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Are technology myths stalling aviation climate policy?

Abstract

Emissions from aviation will continue to increase in the future, in contradiction of global climate policy objectives. Yet, airlines and airline organizations suggest that aviation will become climatically sustainable. This paper investigates this paradox by reviewing fuel-efficiency gains since the 1960s in comparison to aviation growth, and by linking these results to technology discourses, based on a two-tiered approach tracing technology-focused discourses over 20 years (1994-2013). Findings indicate that a wide range of solutions to growing emissions from aviation have been presented by industry, hyped in global media, and subsequently vanished to be replaced by new technology discourses. Redundant discourses often linger in the public domain, where they continue to be associated with industry aspirations of 'sustainable aviation' and 'zero-emission flight'. The paper highlights and discusses a number of technology discourses that constitute 'technology myths', and the role these 'myths' may be playing in the enduring but flawed promise of sustainable aviation. We conclude that technology myths require policy-makers to interpret and take into account technical uncertainty, which may result in inaction that continues to delay much needed progress in climate policy for aviation.

Keywords: Aviation, climate change, discourse, technology, climate policy

1. Introduction

Aviation has experienced substantial growth over the last 40 years. Aviation industry data show there were about 3,700 aircraft in the global commercial fleet in 1970, and 9,100 by 1990 (Boeing 2014, Airbus 2014). By 2010, this number had again more than doubled to 21,000. Even greater has been growth in revenue passenger kilometres

(RPK), which increased nearly nine-fold between 1970-2010, from 500 billion RPK in 1970 to 4,500 billion in 2010 (Airbus 2014). By 2030, industry expectations are that there will be approximately 40,000 aircraft producing more than 10,000 billion RPK per annum (Boeing 2013). Continued growth after 2030 is expected: air travel will almost quadruple between 2005 and 2050, with an average worldwide growth rate of 3.5% per year, and energy use triple, accounting for 19% of all transport energy use in 2050, compared to 11% in 2006 (IEA 2009; see also Owens et al. 2010).

There is thus strong evidence that aviation's global energy use and associated emissions have consistently grown and will continue to grow. This is in sharp contrast to pledges by industry to reduce *absolute* emissions from aviation through technology (e.g. IBAC 2009; IATA 2014). Formal responsibility for emission reductions, however, was assigned to the International Civil Aviation Organization, under the 1997 Kyoto Protocol, some 20 years after interactions between exhaust fumes and atmosphere chemistry had first been established (Fabian 1974, 1978), and three years after aviation's impact on climate was first discussed in a comprehensive set of scientific proceedings (Schumann and Wurzel 1994). Article 2(2) of the Kyoto Protocol excludes international aviation bunker fuel emissions from the reduction commitments of Annex I Parties. Aviation emissions are instead to be pursued through ICAO, in recognition of the difficulty of assigning responsibility for international emissions through individual countries (Clarke and Chagas 2009). Emissions from domestic flights are included in national GHG inventories and are part of national emission reduction targets (Bows and Anderson 2007).

The EU had been increasingly critical of ICAO's role in mitigation (Clarke and Chagas 2009), and in 2005 commissioned a study to assess options to include aviation in the EU emission trading system (ETS) (Wit et al. 2005). Emissions from all flights from, to and within the European Economic Area (EEA) were initially to be included from 2012, with a cap of 97% of average annual emissions from 2004-2006, declining to 95% in subsequent years (European Parliament and Council 2009). However, due to resistance from in particular the US, China, and Russia (Euractiv 2014), until 2016 only emissions from flights within the EEA will fall under the EU ETS. In the meantime a global market-based mechanism addressing international aviation emissions is to be developed by

ICAO to be implemented by 2020 (European Commission 2014).

As a consequence, while global emissions from aviation continue to increase rapidly, no international policy will in the foreseeable future address this situation. The only approach to emission reductions, the EU ETS, is, as outlined, not functional, as it only includes aviation within the EEA: it is long-distance flights, however, that make up the majority of emissions (e.g. Peeters et al. 2007; Pels et al. 2014; Wood 2011). Moreover, the system does not consider non-CO_2 emissions, implying that the contribution of aviation to radiative forcing may actually increase through emission trading (Lee and Sausen 2000), which will result in cost increases too small to lead to significant behavioural change towards less flying (Jotzo 2010; Mayor and Tol 2009; Pentelow and Scott 2010, 2011). In contrast, communication by airlines and airline organisations proposes that emissions from aviation will continuously decline and 'zero emission flight' will be achieved in the future, as evident in industry 'roadmaps" towards climatically sustainable aviation (Figure 1; ATAG 2010).

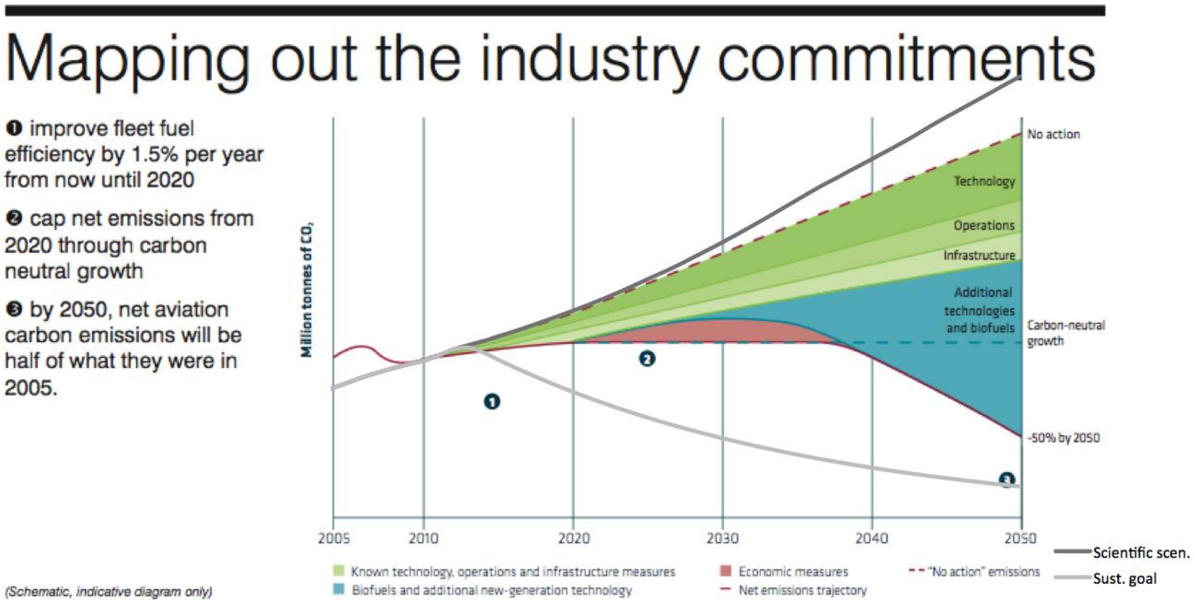

Figure 1: Industry's view on long-term emission reductions

Source: ATAG (2010); emission growth from Gössling and Peeters 2015; sustainable goal assuming 80% reduction by 2050 from 2015 levels.

As Figure 1 indicates, technology, air transport management (operations), infrastructure, as well as additional technologies and biofuels will ultimately result in absolute emission reductions – by 2050 (ATAG 2010). Notably, the strategy implies that emissions from aviation continue to grow, and ATAG (2010) anticipates only modest growth rates until about 2020 (lower than the peak in 2007), when 'economic measures' will add to the effect of technology, operations, infrastructure and additional (yet unknown) technologies and (yet non-existing) biofuels. Underlying the graph is a proposition that aviation will become increasingly efficient, and that in the long run, low-carbon fuels will replace fossil fuels.

Yet, the strategy, presented in 2010, already contradicts actual emission pathways (Figure 1, 'Scientific scenario' curve). By contrast, the sustainable emission pathway (Figure 1, 'Sustainability goal' curve) clearly illustrates that the ATAG scenario represents a watering down of the challenge for sustainable aviation. With regard to efficiency gains, airlines have indeed become more efficient (Peeters and Middel 2007), i.e. there has been a decline in fuel consumption per passenger kilometre (pkm) (Figure 2). Since the 1960s, fuel consumption per pkm has declined rapidly, by some 70% (notably, however, jet pistons have been far more efficient). In particular A380 and B787 have made contributions to efficiency improvements, with the A380 being somewhat less efficient than the B787. While further improvements in efficiency can be expected, it also appears clear from Figure 2 that year-on-year savings are likely to decline and it is questionable whether efficiency gains of 1.5% per year can be maintained up to 2020, or even to 2050, as envisaged by industry. Indeed, Peeters and Middel (2007) expect fuel efficiency gains to decline to <1% per year in the 2020s, a suggestion that would also be mirrored in comparisons of year-on-year fuel efficiency gains and observed absolute emission growth rates (Figure 3). As shown in Figure 3, growth in emissions has since the 1960s outpaced efficiency gains, a result of pkm volumes growing faster than efficiency gains.

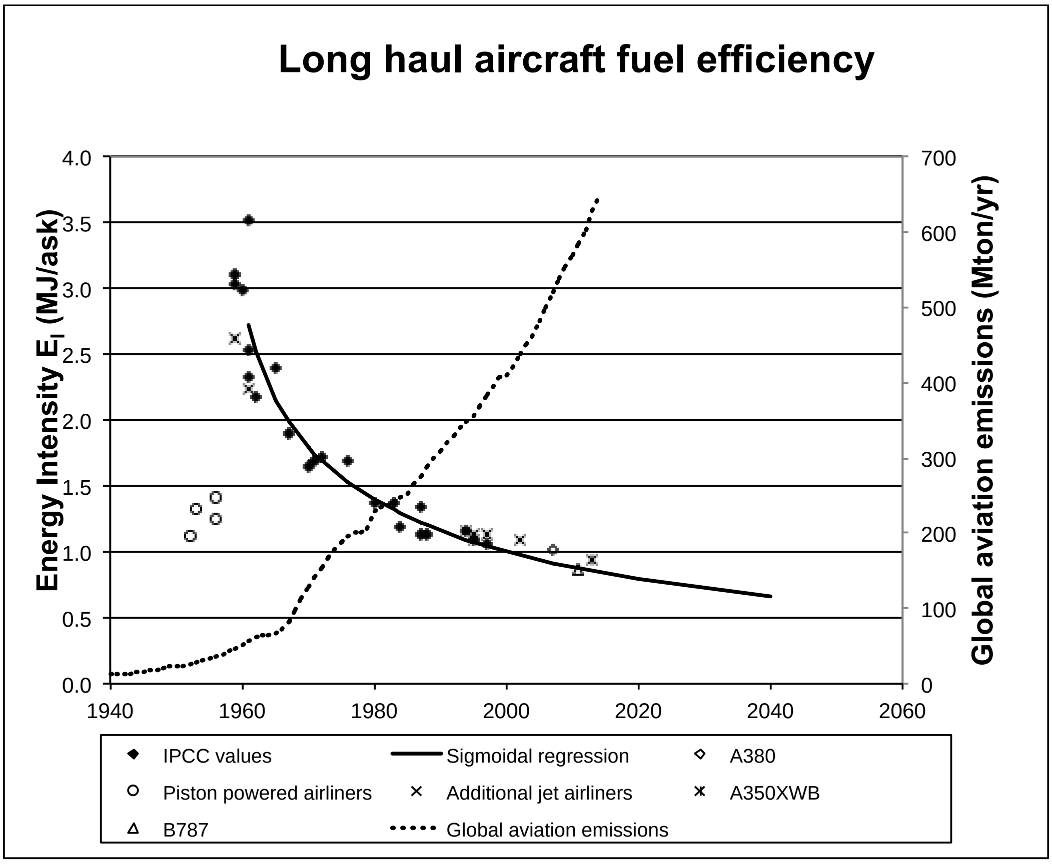

Figure 2: Energy efficiency gains and absolute emission growth
Source: based on Peeters and Middel 2007; Gössling and Peeters 2015

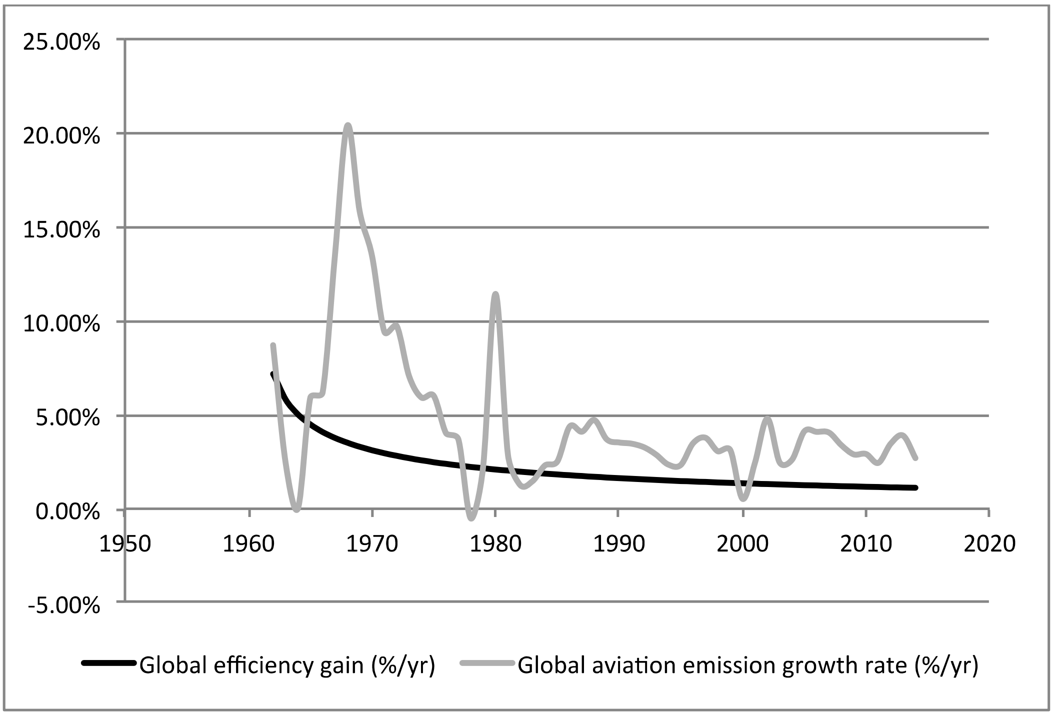

Figure 3: Annual efficiency gains (%/year reduction of energy consumption per pkm) and absolute emissions growth rate (%/year)
Source: based on Peeters and Middel 2007; Gössling and Peeters 2015

In light of this situation, this paper focuses on the discourses surrounding aviation technology and specifically 'zero emission flight', a concept proposed by Snyder (1998) nearly two decades ago. New technologies, such as hydrogen fuel, have been sought in an "effort to achieve carbon neutral growth on the path to a zero emission future in aviation" (Nolte, Apffelstaedt, and Gollnick 2012, p. 514), referring to aviation without impact on climate. As technological expectations have become increasingly hyperbolic in late industrial modernity, it is important to note that visions surrounding future technologies are not just important for mobilising engineers and scientists; they also play a central role in shaping market-based measures and infrastructure policy (Borup et al. 2006).

In this paper, such aviation technological discourses are framed as 'technology myths', with a 'myth' defined as an idea, story or narrative believed by many people, including decision makers, even though unfounded or false (Oxford English Dictionary, 2014). Myths may be uncritically held for various reasons (Heehs 1994; Wessels 2013), including in order to remain in denial of a given truth (*cf.* Stoll-Kleemann et al. 2001). Myths thus serve specific purposes and have real consequences, though in contrast to Sorel (1941), who originally discussed myths as mechanisms instigating action, this paper focuses on the role of technology myths in stalling progress in climate policy for aviation. As outlined by Gotesky (1952: 530), the function of a myth is to keep "…going against defeat, frustration, disappointment; and … [to] preserve institutions and institutional process." Notably, according to Gotesky (1952), myths are accepted even though (or because) they are beyond empirical testing given their social utility.

Conceptions of myths in transport studies were first introduced by Essebo and Baeten (2012), who discuss notions of sustainable mobility as myths that incorporate two contradictory beliefs, i.e. that quantitative growth in mobility can be integrated with environmental conservation. Essebo and Baeten (2012: 555) consequently note a contradiction between rising emissions from transport in spite of technological innovation, concluding that "…myths create internal logics that help relieve anxiety [and] rationalise behaviour…". Importantly, they note that fear is an element of myths; invoking an understanding that "straying from the staked path" (ibid: 560) has consequences, not unlike the 'transport taboos' described by Gössling and Cohen

(2014). Myths, in this interpretation, represent order, while transcending the myth of sustainable aviation would imply disorder, i.e. the threat of restrictions on air travel.

2. Method

To identify technology-based solutions to greenhouse gas emissions in aviation, a two-tiered methodology was developed, consisting, first, of an iterative expert-based (Delphi) process (cf. Delbecq et al. 1975), in which the authors reflected on past and present technical 'solutions' suggested by aircraft manufacturers, airlines, and airline organizations to address climate change. This brainstorming resulted in a list of 20 items: generic solutions, such as 'biofuels', were excluded from the list, while individual biofuels based on for instance Jatropha, Camelina, or algae were included. This Delphi-process appeared to be the best approach in the absence of an objective model or other appropriate overviews on technology solutions in aviation, even though the key literature was also considered (e.g. Bowles 2010; Bruner et al. 2010; Green 2003a; Nolte et al. 2012). All technologies were also required to be a suggested solution within the period 1994-2013 for mitigating aviation's GHG emissions, i.e. beginning in the year when the first comprehensive proceedings on aviation's climate-related impacts were published (Schumann and Wurzel 1994), and covering 20 years to the last full calendar year (2013). It should be noted, however, that several of the technologies, such as hydrogen, propfan/open rotor and laminar flow have a much longer history in relation to, for instance, oil crises.

The 20 items identified were then each entered into Google Analytics to test their relative importance in terms of mentions on the Internet over time. The results indicated a relative dominance of fewer items, reducing the total to eleven items that were organised into three categories (Table 1).

Table 1: Aviation technology categories and items derived from Google Analytics (1994-2013)

Category	*Item*
Airframe	Laminar flow
	Composite aircraft
	Blended wing body
Engine	Solar flight
	Electric flight
	Open rotor or Propfan
Alternative fuels	Jatropha
	Animals fats
	Hydrogen
	Algae
	Camelina

The second tier of the methodology was the selection of daily print media, from which people derive most news (Boykoff and Boykoff 2007), to analyse public discourses. Several trial keyword searches were conducted on selected large newspapers, including The Daily Mail (UK), The Guardian (UK), the New York Times (US), the Washington Post (US), and the China Daily. As these searches yielded only between one and eleven news items, a database covering a variety of global newspaper publications was instead used. First, two of the items (Jatropha and Propfan) were entered into two different newspaper databases, ProQuest News & Newspapers (ProQuest.com) and Factiva (Factiva.com) to establish the functionality of the database and comparability of the search results. While the results appeared comparable within the timeframe under study, Factiva was chosen as the final database due to its data export functionality. Factiva claims to be one of the leading global providers of economic and financial information and offers access to a wide variety of global newspaper publications, such as The New York Times, The Washington Post, The Financial Times, and The Guardian, going back to 1980 (Factiva 2014).

Developing their own iterative search process using Factiva, the authors conducted keyword searches of the 11 items, including some commonly used alternative terms, and with a focus on English news items only. Alternative search terms included the keywords “solar aircraft/airplane”, “electric aircraft/airplane”, “novel aircraft configurations”, “wing-tube aircraft”, “animal fats”, “laminar aircraft/wing”, and “carbon fibre aircraft”. In addition, keyword searches were conducted based on a crossword search with aviation-related search terms, including “aviation”, “airplane”, “aeroplane”, “airline”, “Boeing” or “jet fuel”, to ensure the relevance of the results to the aviation sector. Additional search parameters in Factiva were set to the source category ‘Newspapers: All’, to include keyword hits anywhere in the text, to include all authors, companies, subjects, industries and regions, and to report duplicate publications (publications of the same article in a different outlet) separately from the total article count. At a minimum eight different keyword searches were conducted per technology with at least double the amount for technologies with commonly used alternative terms. The majority of the keyword search results were below 100 articles, however, for searches yielding over 200 news items, downloads of full text articles were limited to the first 200 most relevant articles. Full text articles were checked with regard to the correctness of the interconnection between the keywords. In some cases, such as “solar flight”, searches were repeated using operators to exclude certain keywords from the search to ensure only ‘relevant’ articles were included in the final results. Once the search results were finalized the total number of all articles under review was 1,532.

For technologies that are not inherently linked to aviation, such as biofuels derived from animal fats or hydrogen, which are commonly used in many different types of related industry sectors, additional operators were included to ‘focus’ the results on those associated with the aviation sector. For instance, for “animal fats”, the search term “biofuel” was included. After extensive searches and analyses two items, propfan/open rotor and Camelina fuel, were excluded from our analysis. Propfan/open rotor was mentioned at a rate of only 1-2 news items per year, with a number of media mentions lacking reference to it as a new engine type. Camelina closely paralleled the Jatropha biofuel discourse and was therefore removed from the analysis.

Upon the removal of propfan/open rotor and Camelina fuel, nine key technologies and the associated 1,294 articles were selected for further analysis. Of the 1,294 articles, 965 articles were downloaded in PDF format for qualitative analysis and in accordance with the cut-off at the first 200 for items with over 200 results. Finally, 20 newspaper articles were randomly selected from among the results of each aviation technology (including every 10th article[1]), which were, as outlined, sorted by relevance and based on the number of results obtained. The resulting 180 randomly selected articles were qualitatively reviewed for content relating to the emergence, peaking and decline of the technologies, with the results coded thematically using NVivo 10 (QSR International, 2012).

The focus of our analysis fell upon daily print media to analyse public discourses relating to sustainable aviation technology solutions, and how successive discourses have evolved over time. A limitation of our work relates to the link between press agencies and organisations, media reporting and the response of policy makers. Our research did not extend to exploring the relationship between agency releases, media reporting and policy action. Such relationships are too complex to address across a broad twenty-year period of media reporting (1994-2013), and across spatial ranges (national/global) that vary greatly in terms of press agency uptake and influence.

3. Technology for sustainable aviation

Keyword searches in Factiva ultimately yielded 9 technologies, related to the three categories, i.e. airframe (A), engine (E) and fuel (F). Table 2 summarizes the results by category for each technology through graphics on the number of news items over time, notes on levels of media interest, and key industry sources supporting the technology as a potential solution for aviation emissions. Each of the technologies in these categories is discussed in the following sections, including both the quantitative and qualitative content analyses of the daily print media.

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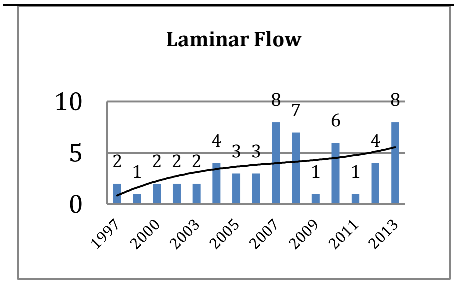
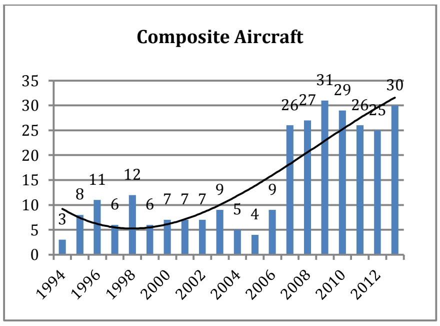
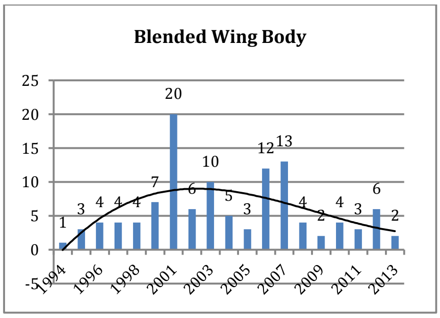
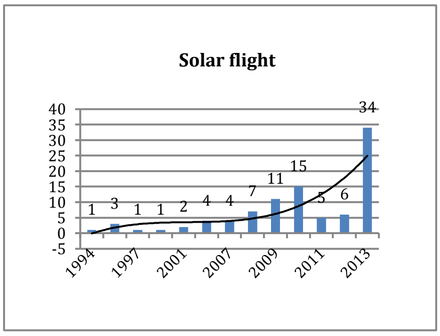
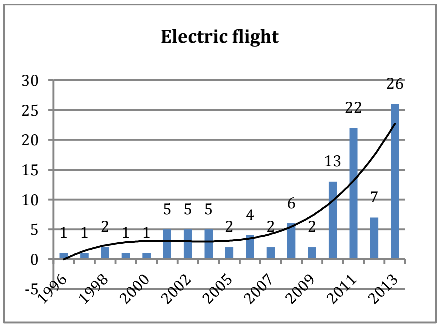
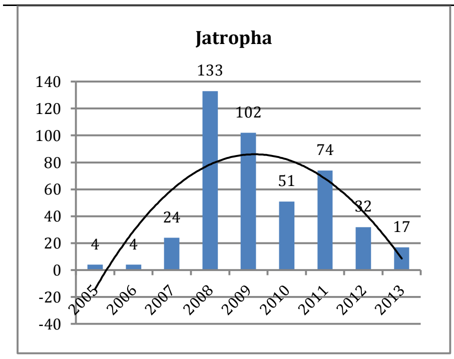
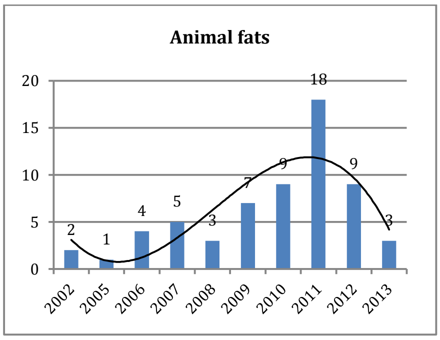
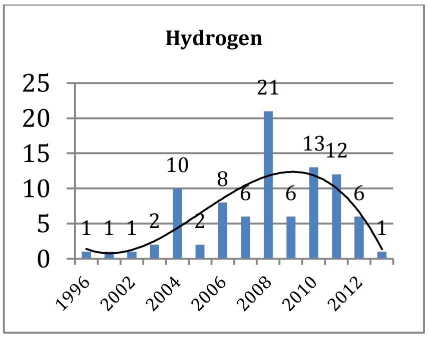
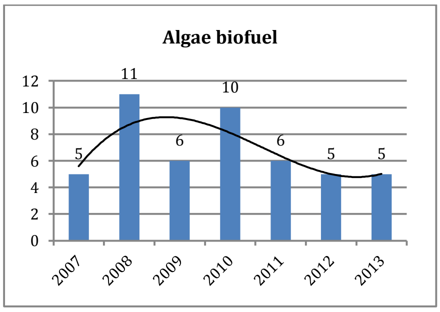
[1] Where article results were below 200, this number was adjusted to ensure random selection of 20 articles.

Table 2: Overview of technologies by category and relative interest

Graphics	*Stats*	*Category **	*Supporting industry sources*
	Total: 54 Low interest Emerging	A	(Airbus, 2011; Committee on Climate Change, 2009; FAA Office of Environment and Energy, 2005; IATA, 2009a, 2011, 2012; ICAO, 2014; Sustainable Aviation, 2008)
	Total: 288 High interest Emerging	A	(Airbus, 2007; IATA, 2009a, 2011; ICAO, 2007, 2014)
	Total: 113 Medium interest Abandoned	A	(IATA, 2009a, 2011, 2012; UNWTO & ICAO, 2007)
	Total: 94 Low interest Emerging	E	Negative: (Airbus, 2011; ATAG, 2011a) Positive: (ICAO, 2014)
	Total: 105 Medium interest Emerging	E	(ICAO, 2014; Snyder, 1998; Snyder et al., 2009)

Graphics	*Stats*	*Category **	*Supporting industry sources*
	Total: 441 High interest Abandoned	F	(Airbus, 2011; ATAG, 2010, 2011a, 2011b; Boeing, 2012; IATA, 2009a, 2009b; ICAO, 2009; WTTC, 2009)
	Total: 61 Low interest Abandoned	F	(ICAO, 2007, 2014)
	Total: 90 Low interest Abandoned	F	(ATAG, 2011a, 2011b)
	Total: 48 Low interest Ongoing	F	(Airbus, 2011; ATAG, 2010, 2011a, 2011b; IATA, 2005, 2009a, 2012; ICAO, 2007, 2009, 2014; WTTC, 2009)

* A=Airframe, E=engine, F=fuel

3.1 Airframe

Laminar flow

This technology was first mentioned in 1997 and was discussed just 54 times in the media search, indicating low media interest despite being frequently referred to by industry (Airbus, 2011; Committee on Climate Change, 2009; FAA Office of Environment and Energy, 2005; IATA, 2009a, 2011, 2012; Sustainable Aviation, 2008). Laminar flow addresses the fact that when a body moves through the air, a 'boundary layer' will develop on the body's skin where the air speeds transits from the body's speed to zero. Under ideal conditions this boundary layer is laminar, reducing drag forces (Abbott & von Doenhoff 1959; Hoerner 1965). Application of laminar flow goes back to the 1950s in sailplanes and gliders (Raspet, 1951) and has been gradually applied to commercial airliners in different contexts (e.g., supersonic laminar flow technology) over time (Atkin, 2008).

Despite relatively little media interest in laminar flow, a spike in interest occurred in 2008-2009. Improved aerodynamics through 'active' laminar flow techniques involves "…peppering wings with thousands of tiny holes", which suck turbulent air creating a laminar flow, and [t]ests have found efficiency gains of 20% or more, though durability remains an unresolved issue" (*The Edmonton Journal*, 12/08/2007). The critical challenge for natural laminar flow is to design wings "…whose shape maintains laminar flow from front to back" (*The New Zealand Herald*, 16/03/2011).

Media references to laminar flow tend to focus on supersonic air travel and less on subsonic flight where emissions reduction is currently most important. An exception is the Boeing 777X which, at the 2013 Dubai Air Show, was profiled as "…equipped with a larger, fourth-generation composite wing and a new advanced GE engine with Laminar Flow Nacelles" (*The Khaleej Times*, 15/11/2013). These combined technologies were expected "…to cut fuel burn by around 20 per cent, making it the most economical aircraft in the world" (ibid). Laminar flow is a technology that has been and will be applied in current and future generation airliners, but offering marginal fuel efficiency gains.

Composite aircraft

Composites are composed of high strength fibres bonded together in a mass of resin. Composites offer the advantages of lighter weight structures and better ability to reach the ideal aerodynamic form. It is not a new technology, with reference in aircraft design handbooks in the 1970s (e.g. Corning, 1976), however it has received steadily increasing media attention since 2007, much associated with the Boeing 787 Dreamliner. Media search on composite aircraft yielded 288 articles published in the period 1994-2013; this technology has been received with great anticipation. The B787 was described as a "revolutionary carbon-composite aircraft" (*The Independent*, 24/6/2009). *The Daily Telegraph* described new carbon composite aircraft as "a 'game changer' for the aviation industry" and "the greatest aviation advance since the passenger airline jet age began in the early 1950s" (17/11/2011). Airlines were quick to place orders for the "…new generation of lighter weight, composite aircraft such as the A350 or B787" (*The South China Morning*, 2/12/2005).

Media reference to the potential advantages of composite aircraft has focussed overwhelmingly on the financial performance of airlines rather than emissions mitigation. Regarding a Jetstar fleet upgrade, *The Australian* (2/3/2012) referred to the "…composite aircraft's much touted 20% boost to fuel efficiency", but only in relation to a projected "…10 to 15% boost to the airline's bottom line". When Qantas received new carbon-composite aircraft in 2011 it was announced as keeping "…airfares affordable in coming decades by curbing the worst of fuel price spikes" due to …"cheaper cost per kilometre" (*Daily Telegraph*, 17/11/2011).

Post-war metal fuselage airliners are being steadily succeeded by new generation composite aircraft, which provide weight advantages that should be considered evolutionary rather than revolutionary (Airbus, 2007; IATA, 2009a, 2011; ICAO, 2007). The contribution of carbon-composite aircraft to fuel savings however is relatively small: on average an empty weight reduction of 5% can be expected where composites replace conventional aluminium structures (Raymer 2012). The A350 and B787 have over 50% composites (ICAO, 2014); Raymer et al. (2011) calculate that replacing half an aircraft's structure with composites may save 1-4% of fuel, i.e. considerably less than communicated in the media. Like laminar flow, composite can be viewed as a technology that will gradually enhance fuel efficiency, but at a slow pace.

Blended wing body

The idea of blended wing body (BWB) dates back to at least the 1960s, and is a flying wing big enough to contain the cargo holds and passenger cabin; it forms an alternative for the current standard wing-tube aircraft configuration (Green, 2003). A study by Boeing revealed BWB could reduce fuel consumption by 27% compared to a similar technology-level conventional design (Liebeck, 2004). It was reported that "[t]he blended wing aircraft could carry twice as many passengers as the Boeing 747 jumbo jet but is said to use 30 per cent less fuel than the proposed next generation of 550-1,000-seat super jumbos" (*The Independent*, 25/1/1997). By 2001 claims emerged that Boeing was "…developing an 800-seat plane in which passengers will travel on two decks inside a giant wing… If all goes well (with test flights) a BWB could be ready to carry passengers by 2010" (*Sunday Mail*, Queensland, 11/2/ 2001).

This discourse was perpetuated in 2003 when it was stated that BWB provides more lift, offering greater range and fuel economy than tube and wing designs. "We see blended wing as the wave of the future…" (*Daily News*, 17/11 2003). BWB was described as "the shape of things to come" (*The Independent*, 30/11/2006), noting that in order to achieve fuel efficiency gains "planes are going to have to look very different in the future". *The Los Angeles Daily News* (30/7/2007) remained upbeat when it quoted Bob Liebeck (BWB programme manager for Boeing Phantom Works) that "we've successfully passed another milestone in our work to explore and validate the structural, aerodynamic and operational efficiencies of the BWB concept", and that the "BWB concept holds tremendous promise for the future…".

Despite these media claims, a year previously *The New Zealand Herald* reported that "Boeing once toyed with a blended wing-body… but tests with a mock-up produced such a negative reaction that the company dropped the technology" (12/6/2006). Indeed a decade earlier, in an article titled *'Airbus shies away from flying giant wing'* an Airbus spokesperson was quoted to have said the BWB "…has significant drawbacks. The problems associated with it are huge. How would you pressurise a vessel of that size…

There is also the difficulty of controlling the aircraft… because the design is aerodynamically unstable" (*The Independent*, 251/1997). It appears the BWB, though theoretically more fuel efficient, suffers practical problems making its design look improbable.

3.2 Engine

Solar flight

This technology was referred to 94 times, with little interest in solar flights expressed in media discourses prior to 2013, when *The New York Times* (2/5/2013) reported the intentions of Solar Impulse to "…be the first sun-powered plane to fly; its chief distinction is its ability to go through the night". The Solar Pulse project "…received the official patronage of the European Commission, which sees in it an example of what industry and energy policy makers should be doing to foster energy efficiency and clean mobility" (*The Wall Street Journal*, 29/5/2008). Solar Pulse made history in July 2010 as the first manned plane to fly around the clock and through the night on the sun's energy (*The Financial Express*, 15/5/2011). The goal of the Solar Pulse project was not speed, (traveling just 43mph), but rather "…to showcase that the trip can be made at all without the use of fuel" (*Pittsburgh Post-Gazette*, 4/5/2013).

In terms of energy efficiency, Solar Impulse "…has a wingspan matching that of a Boeing 747 but the weight of a midsize car…including the special batteries used to store solar energy" (*The New York Times*, 2/5/2013). It was thus claimed that Solar Pulse "…could revolutionise air travel" (*The Sunday Times*, 4/11/2007), and would "…provide an exponential boost for interest in renewable energy and clean technologies" (*The Bay of Plenty Times*, 6/5/2013). Interest in solar flight is perhaps directed more towards becoming "…a cheap alternative to space satellites" (*The Observer,* 29/6/2003), and "…the long-desired 'eternal airplane' that seldom has to land" (*The New York Times,* 12/1/1999). The creators of Solar Impulse have frankly acknowledged, however, that "…solar planes will never replace fuel-powered commercial flights" (*Pittsburgh Post-Gazette*, 4/5/2013). Flying directly on solar energy, i.e. with solar cells on wings, with a significant payload and at a significant speed, is therefore physically impossible (Noth, 2008).

Electric flight

Media research revealed growing recent interest in this technology over the last four years (with 105 news items since 1994). Most notably *The Australian* (2/11/2012) reported ‘revolutionary aircraft technologies’ make it possible that a “…zero-emission electric aircraft could be flying by 2035”. This promise is derived from claims that “…lithium batteries will go from 200 watt hours per kilogram energy density delivered by today's mobile phones to 1500W and 2000W hours per kilogram in two decades”, allowing “zero emissions from gate to gate”. An electric aircraft design could reportedly fly almost 900 nautical miles and transport 190 passengers, capturing 79% of flight traffic (increasing to 95% at 1400nm) by the target entry into service date of 2035 (ibid).

The rhetoric associated with electric flight is attention grabbing. *The Australian* alludes to the “… dramatic leap into zero emissions” (2/11/2012). *The Times* (5/7/2012) refers to “a revolution in our skies”, describing the technology as an “unmissable opportunity”. Coining it the “e-flight”, *The Times* noted “…electricity is not only a viable but, in fact, a beautiful way of powering airplanes. We’re at the point where personal air travel is becoming both affordable and truly green." While it is commonly discussed in relation to “personal air vehicles” (*The Press Democrat*, 28/9/2011), electric flight is “…also intended for later use in large-scale aircraft, cutting fuel consumption and emissions by 25% compared with today's most efficient aircraft drives (*The Hindu Business Line*, 21/6/2011). However, there is also evidence of tempered realism in these discourses. *The Times* (5/7/2012) reported “…the dirty little secret with batteries that are appropriate for medium-to-high-performance electric vehicles is that there has been no real measurable improvement since about 2009”.

A feasibility study into hydrogen fuelled aircraft, using fuel cells for conversion to electricity, observed that developing electronic flight through the combination of several major new technologies is not without significant challenges (Peeters, 2000; Snyder et al., 2009). These include development road blocks such as the need for a completely new fuel infrastructure at airports. Pure electric battery-fuelled flights would furthermore require significant future improvements in the performance of the low energy density of batteries. Lithium batteries presently have an energy density of only 1% of kerosene (Kivits, Charles, & Ryan, 2010). The low energy density of batteries means that purely electric flight is not practically possible.

3.3 Alternative fuels

Jatropha

Jatropha is a crop with the ability to grow on very poor soils and thus does not compete much with food production (Rosillo-Calle, Thrän, Seiffert, & Teelucksingh, 2012). Media interest in this technology was high in 2008-2009, declining steadily in subsequent years. In 2008, Air New Zealand "had successfully test-flown a Boeing 747 using a 50-50 blend of Jatropha and aviation fuel" (*The Wall Street Journal,* 9/3/2009). Later that year a quote attributed to Air New Zealand that confuses relative and absolute efficiency gains, claimed that:

> …a 50% blend of biofuels and traditional fuel would increase fuel efficiency by 1 percent. That might not sound like much, but that would save 1.4 metric tons of fuel on a 12-hour flight. The environmental benefits are even greater, with a reduction in carbon dioxide emissions of about 4.5 metric tons for the same flight (*The Spokesman Review*, 2/6/2009).

Numerous other international airlines were reported at the time to be exploring Jatropha biofuel solutions. *The Wall Street Journal* (9/3/2009) observed that fuels based purely on plant oils "performed well in test flights by airlines and jet-engine makers … ", quoting Honeywell International Inc., which refined the fuel for the Air New Zealand test flight as well as for Continental Airlines and Japan Airlines flights. "When burned, the oils produce less soot and particulate matter than regular jet fuel (and) cultivating and refining the oilseeds produces 50% less greenhouse-gas emissions than regular jet-fuel production" (ibid).

Referred to 441 times in a period of just 8 years, Jatropha was a pillar of sustainable aviation discourses, mentioned in many industry reports on climate change (Airbus, 2011; ATAG, 2010, 2011a, 2011b; Boeing, 2012; IATA, 2009a, 2009b; ICAO, 2009; WTTC, 2009). This is despite its high associated water use (Rosillo-Calle et al., 2012) and evidence that its lifecycle GHG emissions are higher than for kerosene from crude oil (ICAO, 2009). Jatropha has been widely taken up in the media and is still mentioned by industry (ICAO 2014), but seems to offer little prospect for climate change mitigation, particularly when set in the context of high current and future growth in aviation.

Animal fats

Animal fats were referred to in 61 media articles, with a short peak in interest in 2011. *The Austin American Statesman* reported (21/8/2009) that "[a] company called Dynamic Fuels is building a $138 million factory in Louisiana that will turn animal fat into high-grade synthetic diesel and potentially even jet fuel", further claiming that "[t]his is the cleanest fuel on the planet". In 2011 *The Business Standard* (1/7/11) stated that "KLM Royal Dutch became the first airline in the world to operate a commercial flight, carrying 171 passengers, on bio-kerosene produced from used cooking fuel oil". It was claimed in the US that "[h]istorians may look back at this week, when passenger jets in the United States first made regular flights with fuels made from algae and French fry grease, both as the beginning of a new era in aviation" (The Origonian, 10/11/2011).

That same year IATA was reported to have estimated that "… replacing 3 percent of the kerosene in jet fuel would reduce aviation CO_2 emissions by over 10 million tons, at an initial cost of $10 to $15 billion in production and distribution facilities" (*The International Herald Tribune*, 26/10/2011). While animal fats are suggested as biofuel feedstock wastes that do not compete with food production (Hileman et al. 2009), a critical barrier arises from the fact that bio-kerosene produced from animal fats has far too high a freezing point (Vera-Morales & Schäfer 2009). Therefore it is used in blends of up to a maximum of 20% (Hileman et al. 2009). Overall, the public discourse of animal fats was short-lived.

Hydrogen

Hydrogen was referred to in 90 articles, peaking in 2008 and again in 2010-2011. While dating back to 1994, in 2007 Airbus formally announced it was exploring hydrogen as an alternative fuel, along with nuclear fusion and possibly superconductivity (*The Australian Financial Review*, 26/10/2007), with a particular interest in developing fuel cell technology, which "…transforms the energy in hydrogen and oxygen into electricity at low temperatures without moving parts, is cleaner and more efficient than combustion engines and the waste product is water". Airbus believed at that time that the technology would achieve "…the target of a 50 percent reduction in aircraft emissions and noise in nine years' time" (ibid). In the same year Boeing "…claimed a first with the flight of a two-seat Diamond motor glider fitted with a hydrogen-powered fuel cell and lithium-ion batteries" (ibid).

Although Airbus vowed to "…replace kerosene with hydrogen by 2020" (*The Independent*, 17/11/2011), hydrogen may suffer from public perceptions influenced by iconic images of the fatal Hindenburg inferno 70 years ago. Indeed in 2011 *The Independent* (17/11/2011) reported that "…hydrogen has been ditched again by the flight industry" and "…the promised 'green' fuel for powering flights of the future has been quietly shelved in favour of biofuels and more fuel-sipping aviation... In principle, it is possible to fly with hydrogen… but now we cannot produce enough hydrogen in an environmentally friendly manner for aviation". This discourse of media scepticism dates to 2008 when *The Toronto Star* (15/8/2008) reported that "[t]he alternatives for aviation are more limited than the options for ground transportation. Most engineers will tell you that using hydrogen or electricity to power a passenger jet just isn't realistic, at least not for decades". Furthermore, Boeing stated earlier that year that it "…didn't believe hydrogen, which contains about a quarter of the energy as kerosene-based jet fuel, could be the primary source for large aircraft" (ibid).

The idea of hydrogen as an alternative fuel has been in discussion for a long time (Brewer 1991), and is still referred to in the media. A key barrier to the use of hydrogen includes storage: Kerosene is easily stored in the wings, but hydrogen would occupy a substantial part of the fuselage, reducing the payload capacity of aircraft (ibid). Another barrier is that large investment in a new fuel distribution system at airports would be required. Despite media interest in hydrogen that was particularly apparent in 2008, perceptual, economic and technical barriers remain.

Algae

Media search for algae biofuel returned only 48 items, centred on optimistic reporting in 2008 accompanied by increasing realism in 2010. In 2007 Air New Zealand and Boeing collaborated to "…create the world's first environmentally friendly aviation fuel, made of wild algae" (*The Independent Financial Review*, 18/7/2007). At that time Boeing stated publicly "…that it believes algae is the airline fuel of the future" and that "…algae ponds totalling 34,000 square kilometres could produce enough fuel to reduce the net CO_2 footprint for all of aviation to zero" (ibid).

Forecasts published in 2008 noted that "…by 2030, algae-based biofuels could replace fossil-derived fuels usage to the equivalent of 12% of the world's annual jet fuel consumption - cutting more than 160 million tonnes of CO_2 yearly" (*The Evening Herald*, 27/10/2008). Media interest in algae biofuel was particularly apparent in the US:

> Algae are fast-growing, consume CO_2 and have the potential to produce more oil per acre than other biofuels. The oils they produce can be used to make substitutes for diesel fuel, aviation fuel and gasoline. Backers say the U.S. could meet its entire liquid-fuel needs with algal biofuels (*The Wall Street Journal*, 22/2/2010).

The following year *The Portland Press Herald* (14/6/2011) described the US algae biofuel industry as being "…on the cusp of economic feasibility" given increasing "…investment in biodiesel by oil companies, airlines and the US government".

These discourses have been accompanied by less optimistic forecasts. *The National Post* (16/6/2007) suggested "[a] 10% mix of biofuels with jet fuel would be a more likely scenario in the near future" and that "just to meet the 10% goal for the U.S. airline industry for one year, a land mass the size of Florida would be required". Indeed "…as promising as the technology is, it hasn't proved that it can produce fuels in sufficient quantities or at a low enough cost to make a dent in US liquid-fuel consumption" (*The*

Wall Street Journal, 22/2/2010). More recently the "…economic viability of such biofuels of algae has been questioned", with predictions that algae biofuels will "…only be viable when oil hits $800 a barrel" (*The Washington Post*, 28/2/2012).

Despite modest media uptake, microalgae are often mentioned in industry reports as an alternative fuel for crude oil-based kerosene (Airbus 2011; ATAG 2010; 2011a; 2011b; IATA 2005; 2009a; 2012; ICAO 2007; 2009; WTTC 2009). Microalgae are considered to have several advantages over other feedstocks, such as the ability to live on marginal grounds (but in artificial or natural water-basins), efficiently convert sunlight to oil, grow year-round and produce many high value by-products (Hu et al. 2008). But there are also barriers: land-use (Skarka 2012) and water use, low or negative lifecycle carbon emission reductions (Quinn & Davis 2014), cost and alternative use (Coplin 2012). The prospects of algae as a feedstock to produce biofuels consequently remain unclear.

4. Discussion and conclusion

This analysis has shown that there exists a wide range of discourses with regard to the potential of technology to make significant contributions to climate change mitigation in aviation. Analysis with regard to airframes, engines and fuels reveals, however, that many of the proposed solutions emerge and are hyped in the media, only to subsequently disappear again from public discourse. This was shown on the basis of a media analysis, which provided evidence that all fuel solutions (hydrogen, animal fats, Jatropha and algae) had already 'peaked' in terms of media attention, and, except for algae, been abandoned as feasible solutions. Hydrogen, Jatropha and algae each saw a spike in interest in 2008, i.e. the year after the fourth assessment report of the IPCC (2007) had been released, drawing worldwide attention to the need to engage in mitigation and increasing pressure on the aviation industry to act on climate change. With regard to the remaining discourses, results suggest that blended wing body has also been abandoned as a solution, while solar and electric flight (engine), and laminar flow and composite aircraft (airframes) represent emerging discourses in the public domain, despite the increasing application of laminar flow and composites, and research on solar and electric flight, since the 1970s. Notably, the notion of commercial solar flight is rejected by Airbus and ATAG, but considered a feasible innovation by ICAO (Table 2).

Given these findings, this paper concludes that most of the 'solutions' that have been presented over the past 20 years constitute technology myths. Specifically, it is possible to distinguish three types of myths, i.e. i) myths that refer to abandoned technologies once seen as promising; ii) myths that refer to emerging technology discourses, though generally overstating the realistic potential offered by these technologies (and some of these potentially representing dead ends as well); and iii) myths that refer to solutions that are impossible for physical reasons; this latter type of myth exemplified by the notion of solar flight. Results also indicate that there are always various technology discourses co-existing, i.e. even in a situation where a discourse is abandoned, various other 'solutions' remain available. This is likely to have repercussions for governance.

Policymakers are increasingly confronted with technological promises that require them to make decisions based on interpreting technical uncertainties (Borup et al. 2006). As shown in Figure 1, industry has created a vision of climate mitigation in aviation that incorporates various elements of non-accountability, as the solution is built on a range of strategies; foresees continued growth in emissions for another two decades; and will consequently contribute to mitigation only in the long-term future. As such, the roadmap to mitigation is difficult to question, because continued emission growth is an anticipated development, while the effectiveness of the various strategies to contribute to absolute emission reductions cannot be presently judged and evaluated. Multiple technologies providing partial solutions make it difficult to monitor progress. Furthermore, this vision of sustainable aviation is embedded in notions of progress towards sustainability goals, i.e. presenting aviation as an energetically efficient transport mode and a marginal source of emissions in global comparison (Gössling and Peeters 2007), which obscures continued absolute growth in greenhouse gas emissions with relative (annual) efficiency gains. Under these prevailing conditions an understanding of aviation as a sector soon-to-become-sustainable has been, and continues to be, successfully perpetuated. Ultimately, this would constitute a form of propaganda in which emotional responses to aviation, for instance framed as the sector's social and economic benefits, are fuelled by pseudo-rational information –

myths – to generate a widely held understanding of, and continuing faith in a looming future of sustainable aviation, and, ultimately, "zero emission flight" (Snyder, 1998).

This situation has implications for climate policy, because aviation as a transnational activity is difficult to govern politically. In this situation, politicians may embrace myths to justify non-action beyond efficiency improvements achieved through technology. For instance, UK Energy Secretary Ed Davey suggested that "If you look at the future of flight it is possible to imagine, with technological innovation, that we will have zero-carbon flight in the future" (Guardian, 7/10/2014). This view may reflect a genuine belief in technology myths, or represent a convenient way to avoid upsetting the established 'order' (Gössling and Cohen 2014), i.e. to initiate legislation aimed at the reducing growth in the volume of air transport itself and replacing it with other transport modes or alternative travel patterns (Peeters and Dubois, 2010). Such policy measures would likely to lead to resistance from lobby groups, industry, the public, and political opposition. Indeed this line of research might be carried forward in a comparative analysis to identify the relationships, including lag effects, between the media and policy-makers (and others such as lobby groups and industry). While our research did not investigate the relationship between agency releases, media reporting and policy action, research that is theoretically grounded in agenda setting and applied in a defined socio-political and temporal context would provide valuable insights into the agency-media-policy nexus. In the meantime, in this paper we conclude that aviation technology myths must be recognised, confronted and overcome as a critical step in the pathway to sustainable aviation climate policy.

References

Abbott, I. H., & von Doenhoff, A. E. (1959). *Theory of wingsections; Including a summary of airfoil data* (Dover edition ed.). New York: Dover Publications, Inc.

Airbus (2014). *Global Market Forecast for 2014-2033.* Available at: http://www.airbus.com/company/market/forecast/ Accessed 10 November 2014.

Airbus. (2007). *Flying by nature. Global market forecast 2007-2026*. Paris: Airbus S.A.S.

Airbus. (2011). *Delivering the future. Global market forecast 2011-2030*. Paris: Airbus S.A.S.

Atkin, C. (2008). *Laminar Flow Control: Leap or Creep?* Paper presented at the 38th Fluid Dynamics Conference and Exhibit, Seattle.

ATAG. (2010). *The right flightpath to reduce aviation emissions*. Geneva: ATAG.

ATAG. (2011a). *Beginner's Guide to Aviation Biofuels* (No. Edition 2, September 2011).

ATAG. (2011b). *Powering the future of flight. The six easy steps to growing a viable aviation biofuels industry* (No. web version). Geneva: Air Transport Action Group (ATAG).

Atmosfair 2014. Atmosfair Airline Index 2014. Available at: https://www.atmosfair.de/atmosfair_airline_index Accessed 20 December 2014.

Boeing. (2012). *Current market outlook 2012-2031*. Seattle: Boeing Commercial Airplanes. Marketing.

Boeing (2014). *Current Market Outlook 2014-2033.* Available at: http://www.boeing.com/assets/pdf/commercial/cmo/pdf/Boeing_Current_Market_Outlook_2014.pdf

Borup, M., Brown, N., Konrad, K. and Lente, H.V. (2006). The sociology of expectations in science and technology. *Technology Analysis & Strategic Management*, 18(3/4), 285-298.

Bowles, M. D. (2010). *The "Apollo" of aeronautics NASA's Aircraft Energy Efficiency Program, 1973-1987*. Washington, DC: National Aeronautics and Space Administration.

Bows, A., & Anderson, K. L. (2007). Policy clash: Can projected aviation growth be reconciled with the UK Government's 60% carbon-reduction target? *Transport Policy, 14*(2), 103-110.

Boykoff, M.T. and Boykoff, J.M. (2007). Climate change and journalistic norms: A case-study of US mass-media coverage. *Geoforum*, 38(6), 1190-1204.

Brewer, G. D. (1991). *Hydrogen aircraft technology*. London: CRC Press.

Brown, N. and Michael, M. (2003). A sociology of expectations: Retrospecting prospects and prospecting retrospects. *Technology Analysis and Strategic Management*, 15(1), 3-18.

Bruner, S., Baber, S., Harris, C., Caldwell, N., Keding, P., Rahrig, K., et al. (2010). *NASA N+ 3 Subsonic Fixed Wing Silent Efficient Low-Emissions Commercial Transport (SELECT) Vehicle Study* (No. NASA/CR—2010-216798). Cleveland, Ohio: National Aeronautics and Space Administration.

Clarke, C.F.C. and Chagas, T. 2009. Aviation and Climate Change Regulation. In: Freestone, D. and Streck, C. (eds) 2009. Legal aspects of carbon trading: Kyoto, Copenhagen, and beyond. Oxford, New York: Oxford University Press, pp. 606-

Committee on Climate Change. (2009). *Meeting the UK aviation target – options for reducing emissions to 2050*. London: Committee on Climate Change.

Coplin, L. G. (2012). *Sustainable Development of Algal Biofuels*: The National Academies Press.

Corning, G. (1976). *Supersonic and subsonic, CTOL and VTOL, airplane design*. Maryland.

Delbecq, A.L., Van de Ven, A.H. & Gustafson, D.H. (1975). Group techniques for program planning: a guide to nominal group and Delphi processes. Glenview, IL: Scott, Foresman

Essebo, M. and Baeten, G. 2012. Contradictions of 'Sustainable Mobility' – the Illogic of Growth and the Logic of Myth. *Tijdschrift voor Economische en Sociale Geografie* 103(5), 555–565.

Euractiv (2014). Aviation emissions law 'puts Europe's global power to the test', MEPs say. Available at : http://www.euractiv.com/transport/aviation-emissions-legislation-p-news-533007 Accessed 19 November 2014.

European Commission (2014). Reducing emissions from aviation. Available at: http://ec.europa.eu/clima/policies/transport/aviation/index_en.htm Accessed 19 November 2014.

European Parliament and Council (2009). Directive 2008/101/EC of the European Parliament of the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community. *Official Journal of the European Union*.

FAA Office of Environment and Energy (2005). *Aviation & Emissions A Primer*: Federal Aviation Administration, Office of Environment and Energy.

Fabian, P. (1974) Residence Time of Aircraft Exhaust Contaminants in the Stratosphere, CIAP Contract No. 05-30027. Washington, DC: US Department of Transportation.

Fabian, P. (1978) Ozone increase from Concorde operations? *Nature* 272, 306-307.

Factiva Inc. (2014) *Factiva*. New York, USA: Dow Jones & Company, Inc.

Gössling, S. & Peeters, P. M. (2007) "It does not harm the environment!" An analysis of industry discourses on tourism, air travel and the environment. *Journal of Sustainable Tourism,* 15 (4)**,** 402-417.

Gössling, S. and Cohen, S.A. (2014). Why sustainable transport policies will fail: EU climate policy in the light of transport taboos. *Journal of Transport Geography*, 39, 197-207.

Gössling, S. and Peeters, P. (2015). Assessing tourism's global environmental impact 1900-2050. *Journal of Sustainable Tourism,* DOI: 10.1080/09669582.2015.1008500

Gotesky, R. (1952) The nature of myth and society. *American Anthropologist,* 54 (4)**,** 523-531.

Green, J. E. (2003a). Civil aviation and the environmental challenge. *The Aeronautical Journal, 107*(1072), 281-299.

Green, J. E. (2003b). Greener by design. In R. Sausen, C. Fichter & G. Amanatidis (Eds), *Proceedings of the AAC-Conference, June 30 to July 3, 2003,* (pp. 334-342). Friedrichshafen: European Commission.

Guardian (2014). Lib Dem leadership backs Gatwick expansion. http://www.theguardian.com/politics/2014/oct/07/lib-dem-leadership-back-gatwick-expansion. Accessed 22 November 2014.

Heehs, P. (1994). Myth, History, and Theory. History & Theory, 33, 1–19.

Hileman, J. I., Ortiz, D. S., Bartis, J. T., Min Wong, H., Donohoo, P. E., Weiss, M. A., et al. (2009). *Near-Term Feasibility of Alternative Jet Fuels*. Santa Monica, CA: RAND.

Hoerner, S. F. (1965). *Fluid-Dynamic Drag: Theoretical, Experimental and Statistical Information*. Bakersfield, CA.

Hu, Q., Sommerfeld, M., Jarvis, E., Ghirardi, M., Posewitz, M., Seibert, M., et al. (2008). Microalgal triacylglycerols as feedstocks for biofuel production: perspectives and advances. *The Plant Journal, 54*, 621-639.

IATA. (2005). *Environmental Review 2004*. Geneva: International Air Transport Association.

IATA. (2009a). *The IATA Technology Roadmap Report* Montreal: IATA.

IATA. (2009b). *World air transport statistics* (53rd ed.). Montreal-Geneva-London: International Air transport Association.

IATA. (2011). *Vision 2050*. Montreal-Geneva: IATA.

IATA. (2012). *A global approach to reducing aviation emissions. First stop: carbon-neutral growth from 2020*. Montreal: IATA.

IATA (2014). Climate Change. Ambitious targets. Available at: http://www.iata.org/policy/environment/Pages/climate-change.aspx Retrieved 19 November 2014.

IBAC (2009) Business Aviation Statement on Climate Change . Montreal: International Business Aviation Council. Retrieved 22-02-2015, from http://www.ibac.org/business-aviation-and-the-environment/business-aviation-statement-on-climate-change

ICAO. (2007). *ICAO environmental report 2007*. Montreal: International Civil Aviation Organization.

ICAO. (2009). Comparison of life cycle GHG emissions from select alternative jet fuels, CAAF/09-IP/6. Paper presented at the Conference on Aviation and Alternative Fuels, Rio de Janeiro. 16-18 November 2009.

ICAO. (2012). Aircraft CO_2 emissions standard metric system. ICAO Fact Sheet. from http://www.icao.int/environmental-protection/Documents/CO2 Metric System - Information Sheet.pdf

ICAO. (2014). *2013 Environmental report. Destination Green*. Montreal: ICAO.

IEA (International Energy Agency) (2009). Transport, Energy and CO2: Moving Towards Sustainability. Paris: International Energy Agency; 2009.

Jotzo, F. (2010). *Comparing the Copenhagen Emissions Targets*, CCEP Working Paper. Canberra: Centre for Climate Economics & Policy, Crawford School of Economics and Government, The Australian National University.

Kivits, R., Charles, M. B., & Ryan, N. (2010). A post-carbon aviation future: Airports and the transition to a cleaner aviation sector. *Futures, 42*(3), 199-211.

Lee, D.S. and Sausen, R. 2000: New Directions: Assessing the real impact of CO_2 emissions trading by the aviation industry. *Atmospheric Environment 34*, 5337-5338.

Liebeck, R. H. (2004). Design of the blended wing body subsonic transport. *Journal of Aircraft, 41*(1), 10-25.

Mayor, K. & Tol, R.S.J. (2009). Aviation and the environment in the context of the EU–US Open Skies agreement. *Journal of Air Transport Management*; 15:90–95.

Mol, A.P.J., Sonnenfeld, D.A., Spaargaren, G. (Eds.), 2009. The Ecological Modernization Reader: Environmental Reform in Theory and Practice. Routledge, London.

Nolte, P., Apffelstaedt, A., & Gollnick, V. (2012 of Conference). Quantitative Assessment of Technology Impact on Aviation Fuel Efficiency. Paper presented at the Air Transport and Operations. Third International Air Transport and Operations Symposium 2012.

Noth, A. (2008). *Design of solar powered airplanes for continuous flight.* Unpublished PhD, ETH Zürich.

Owens , B. , Lee , D.S. and Lim , L . (2010) Flying into the future: aviation emissions scenarios to 2050. *Environmental Science Technology* 44: 2255-2260 .

Peeters, P. M. (2000). Annex I: Designing aircraft for low emissions. Technical basis for the ESCAPE project. In *ESCAPE: Economic screening of aircraft preventing emissions - background report*. Delft: Centrum voor Energiebesparing en Schone Technologie.

Peeters, P. M., & Middel, J. (2007). Historical and future development of air transport fuel efficiency. In R. Sausen, A. Blum, D. S. Lee & C. Brüning (Eds.), *Proceedings of an International Conference on Transport, Atmosphere and Climate (TAC); Oxford, United Kingdom, 26th to 29th June 2006* (pp. 42-47). Oberpfaffenhoven: DLR Institut für Physik der Atmosphäre.

Peeters, P., Szimba, E. & Duijnisveld, M. (2007). Major environmental impacts of European tourist transport. *Journal of Transport Geography* 15, 83-93.

Pels, J., Eijgelaar, E., Peeters, P., Landré, M., & Dirven, R. (2014). Travelling Large in 2009 'Inbound tourism': The carbon footprint of inbound tourism to the Netherlands in 2009. Breda, The Netherlands: NHTV Breda University of Applied Sciences.

Pentelow, L. & Scott, D. (2010). The implications of climate change mitigation policy: volatility for tourism arrivals to the Caribbean. *Tourism and Hospitality Planning and Development* 7(3),301-315.

Pentelow, L. & Scott, D. (2011). Aviation's inclusion in international climate policy regimes: Implications for the Caribbean tourism industry. *Journal of Air Transport Management* 17, 199-205.

QSR International (2012). NVivo qualitative data analysis software; QSR International Pty Ltd. Version 10, 2012.

Quinn, J. C., & Davis, R. (2014). The potentials and challenges of algae based biofuels: A review of the techno-economic, life cycle, and resource assessment modelling. *Bioresource Technology* (0).

Raspet, A. (1951). Systematic improvement of the drag polar of the sailplane RJ.-5. *Soaring* (Sept., Oct. 1951).

Raymer, D. P. (2012). *Aircraft Design: A conceptual approach* (fifth ed.). Washington: AIAA.

Raymer, D. P., Wilson, J., Perkins, H. D., Rizzi, A., Zhang, M., & Puentes, A. R. (2011). *Advanced Technology Subsonic Transport Study N+3 Technologies and Design Concepts* (No. NASA/TM—2011-217130). Cleveland, Ohio: Glenn Research Center.

Rosillo-Calle, F., Thrän, D., Seiffert, M., & Teelucksingh, S. (2012). *The potential role of biofuels in commercial air transport – biojetfuel*. London: IEA Bioenergy Task 40 Sustainable International Bioenergy Trade.

Schumann, U., and D. Wurzel (eds) (1994). Impact of Emissions from Aircraft and Spacecraft Upon the Atmosphere, Proceedings of an International Scientific Colloquium, Köln, Germany, April 18.-20, DLR Mitteilung 94-06.

Skarka, J. (2012). Microalgae Biomass Potential in Europe Land Availability as a Key Issue. *Technikfolgenabschätzung – Theorie und Praxis 21*(1), 72-79.

Snyder, C. (1998). Zero-emissions aircraft? Scenarios for aviation's growth: opportunities for advanced technology. Paper presented at the NASA Environmental Compatibility Research Workshop III, Monterey, CA. July 7, 1998

Snyder, C. A., Berton, J. J., Brown, G. V., Dolce, J. L., Dravid, N. V., Eichenberg, D. J., et al. (2009). Propulsion Investigation for Zero and Near-Zero Emissions Aircraft. *NASA TM-215487*.

Sorel, G. (1941). Reflections on Violence. New York: Peter Smith.

Stoll-Kleemann S. , O'Riordan T. and Jaeger C.C . (2001). The psychology of denial concerning climate mitigation measures: evidence from Swiss focus groups, *Global Environmental Change* 11, 107-117.

Sustainable Aviation. (2008). Sustainable Aviation CO_2 Roadmap. From http://www.sustainableaviation.co.uk/images/stories/key documents/sa road map final dec 08.pdf. Accessed 22 December 2009.

UNWTO, & ICAO. (2007). *Tourism, aviation and the environment*. Madrid: UNWTO.

Vera-Morales, M., & Schäfer, A. (2009). *Fuel-Cycle Assessment of Alternative Aviation Fuels*. Manchester: Manchester Metropolitan University.

Wit, R.C.N., Boon, B.H., van Velzen, A., Cames, M., Deuber, O. and Lee, D.S. (2005). Giving wings to emission trading. Inclusion of aviation under the European emission trading system (ETS): design and impacts. Delft, CE.

Wood, F.R. (2011). Who's flying? The spatial distribution of aviation emissions in Great Britain. *Carbon Management* 2(1), 85-98.

WTTC (2009). *Leading the Challenge on Climate Change*. London: World Travel & Tourism Council.