provide the space for international transport to grow as much as demand for these services requires. There are two principal reasons why emissions trading is a red herring when aimed at delivering a satisfactory outcome of avoiding 2 °C 'consistent with the science and on the basis of equity' (UNFCCC, 2009). First, if a strict global carbon cap were in place, the carbon prices necessary to achieve an urgent and rapid cut in CO_2 would evidently need to be well in excess of fuel price rises seen over the past decade (otherwise CO_2 emissions would have fallen). Such price rises are substantially higher than those countenanced by policy makers. Conventional economic tools such as computable general equilibrium models, often used by governments, are unable to capture potential outcomes of non-incremental adjustments to carbon prices, with their inevitable social and institutional impacts (Scrieciu, 2007). Moreover, if trading or other global mechanisms are to deliver cuts in absolute CO_2 in line with 2 °C, they must start by setting an appropriately stringent cap and avoid both weak and strong carbon leakage (Peters & Hertwich, 2008). Furthermore, the long-term implications for CO_2 of the trading mechanisms used to support development projects must be taken into account.

Second, waiting for global trading or a comparable mechanism to begin, with a similar phase-in period as the EU ETS had, means that CO_2 growth from international transport continues. This will consume more than a fair proportion of the available CO_2 budget given emissions need to reach a peak by 2015–2020 (Figure 1). Even if these obstacles could be overcome, the aviation industry's current goal – a net CO_2 cut of 50% by 2050 from 2005 – falls substantially short of the 80% cut necessary to remain within a 2 °C budget, even with trading functioning successfully. The rapidity with which the CO_2 budget is being consumed requires immediate cuts in CO_2 growth rates across all sectors. As long as aviation and shipping are outside of a global and strictly bound trading scheme, 2 °C implies CO_2 growth rates need to be near zero by 2015 to 2020. Technology and operational change will not be sufficient to deliver such a shift in the aviation sector, although this could be the case for shipping. For aviation, this implies a need for demand-side intervention, at least in Annex I nations where per capita flying is high. Policies that could intervene include a moratorium on airport expansion, the implementation of an individual carbon quota scheme to include flights or, if considered feasible, additional price mechanisms to curb growth to the extent required to stay within the budget. However, nations would probably also need to accept responsibility for a portion of international aviation emissions for such policies to be enacted.

Drawing on the literature and stakeholder engagement and interviews, Table 1 captures some of the differences and similarities between aviation and shipping within the context of the climate debate. International shipping and aviation are similar in terms of CO_2 growth rates but differ significantly in options for future decarbonization. To remain commensurate with the scientific interpretation of

Table 1 Characteristics summarizing similarities and differences between the international aviation and shipping sectors.

Characteristic	Aviation	Shipping
Primary function	Leisure (passengers)	Trade (goods)
Typically annual efficiency gain (Mtoe/freight tonne or passenger-km)	1–2% (–)	<1% (–)
Typical recent annual global CO_2 growth rate	+3% (–)	+3% (–)
Potential future fuels	Bio-kerosene (+)	LNG (?); biofuels; wind propulsion; nuclear; electric drive; fuel cells; hydrogen (+)
Operational changes	Single European Sky (?)	Slow-steaming; weather routing (+)
Opportunities for retrofit	Few (–)	Many, but depends on ship type (+)
Public perception	Precious; necessary (–)	Distant; importance largely unrecognized (?)
Demand management	Highly unpopular with industry, public and policy makers (–)	Direct intervention not being considered but external drivers may alter demand (+)
Industry structure	Two dominant manufacturers; a few key airlines within nations (+)	Many ship builders, operators, shippers, ship owners, charterers, end-users (–)
Manufacturing/construction	Largely based in Annex I nations (+)	Ship building largely based in non-Annex I nations (–); engine manufacture in Annex I (+)
Policies currently in place	EU emissions trading for intra-EU flights; voluntary efficiency goals; industry standard for aircraft efficiency to be met by 2016 (?)	Energy Efficiency Design Index (EEDI) to cut CO_2 from new ships by 30% by 2025; Ship Energy Efficiency Management Plan (SEEMP) (?)
Future potential policies	ICAO: global emissions trading scheme to start 2020 (?)	EU: monitoring, reporting, and verification to start 2018 (?)
Options for step-change in decarbonization	Demand management and biofuels	Many options, particularly combining slow-steaming with wind propulsion and/or biofuels

Notes: + designates something that may support decarbonization; – designates something that presents a barrier to decarbonization commensurate with 2 °C; ? designates a change that may increase or decrease CO_2 depending on the wider system. The table is not comprehensive, but aims to capture key features and important emerging technologies.

2 °C, requiring urgent and rapid decarbonization, a pragmatic approach would be to influence, incentivize, or set standards around technology and the operational options for shipping, and constrain demand for aviation. Combining slow-steaming with a range of renewable technologies such as wind-assist methods of propulsion and biofuel, and encouraging a widespread programme of retrofit through port-state influence, could lead to a significant shift in the emissions associated with shipping, at least at an EU scale (High Seas, 2013). The issue of paramount importance for decarbonizing shipping is how to influence this complex confluence of varied markets and shipping actors. For aviation the situation is vastly different. Technologies to cut CO_2 in the required timeframe are few and far between. Nations where per capita flying as well as growth rates are high have no option but to consider constraining growth in the short term, until fuel efficiency improvements or the use of biofuel can more than offset the CO_2 produced by a further rise in passenger-km.

7. Conclusions

International aviation and shipping are distinct from other sectors in terms of governance arrangements to curb their CO_2 emissions. They have also had similar CO_2 growth rates since 1990, above the global average. Nevertheless, allowing the debate around these sectors to be too closely linked (as in the instance highlighted in the UK) could hamper opportunities for developing targeted measures to cut CO_2 emissions in the short to medium term. There is a huge divide between the potential for mitigation in shipping compared with aviation. In short, the shipping industry has many technological and operational options that could cut emissions in the short to medium term. Aviation does not. Nevertheless, despite many options on the horizon for shipping, its complex organizational nature is a major barrier to change.

In aviation, the limit to technical and operational change has led the industry towards a preference to use a global emissions trading scheme to provide net emission cuts. In other words, the sector expects CO_2 savings will generally be made in other sectors of the economy to enable aviation-related CO_2 to grow or be cut by less. Yet, even with trading, a target of a 50% net CO_2 cut is not sufficient to meet the 2 °C goal. Ironically, by comparing aviation with shipping, it becomes clear that if there were mitigation options available to the air transport sector, its relatively simple institutional set-up, with its small number of manufacturers, fewer markets and actors, as well as a lower number of major national players, would make incentivizing change practical. Instead, with emissions trading disconnected from the 2 °C challenge, demand-management and biofuels offer the only feasible ways of cutting CO_2 in the timescale compatible with the available CO_2 budget. Yet, both raise interesting ethical and moral issues. Should aviation, which in a global context continues to be dominated by relatively affluent leisure passengers (Williams, 2007), take priority over other sectors for the use of sustainable biofuels in preference to less popular policies aiming to curb or even cut growth rates?

The highly constrained carbon budget commensurate with 2 °C does not permit any further delay in rolling out mitigation policies for aviation and shipping. All opportunities for urgent change need to be harnessed. Immediate CO_2 cuts in the shipping sector could be delivered, at least in waters around port-states, through regulations or incentives at a sub-global scale that further encourage and maintain the recent shift towards slow-steaming, better ship efficiency, and the retrofit of low-carbon technologies. For aviation, pinning so much hope on emissions trading to meet the 2 °C challenge is misguided.

Ultimately, an uncomfortable and familiar conclusion for aviation remains: a moratorium on airport expansion at least in wealthy nations is one of the few options available to dampen growth rates within a timeframe befitting of the 2 °C target.

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