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# Aviation and Climate Change—The Continuing Challenge

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## 1 INTRODUCTION TO AVIATION & CLIMATE CHANGE POLICY

International aviation's contribution to global CO<sub>2</sub> emissions has come under scrutiny since the early 2000s. Prior to that, mitigation focused on the CO<sub>2</sub> released within national borders, given the exclusion of international aviation from the Kyoto Protocol's national targets. Although a considerable body of research has since interrogated aviation's CO<sub>2</sub> contribution, discussing cuts in the CO<sub>2</sub> produced by flights remains controversial and unpopular for many reasons voiced by industrial stakeholders and the general public (Budd and Ryley, 2013). So, while there are arguments for treating aviation on a level playing field with other sectors and implementing stringent mitigation policies aimed at tackling CO<sub>2</sub>

(Bows, 2010; Budd and Ryley, 2013; Peeters, Williams, and Haan, 2009), this is not a universal view.

Aviation's economic importance is regularly cited as a key reason to avoid stringent CO<sub>2</sub> mitigation (Wood, Bows, and Anderson, 2012). Another argument can be attached to its role in connecting nations at different stages of development. The sector's growth rate, coupled with few options for reducing carbon emissions per passenger-km (gC/RPK), drives up aviation's CO<sub>2</sub> emissions. Increasing mobility and high rates of economic growth in industrializing nations influence demand. These industrializing nations do not in general foresee CO<sub>2</sub> targets for their other sectors before 2020, and therefore few direct drivers toward cutting emissions. Globalization supports arguments for treating international aviation and shipping differently to sectors that do not operate within international airspace or waters, with policies that can allow for high growth rates in some countries. While this may have some traction, it only holds within a climate change context if globally averaged growth rates do not jeopardize the international commitment to remain within the 2 °C global temperature target.

There has been widespread political consensus enshrined in various accords, agreements, and declarations that "2 °C" represents the threshold between acceptable and dangerous climate change. Controlling emissions of greenhouse gases across sectors is critical if the carbon budgets underpinning this commitment are not to be exceeded. Yet the sizeable and growing emissions from international aviation (and shipping) were exempt from national targets enshrined in the Kyoto Protocol. Domestic aviation emissions were included, but as

the United States, with its dominant share of the CO<sub>2</sub> from all internal flights when the Protocol was adopted (63% in 1997, IEA, 2014), did not ratify it, the already weak constraints on aviation emissions were watered down still further.

In a bid to include international aviation's CO<sub>2</sub> within global climate commitments, the Kyoto Protocol tasked the UN's specialist agency, the International Civil Aviation Organization (ICAO), with responsibility for mitigating CO<sub>2</sub> from aviation. However, slow progress during the 1990s led the EU Commission, having voiced its frustration, to independently develop proposals for including aviation within its Emissions Trading Scheme (ETS) and impose a carbon price on the industry (Bows, 2010). So, by the Kyoto Protocol's final official year, the EU had included aviation within its ETS despite concerns coming from the industry regarding elevated costs and doubt surrounding the resulting impact on CO<sub>2</sub> emissions.

Yet even before the policy began operating, the EU suspended the inclusion of non-EU nations' flights in response to progress by ICAO toward establishing a global trading scheme, and in light of strong opposition to the scheme from some countries including the United States (Bows-Larkin, 2014). This suspension remains in place until 2016, when the ICAO mechanism is scheduled to be agreed. Other policy mechanisms promoted through ICAO include a voluntary global annual 2% fleet fuel efficiency improvement up to 2050, with a 50% reduction in net emissions from 2005 levels, and an aim for "carbon neutral growth" from 2020 (ICAO, 2013a).

By October 2013, development of ICAO's global trading scheme was underway, with derived revenue hypothecated to alleviate the impact of aircraft engine emissions, and developing low-carbon alternative fuels. However, with no mechanism agreed before 2016, and then further time needed for implementation, emissions are expected to rise unabated at least until then. Meanwhile, there have been developments within the United States. In 2014, the US Supreme Court upheld the United States Environmental Protection Agency's (EPA) power to regulate CO<sub>2</sub> under the Clean Air Act. Now, the EPA is considering if aviation has an impact on human health, releasing an information sheet with potential plans to impose a CO<sub>2</sub> standard on aircraft.

With cuts of at least 80% from 2010 levels by 2050 necessary across all sectors for a reasonable chance of avoiding 2 °C (Bows-Larkin, 2014), the current mitigation strategy for international aviation assumes other sectors will proportionally cut CO<sub>2</sub> by more than aviation. Bows (2010) assessed aviation's climate impact, comparing scenarios for future aviation CO<sub>2</sub> with carbon budgets associated with 2 °C. The paper presented the mitigation challenges for aviation and highlighted the importance of understanding the broader

climate change context when assessing aviation's climate impact. This chapter updates Bows (2010) by comparing updated aviation scenarios with more recently published 2 °C carbon budgets. It discusses insights in the context of emerging developments, to reassess if that paper's conclusion that "without a large reduction in growth rate or significant penetration of alternative fuel by 2050, aviation's projected CO<sub>2</sub> emissions will be incompatible with the 2 °C target" remains sound.

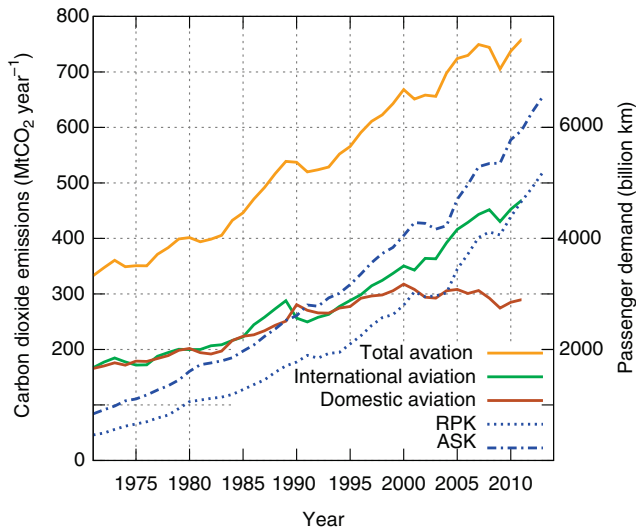
## 2 TRENDS IN THE AVIATION SECTOR'S CO<sub>2</sub> EMISSIONS

The civil aviation industry's CO<sub>2</sub> emissions have grown almost consistently year-on-year since its emergence. The regional profile of aviation-related CO<sub>2</sub> emissions shifts as economies develop. Nevertheless, growth remains high even in industrialized economies for two principal reasons: its role in connecting nations especially at different stages of industrialization; the shift from occasional use to frequent flying, facilitated by falling air fares (Randles and Mander, 2009). Its high growth rate poses great challenges for climate change mitigation. Unlike almost all other sectors, technologies available for deployment in the time window consistent with avoiding 2 °C are few and far between. Thus, long lifetimes of aircraft coupled with the longevity of design specifications risk leaving the sector locked into conventional technologies for many decades. Even as fuel efficiency improves, Figure 1 illustrates that high demand growth leads to rising CO<sub>2</sub> emissions.

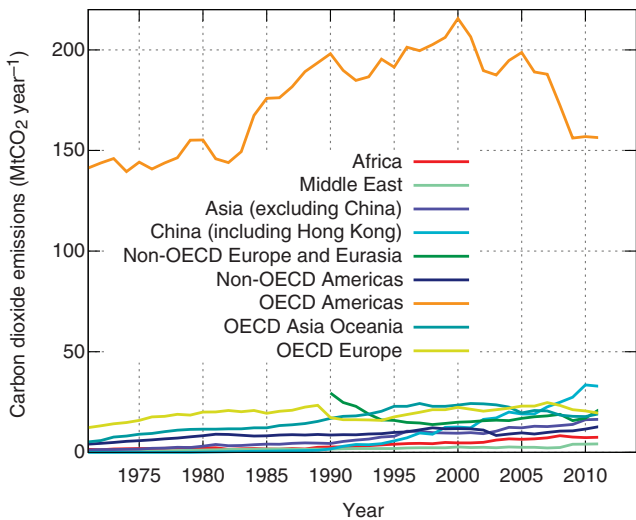
Regions currently experiencing rapid growth in aviation CO<sub>2</sub> differ depending on whether domestic or international travel is interrogated. Obviously nations with large land masses have much greater propensity for domestic air travel than smaller nations, where international flights dominate. Nevertheless, the construct of "domestic" and "international" aviation is important in a climate policy context, as international flights are not subject to national mitigation strategies.

### 2.1 Trends in Domestic Aviation CO<sub>2</sub> Emissions

CO<sub>2</sub> emissions from aviation have historically been dominated by those from domestic flights in the United States – and they remain a major share (50% of the CO<sub>2</sub> from all domestic flights globally in 2011, IEA, 2014; Figure 2). However the picture is in flux, with CO<sub>2</sub> from domestic flights in the United States recently declining. China has just one-fifth of the domestic aviation CO<sub>2</sub> of the United States, but is

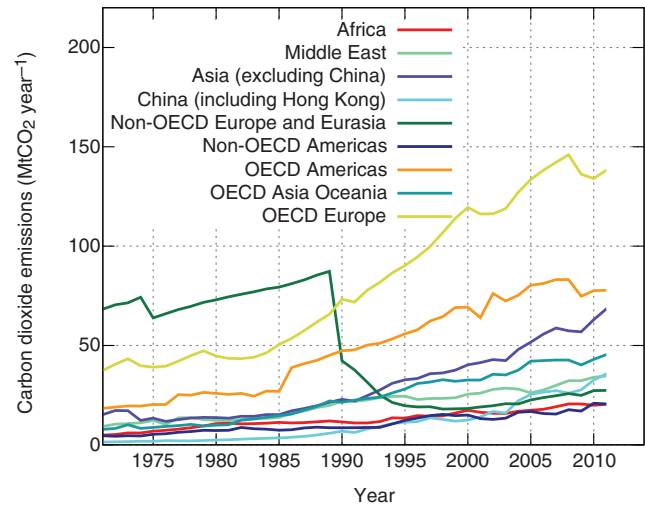


**Figure 1.** Trends in aviation indicators. Revenue Passenger-km (RPK), Available Seat-km (ASK), and the CO<sub>2</sub> emissions for aviation for international and domestic flights. (Source: CO<sub>2</sub> data from the International Energy Agency (IEA, 2014); 1971–2006 RPK and ASK data, Owen (2008); 2007–2013 data calculated from “passenger growth rpk” and “passenger load factor achieved” (IATA, 2014).)



**Figure 2.** Regional split of CO<sub>2</sub> emissions from domestic flights. (Source: Data: IEA statistics (IEA, 2014).)

growing rapidly at rates close to 10% per year (IEA, 2014). Other parts of Asia are experiencing high growth rates too: 6% per year since 1990, but it is the vast geographical area of some regions that will inevitably lead to high levels of CO<sub>2</sub> from domestic flights.



**Figure 3.** Regional split of CO<sub>2</sub> emissions from international flights. (Source: Data: IEA statistics (IEA, 2014).)

## 2.2 Trends in International Aviation CO<sub>2</sub> Emissions

The international aviation CO<sub>2</sub> emissions are captured in Figure 3. OECD Europe dominates in recent years, with OECD Americas and then Asia (excluding China) following. In terms of growth, China has experienced the highest annual rates at 8% on average since 1990 with the rest of Asia at 5%. OECD Europe continues to grow at 3% annually and even in North America where aviation is considered to be a mature industry, average growth has been 2% per year since 1990 – including both the events of September 11th 2001 and the recent global economic downturn.

## 2.3 Future Aviation CO<sub>2</sub> Emissions

In recent years, aviation’s CO<sub>2</sub> profile shifted emphasis from domestic to international, driven primarily by a rise in international travel by EU citizens, as well as fall in demand for US domestic flying, particularly following the events of 11 September 2001 and recent recession. However, the emergence of China as a rapidly growing source of domestic aviation CO<sub>2</sub> suggests the balance could shift back again. Another driver of CO<sub>2</sub> will stem from rapid growth in international flying across all nations, influenced by connections with nations experiencing high levels of economic development. This new landscape raises questions. What might be the impact on innovation and climate policy of rapidly growing domestic aviation in China? Will the growing source of international flight CO<sub>2</sub> continue to fall outside of policy regimes aimed at other fossil-fuel-consuming sectors? And

finally, what drives passenger demand for flying in the first place?

### 3 DRIVERS OF DEMAND FOR AIR TRAVEL

To explore some of the drivers of demand for flying, it is worth considering what air travel is primarily used for. In summary, aviation accounts for approximately 10% of all transport (vehicle) km traveled and moves 35% by value of goods traded internationally (ATAG, 2014). Fifty-three percent of international travelers arrive at their nondomicile destination by air compared with 47% by other modes – 40% by road, 2% by rail, and 5% by water (UNWTO, 2014). Fifty-two percent of flyers do so for leisure, 27% to visit friends and family, religious, or health reasons, while 14% fly for business (UNWTO, 2014). Understanding the drivers of demand for air travel is a key piece of the jigsaw.

#### 3.1 Growing Demand Around the World

Recently, passenger numbers have been on an upward trend following a decline around 2008/2009 (Figure 1), with monthly passenger kilometres for September 2014 in the region of 510 billion (IATA, 2014). Emphasizing the link between the state of economies and demand for aviation, as of September 2014, the International Air Transport Association (IATA) judged the outlook for aviation to be positive though inconsistent across the globe; faltering economic improvement in the EU contrasted with recovery in the United States and on Asia Pacific routes (IATA, 2014). While year-on-year growth in passenger kilometers for September 2014 compared with September 2013 averaged 5.3% globally, there is significant regional variation. The Middle East is the only region where the *rate* of growth continues to increase due to its strong regional economy, with a fall in other regions related to economic slowdown and factors such as strikes and market volatility. Overall growth in demand is highest in emerging economies (IATA, 2014). Forty percent of the international market is centered on Europe, followed by Asia Pacific with 25%. Forty-one percent of the domestic market is the United States with China in second place at 23% (IATA, 2014) and industry forecasts suggest China will become the largest domestic market within 10 years. In terms of flights per capita, in 2014 North Americans and Europeans are the most likely to fly, averaging, 1.6 and 1 flight per person per year, respectively. In 2033, Airbus predicts flights per capita

in China will reach 0.95 up from 0.25 in 2014, with India reaching 0.26 up from 0.06.

#### 3.2 The Role of Socio-Economic Factors in Shaping Demand

Demand for aviation is shaped by factors that affect people's ability and desire to fly, and by supply-side factors within the aviation industry such as capacity or infrastructure. To unpack demand for aviation, a variety of modeling approaches can be used including econometric modeling (for instance Department for Transport, 2013). Aviation demand is often related to economic activity and air fares (see, for example, Department for Transport, 2013), while other studies (see Additional Reading) include variables such as exchange rates, purchasing power overseas, and perceived level of household wealth (O'Connell *et al.*, 2013).

Studies show that most people do not fly because they want to fly per se, but because flying enables them to do things they wish to do. Thus, to gain a more nuanced understanding of drivers for demand for aviation, much can be gained from complementing economic modeling studies with sociological and psychological research. Migration and changing household demographics are an important driver for aviation given that increasing globalization means friends and family can be dispersed; this is reflected in figures that suggest around a quarter of flights are to visit friends and family (Hibbert *et al.*, 2013). Urry (2012) argues that society views high-mobility lifestyles positively, whereby someone's standing is reflected by the places they have visited and mobility patterns; frequent flyer programs and the marketing strategies of airlines also link status with mobile lifestyles.

Supply-side changes, namely the emergence of low-cost airlines specializing in domestic and short-haul routes has helped create new markets. For those who can afford it, the low cost of flights in the United Kingdom has contributed to raising the "standard" of occasions such as a hen party or trip with friends (Randles and Mander, 2009). Changing practices of celebrating, holidaying, and visiting friends and family abroad represents an upward ratchet on the number of flights taken per year. Growth is facilitated further by interacting aspects such as easy Internet booking and online check-in, speeding up the purchasing and delivery of service (Randles and Mander, 2010).

Finally, aviation is an area of consumption where there is a gap between attitudes toward the environment and behavior. Climate awareness does not lead to people not flying. Instead, a lack of alternatives and the habitual nature of flying lead people away from sustainable choices, in contrast to some other areas of decision-making (Hares, Dickinson, and

Wilkes, 2010). Frew and Winter (2009) highlight how concerns about the time, family commitments, and a desire to see the world can outweigh consideration of the environmental cost of travel (Frew and Winter, 2009). The extent to which flying practices in many wealthy parts of the world transfers to emerging markets, particularly those now served by their own “low cost” airlines such as AirAsia, remains to be seen.

### 3.3 Future Demand for Air Travel

Future demand for aviation is likely to be driven by an increasing middle class population, primarily in emerging economies, whose desire to travel is enabled by supply-side developments such as expanding infrastructure and deregulation of markets. Although national models of deregulation and liberalization differ, a competitive aviation industry is seen as crucial to reduce costs and improve service, both domestically and as carriers look to compete internationally (O’Connell *et al.*, 2013). Airport expansion has supported the enlargement of domestic aviation in emerging economies as shown by the development of airports in smaller cities to support regional commuter travel in China for example. In emerging markets, the development of regional airports can drive growth in international air travel as “Hub and spoke” configurations can be used to attract international travelers (O’Connell *et al.*, 2013). With the support that national governments are giving to the aviation industry within emerging economies, the building blocks that enable industry growth predictions to come to fruition are being put in place (O’Connell *et al.*, 2013).

## 4 TECHNICAL OPTIONS FOR CUTTING CO<sub>2</sub> IN AVIATION

Redrawing attention to climate change, how can rising demand be met if absolute CO<sub>2</sub> emissions from the sector are to be reduced? The obvious place to seek solutions resides in innovative technologies and operational practices available to deliver change. However, previous work highlights the very incremental nature of much of what is available (Bows-Larkin, 2014).

### 4.1 Improving Aircraft Efficiency

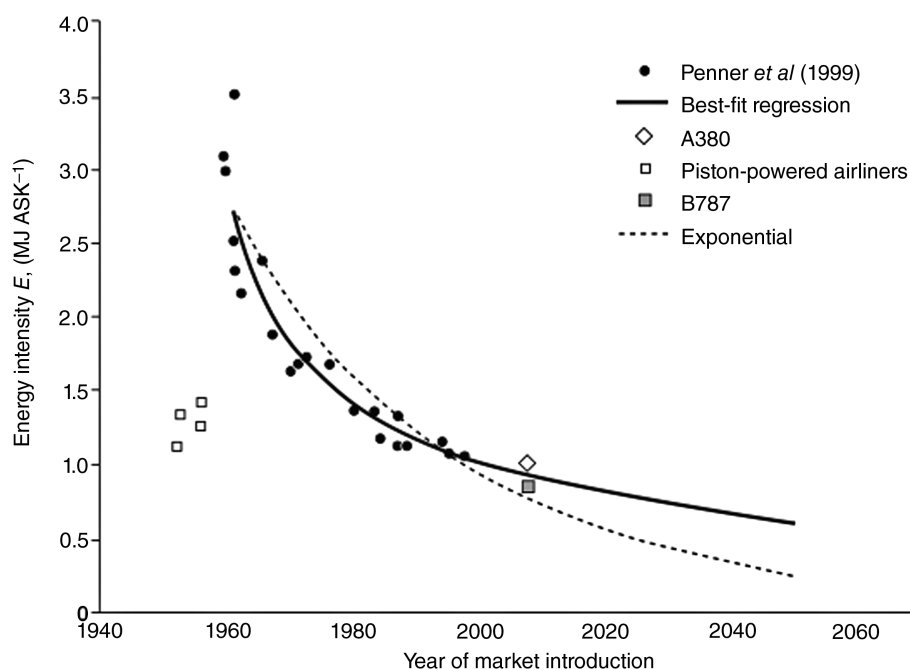
Most technological improvements to reduce fuel burn address structural weight, aerodynamics, or engine efficiency. Decreasing the structural weight of the aircraft and

reducing drag to increase the lift-to-drag ratio, both cut propulsive power and thereby reduce fuel consumption. Increasing aircraft engine fuel efficiency also lowers the CO<sub>2</sub> intensity of flight. Incremental change across all three leads to efficiency improvements between different aircraft generations. With fuel making up a significant share of the running costs for airlines, unsurprisingly, fuel efficiency has been a major research and development goal for many decades. Advances in engine design, optimized wing and body shapes, and material science contributed to new generations of aircraft that consume less fuel per Available Seat Kilometer (ASK) than their predecessors. Coupled with increased utilization factors, this has led to significant fuel efficiency improvements (Figure 4). While there is still potential for future generations of aircraft to be more fuel efficient than today’s, the best-fit regression line in Figure 4 illustrates how aviation faces diminishing returns as technology matures. Aircraft are highly optimized and must meet rigorous safety standards as well as respond to other constraints on noise and local pollution, meaning that fundamental design changes are difficult and costly to achieve. So, while there is certainly promise over the longer term for more advanced, more fuel-efficient, and lower-carbon intensity aircraft, the current challenge is that such changes are highly unlikely within a time frame compatible with climate change targets. Alternative fuels have therefore become attractive, but they come with unresolved issues, such as their full life-cycle CO<sub>2</sub> impacts and wider sustainability concerns.

### 4.2 Beyond Efficiency

To reduce CO<sub>2</sub> emissions beyond annual incremental change, alternative fuels will have to come into play. The only ones considered realistic in the near-term are biofuels or other synthetic fuels. The fuel itself would not be fundamentally different from kerosene, but rather than of fossil origin, produced from biomass or from another low-CO<sub>2</sub> feedstock. There is a burgeoning range of initiatives in this direction but emission savings delivered depend on feedstocks and production methods. Some of the CO<sub>2</sub> from biofuels may be negated by the CO<sub>2</sub> taken up by the plants grown to produce them. However, the CO<sub>2</sub> benefits of producing jet fuel from, for example, *Jatropha*, depend on the current vegetation or land use it displaces and for many areas this may be negative. Furthermore, large-scale production raises wider sustainability issues as feedstock production displaces food production.

In general, life-cycle assessments yield a wide range of potential emission savings or otherwise, depending on the specific production process (Hileman and Stratton, 2014). On-going research seeks to resolve issues around biofuels



**Figure 4.** Trends in energy intensity in the aviation sector since the emergence of the civil aviation industry projected out to 2050. (Source: Reproduced with permission from Peeters, Williams, and Haan (2009), p. 294. © Taylor and Francis.)

with different properties from standard jet fuel and create production routes for second- and third-generation biofuels, such as jet fuel from algae. Replacing plants with alternative mechanisms of using solar (or another source of) energy to combine water and  $\text{CO}_2$  into hydrocarbons could open a production route for a wholly synthetic jet fuel. Going beyond hydrocarbons, hydrogen and battery-electric powered propulsion have been considered, but are far from offering a realistic alternative within an appropriate timescale (Hileman and Stratton, 2014).

## 5 FUTURE OF AVIATION & CLIMATE CHANGE

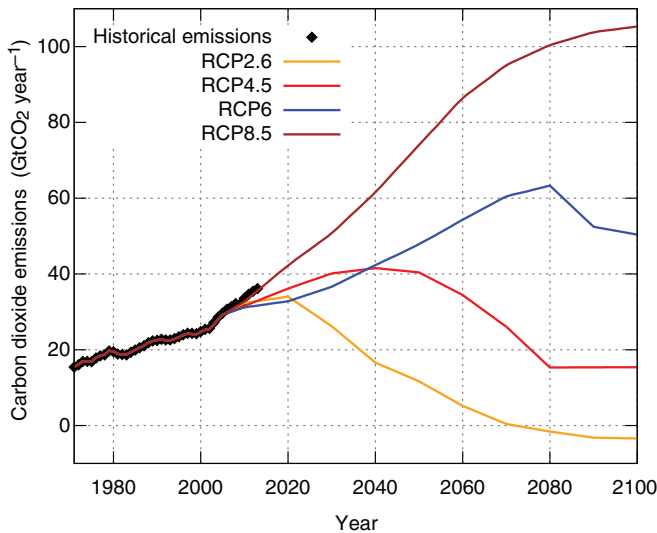
With rising demand and a limit to the technical options available for cutting  $\text{CO}_2$  emissions, it is essential to place aviation in the context of broader climate change policy objectives.

### 5.1 Global Climate Policies and Scenarios

In 2014, the Intergovernmental Panel on Climate Change (IPCC) released its latest synthesis of the global climate change challenge. One of the new areas brought to the fore

is the importance of cumulative greenhouse gas emissions in dictating the future global mean temperature increase. Global cumulative carbon budgets constrain emission pathways for all sectors, varying depending on the desired climate outcome. In short, from 2015 onward there remains around 1100–1400Gt $\text{CO}_2$  for a 50:50 (“reasonable”) chance of avoiding the 2 °C target threshold between “acceptable” or “dangerous” climate change (IPCC, 2014). Naturally, there are various paths that can be followed to remain within this constrained budget, in addition to a range of contributions by sectors that release  $\text{CO}_2$ . However, when the numbers are scrutinized it becomes clear how very challenging this global budget is for any sector. For a reasonable chance of avoiding 2 °C, all sectors will need significant and absolute cuts in  $\text{CO}_2$  in the coming decades. More realistically, energy systems in wealthier countries, including the transportation sector, need to eliminate  $\text{CO}_2$  emissions by very soon after 2050 (Anderson and Bows, 2011).

A more conservative take is presented by the Representative Concentration Pathways (RCP) (Figure 5). The most constrained scenario (RCP2.6) has the best chance within this suite of avoiding 2 °C. Considering this pathway in detail however, it becomes clear that global  $\text{CO}_2$  emissions have in reality risen faster than this “2 °C” scenario. Furthermore, in the vast majority of energy scenarios assumed to “fit” with this emissions pathway, “negative emissions” play a

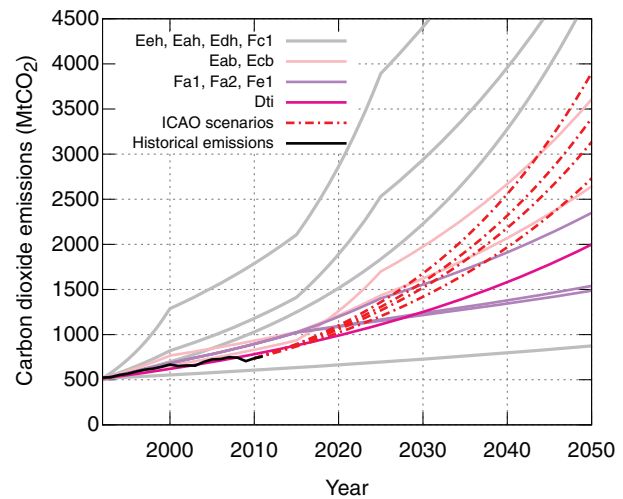


**Figure 5.** Representative Concentration Pathways (RCPs) and historical emissions of fossil fuel and industrial CO<sub>2</sub>. (Source: Historical data taken from the Global Carbon Project (Le Quéré *et al.*, 2014) and RCPs taken from (Meinshausen *et al.*, 2010; Moss *et al.*, 2010)). The number after each “RCP” stands for the amount of future radiative forcing.

significant part in maintaining low temperature rises. In other words, much confidence is placed in the large-scale and rapid deployment of biomass energy sources coupled with carbon capture and storage and/or carbon sinks through land-use change. Without this, the budgets become much more challenging, with all sectors needing to radically adjust expected levels of future emissions to avoid 2 °C.

## 5.2 New Scenarios and Forecasts of CO<sub>2</sub> From Aviation

To formulate a response to the challenge posed by climate change, it is necessary to look out into the future. There are many outlooks, forecasts, and scenarios in the literature, some of which are making predictions, while others are formulated to explore potential future change. “What-if” type scenarios have gained prominence in climate and energy policy, given the nature of end-point climate objectives, such as the 2 °C temperature target. They are also used in various forms within sectors, and aviation is no exception. It is therefore instructive to revisit existing scenarios and consider them in the context of recent trends in CO<sub>2</sub> emissions from aviation. Figure 1 presents data on emissions from domestic and international aviation, which followed a very similar growth trajectory until the mid-1990s. Since then, growth in domestic and international CO<sub>2</sub> combined has for the most part been due to increases in emissions from



**Figure 6.** Future aviation emission scenarios. The ICAO scenarios (ICAO, 2013b) are underpinned by one rising demand scenario. (Source: Data for the other scenarios is from Newton and Falk (1997), Penner *et al.* (1999), and Vedantham and Oppenheimer (1994)). The Environmental Defence Fund (EDF) scenarios (designated E\*\*) have “high” growth assumptions (designated E\*h) and base growth assumptions (designated E\*b). The Forecasting and Economic Analysis Sub-group (FESG) scenarios are designated F\*\*, with variations in growth differentiated by “a,” “c,” or “e.”

international aviation, but as discussed, there is a large potential for domestic aviation within China, and other emerging economies with large land masses, to change this.

Taking a future perspective, Figure 6 presents examples from two generations of aviation emission scenarios alongside the historical CO<sub>2</sub> trajectory from Figure 1. Ten scenarios from the literature (Newton and Falk, 1997; Penner *et al.*, 1999; Vedantham and Oppenheimer, 1994) including a new suite from ICAO (ICAO, 2013b) are scaled to 1992. Out of the older ten scenarios, the three highest and one lowest growth scenarios were considered at the time to be implausible. Indeed over the time period since 1992, many of the older scenarios projected emissions significantly higher than has materialized. This is in part due to the events of September 11th 2001 and recent global economic downturn. It is unsurprising that scenarios influenced by industry perspectives tend to be optimistic about expected demand or lack incentives to develop low-growth scenarios.

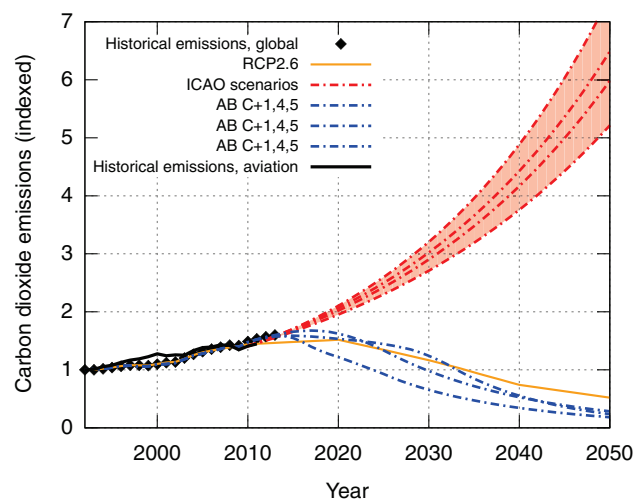
The set of scenarios considered in ICAO’s 2013 Environmental Report (ICAO, 2013b) in Figure 6 all use the same mid-range demand scenario with different assumptions about efficiency gains from technology and operations, resulting in a range of future CO<sub>2</sub> levels. There has not been sufficient analysis yet to include the potential CO<sub>2</sub> savings from alternative fuels out to 2050, although some assessment is made up to 2020 in ICAO’s 2013 report, where it is estimated that

approximately 3% of fuel consumed could be from “sustainable alternative” sources. ICAO scenarios’ average annual passenger demand growth of 4.9% is similar to the rate expected over the time period 2014–2033 by Boeing in its Market Outlook 2014. Of course, this and other assumptions can be called into question. Nevertheless, comparing the outlook with results from climate science allows for conclusions to be drawn.

The “ICAO” scenarios in Figure 6 all show a growing trajectory for aviation’s CO<sub>2</sub> emissions. This is in stark contrast to ICAO’s target of “carbon-neutral” growth from 2020 onward (ICAO, 2013b) and subsequent cutting of emissions in half by 2050. This demonstrates that a step change either in technological or in operational advancements is required, or the CO<sub>2</sub> reductions will need to be met by other sectors through emission trading. While reasonable to assume some sectors will cut emissions more rapidly than others and at different times over the coming decades, the aviation sector will too need to cut its CO<sub>2</sub> significantly during that timeframe, given the constraining 2 °C CO<sub>2</sub> budget. Furthermore, as emissions trading has so far failed to deliver emission reductions in line with 2 °C, and such a scheme is unlikely to be operational for aviation before 2020, pinning hope on trading to deliver on mitigation objectives is arguably misplaced (Bows-Larkin, 2014).

### 5.3 Contrasting the Outlook for Aviation with Avoiding 2 °C

The most recent future aviation scenarios taken from ICAO are contrasted with the global CO<sub>2</sub> scenarios compatible with avoiding 2 °C (Figure 7). In addition to the RCP2.6 scenario, which is already out of kilter with the current global CO<sub>2</sub> trajectory, (global CO<sub>2</sub> emissions are closer to a much higher climate impact scenario since 2000, RCP8.5 and Figure 5) three global scenarios from Anderson and Bows (2011) are overlaid to emphasize the scale of CO<sub>2</sub> reduction necessary across all sectors. These additional global pathways from Anderson and Bows (2011) are commensurate with a reasonable chance of avoiding 2 °C, but take into account a more explicit recognition of momentum within energy systems (for more information on their derivation see Anderson and Bows, 2011). All trajectories are indexed to 1992 = 1 to highlight how projected aviation emissions, under all scenarios, are at odds with the cross-sector 2 °C pathway. Comparing Figures 5 and 6, it is also notable that the absolute level of aviation emissions in 2050 is ~30–40% of total global CO<sub>2</sub> under the RCP2.6. However, these ICAO scenarios do not have a storyline consistent with RCP2.6 where strong mitigation is assumed across all sectors.



**Figure 7.** Four global CO<sub>2</sub> scenarios for all sectors (RCP2.6, AB C + 1 C + 4 and C + 5) and a suite of ICAO aviation CO<sub>2</sub> scenarios from ICAO, 2013b (red). (Note: All scenarios are indexed to 1992 = 1.)

Looking back to Bows (2010), where this gap was previously illustrated, it is clear that its conclusion “... without a large reduction in growth rate or significant penetration of alternative fuel by 2050, aviation projected CO<sub>2</sub> emissions will be incompatible with the 2 °C target” remains, albeit within a now more constrained 2 °C budget. There are few indications that any new technical or operational advances will start to make CO<sub>2</sub> cuts in real terms and across the world’s aircraft fleet that would negate the rise in CO<sub>2</sub> due to growth in activity. Many parts of the world continue to see very high rates of growth, which, without a significant acceleration toward overcoming technical and sustainability barriers around the use of biofuels for aircraft propulsion, will only serve to maintain the high and growing levels of CO<sub>2</sub> from air transport. While other sectors will too struggle to decarbonize in line with 2 °C, it will be necessary for all sectors to play their part. Unpopular as it is, and as long as emissions trading remains inconsistent with the 2 °C goal, there is a clear role in aviation for demand management.

## 6 CONCLUSION

The headline conclusion is clear and unequivocal; the aviation industry’s current projections of the sector’s growth are incompatible with the international community’s commitment to avoiding the 2 °C characterization of dangerous climate change. Even a highly optimistic uptake of the most promising technologies for reducing the CO<sub>2</sub> intensity of flying cannot deliver the rapid and deep rates of mitigation

illustrated in Figure 7 to comply with the IPCC's carbon budgets for a reasonable to likely chance of staying below 2 °C. This stark conclusion holds even with the heroic assumption that other sectors may be able to shoulder some additional mitigation effort to compensate for the aviation sector mitigating less than its counterparts. Ultimately, however construed, the maths forthcoming from the IPCC's 2 °C carbon budget, mandates that the demand for aviation will need to be constrained if the global community is not to renege on its 2 °C commitments.

In contrast to such demand management, market analysis highlights how many nations have rapidly growing aviation sectors, and that if China's domestic aviation broadly follows that of the United States, it will emerge as a strong driver of future CO<sub>2</sub> emissions. As it stands, there is a clear and significant risk that current expansion plans will extend the flying practices of today's frequent fliers both *within* wealthier nations, and *to* and *within* emerging economies. Such a prospect plays against the international community's commitments to mitigate emissions in line with 2 °C.

Juxtaposing existing scenarios and forecasts of aviation-related CO<sub>2</sub> emissions with global CO<sub>2</sub> scenarios for 2 °C illustrates a huge and widening gap between the two. At present, there are few signs that the sector, like most sectors, takes the 2 °C target and carbon budget framing of climate change seriously. While the industry has set out proposals for carbon neutral growth from 2020 and to reduce the sector's emissions by 50% by 2050, there is little evidence to demonstrate that this is at all feasible, even with emissions trading. Furthermore, the 50% reduction falls short of cuts commensurate with a reasonable chance of avoiding 2 °C, leaving the industry relying on other sectors curbing their emissions even more. It will be an enormous challenge for *all* sectors to reduce their own emissions in line with a reasonable to likely chance of avoiding 2 °C, so any assumption that sufficient sectors will be in a position to make much greater cuts than aviation misunderstands the scale of the mitigation challenge. Consequently, if the aviation sector is to reduce emissions in line with the 2 °C commitment, it must acknowledge the veracity of the climate challenge, and put in place the internal mechanisms to manage its own demand in accord with the necessary levels of mitigation.

With the publication of the IPCC's fifth report and explicit inclusion of carbon budgets associated with the 2 °C threshold, a clear framework within which to consider emissions from aviation now exists. Against this backdrop, the United Nations Environment Programme's Gap report (UNEP, 2014) draws attention to the high-level and widespread failure of the global community to constrain emissions in line with 2 °C. This failure is exemplified by ICAO predicting a significant and ongoing rise in emissions, while at the same

time continuing to emphasize the industry's commitment to a sustainable future.

Aviation, as is the case for virtually all sectors, has thus far failed to develop a scientifically credible emission pathway toward a 2 °C future. If such a pathway is not forthcoming in the next few years, it will be evident that the sector either rejects the international community's 2 °C commitment, or has judged itself too important to make its full contribution, relying instead on the untenable assumption that other sectors will compensate. The aviation industry cannot be isolated from the dialogue on climate change, and as a mature industry it is incumbent on it to be clear as to its position on 2 °C, carbon budgets, and the mitigation challenge.

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