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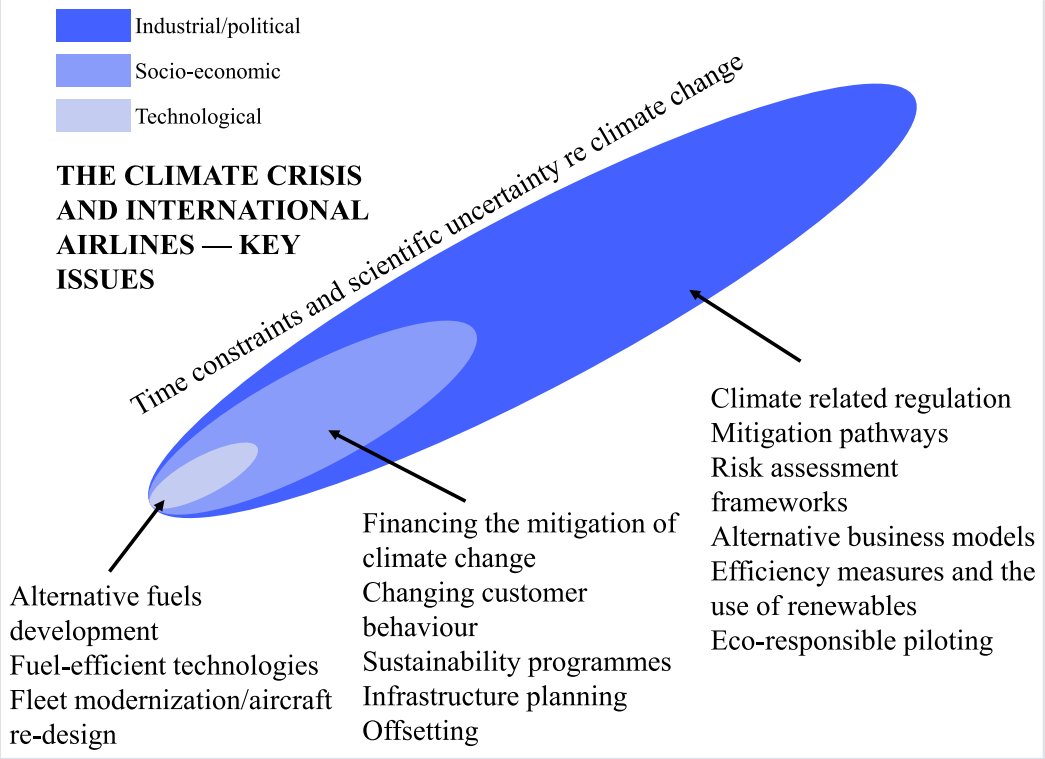

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Article

The Climate Crisis and International Airlines

Martin Wynn * and **Peter Jones**

School of Business, Computing and Social Sciences, University of Gloucestershire, Cheltenham GL502RH, Gloucestershire, UK
* For correspondence: mwynn@glos.ac.uk

Abstract Across the business spectrum companies are under increasing pressure to decarbonize their operations in the fight against climate change, and nowhere is this pressure greater than in the aviation industry. The aviation industry faces a range of challenges in decarbonizing, including costs, the currently limited capability of alternative technologies, a lack of regulatory support, and long aircraft lifespan. This paper explores the ways the leading international airlines are tackling climate change and their approach to achieving net zero by 2050. The research method is based on a scoping review of the existing literature and an analysis of the publicly available material from 10 leading airlines. The article finds that whilst there is a firm commitment from the airlines to initiate the transition to net zero and contribute to the fight against climate change, detail on how this will be achieved is scant. Rather, both the extant literature and evidence from the airlines suggest there are many obstacles to be overcome that will require radical change in technological, socio-economic and industrial/political spheres if the required transition in the industry is to be achieved.

Keywords climate change; net zero; aviation; airlines; decarbonization; sustainable aviation fuel (SAF); offsetting; sustainability

1. Introduction

A simple overview of the global airline industry reveals there are as many as 5000 airlines operating more than 23,000 aircraft, providing service to over 3700 airports. In 2023, the estimated market size of the global airline industry was US $762 billion [1], and the number of flights was estimated to rise to over 40 million in 2024 [2]. Despite the large number of airline companies, the industry has many of the features of an oligopoly market structure, in that a relatively small number of airlines are the dominant players. T4 [3], for example, estimated that the five leading international airlines had a market share of 24.8%. In many ways, this oligopoly within the airline industry reflects the barriers to entry, including high start-up costs, the availability of take-off and landing slots, and the large economies of scale enjoyed by the existing airlines.

The airline industry is one of the most rapidly growing transport sectors in the global economy, and the growth of world air travel has averaged approximately 5% per year over the past 30 years, with substantial yearly variations due both to changing economic conditions and differences in economic growth in different regions of the world. The COVID-19 pandemic saw a dramatic decline in airline traffic, though recent estimates suggest that volumes are now back to pre-pandemic levels [2]. The industry is predicted to continue to grow at 4% per year for the foreseeable future, but concerns have been voiced that net zero by 2050 will not be achievable. As Maslin & Hanson [4] have observed "new generations of technology coming on-stream are not yet proven nor implementable, and aviation needs to reduce its carbon footprint now". Thus, while the airline industry operates in a constantly changing world, with fluctuations in demand reflecting economic conditions and unforeseen events, at the present time decarbonization seems the major challenge facing the airlines.

At the 77th Annual General Meeting of the International Air Transport Association in November 2021, a resolution was approved committing the global air transport industry to achieve net-zero carbon emissions by 2050. A move to net zero involves completely removing the greenhouse gases produced by human activity and is to be achieved by reducing emissions and implementing methods of absorbing carbon dioxide from the atmosphere. Net zero goes beyond carbon neutrality, involving the total elimination of all greenhouse gases, including methane, hydrofluorocarbons and other gases, as well as carbon dioxide. The term is often associated with a wider global movement to progress decarbonization and climate action, and more than 140

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countries have committed to achieving net zero by 2050. The commitment of the global air transport industry aligns with the Paris Agreement goal for global warming not to exceed 1.5 °C, although if the bulk of the effort to decarbonize occurred in the period 2045–2050, for example, the 1.5 °C goal may already have been breached before then. In addition, as Quiggin [5] has pointed out, "while the aviation sector is a critical contributor to the global economy and provides important benefits enabling travel around the world, the sector is notoriously difficult to decarbonize".

In this context, this article looks to explore the multiple aspects of the airline industry's stance on climate change and net zero, and addresses the following research questions (RQs):

RQ1. What is the general approach of airlines in addressing climate change and net zero?
RQ2. How do the airlines envisage meeting their commitments to climate change and net zero?

Following this brief introduction, the research method is then set out in Section 2, whilst Section 3 provides an overview of some of the pertinent literature. In Section 4, the results are oriented around the two main RQs noted above. Section 5 then discusses some broader themes of relevance that were not explicitly covered in the company documents studied. Finally, section 6 provides a brief conclusion to the study, points out its limitations and suggests areas for further study that could build upon the findings set out here.

2. Research Methods

An interpretivist philosophy was adopted, combined with an inductive, qualitative approach to the study. Gill & Johnson [6] suggest that such an approach is most appropriate when the research aim is exploratory in nature and the researchers seek to develop an explanation of the phenomenon being studied. There were two main phases in the research (Figure 1). In Phase 1, a scoping literature review was undertaken to identify key themes and develop the research questions. A scoping review can provide a summary overview of the subject matter "to draw the big picture" ([7], p. 1). It involves a "broad scan of contextual literature" through which "topical relationships, research trends, and complementary capabilities can be discovered" ([8], p. 351).

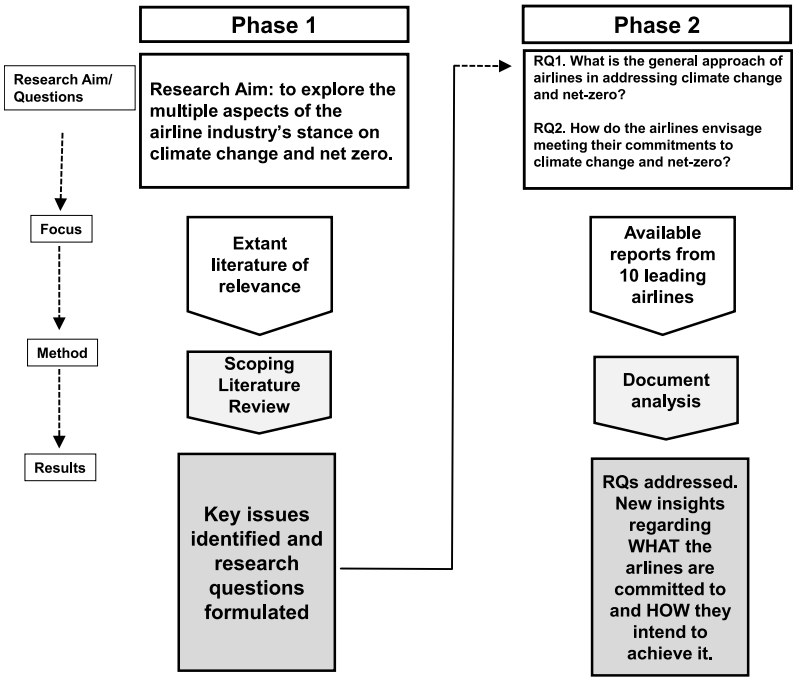

Figure 1. The two-phase research process.

Various academic databases, including Google Scholar and Science Direct, were used to search for relevant sources. In Phase 2, the top ten international airline companies, as measured by revenue, namely Delta, American Airlines Group, United Airlines Holdings, Lufthansa Group, Emirates Group, Air France-KLM, International Airlines Group, Southwest Airlines, Turkish Airlines, and China Southern Airlines, were chosen for investigating the two research

questions developed from the scoping literature review [9]. As the leading players in the international airline industry, the selected airlines might be seen to offer valuable insights into the ways in which the airline industry was addressing climate change and net zero. Brief pen pictures of the selected airlines are provided below.

Delta Air Lines, based in Atlanta, was established in 1929, and it operates over 5400 flights daily and serves 325 destinations in 52 countries. American Airlines, headquartered in Fort Worth, Texas, was formed in 2013, it operates over 6000 flights per day to over 300 destinations in 48 countries. United Airlines Holdings, headquartered in Chicago, originally established in 1968, operates more daily flights than all other airlines and serves destinations throughout the world. Lufthansa Group, established in 1917, operates over 2800 flights per day to over 300 destinations. The Emirates Group, based in Dubai, established in 1985, operates over 3600 flights per week from its hub at Dubai International Airport. Air France-KLM, based in Paris, created in 2004, operates 1500 flights daily and serves 200 destinations in over 50 countries. International Airlines Group, an Anglo-Spanish airline company, established in 2011, operates some 1200 flights per day to destinations in over 130 countries. Southwest Airlines, founded in 1967, and headquartered in Dallas, Texas, operates 4000 flights per day and serves 120 destinations. China Southern Airlines, founded in 1988, and headquartered in Guangzhou, operates over 2000 flights per day to over 200 destinations. Turkish Airlines, founded in 1933, offers more than 16,000 daily flights to 1200 airports in over 180 countries. The airline benefits from the geographic location of its hub at Istanbul airport, which allows the airline to efficiently serve markets across Europe, Asia, the Middle East, Africa, and the USA.

Having selected these ten leading international airlines as the focus for their study, the authors conducted a second round of Internet searches via the Google search engine in September/October 2024, using the names of the selected airlines and climate change as the search terms. The Internet search revealed that the selected airlines presented information regarding their approach to climate change and net zero in a variety of formats: annual Environment, Social, and Governance (ESG) reports; Sustainability reports; Corporate Social Responsibility (CSR) reports; Annual reports; and Climate Transition Plans. Some elements of these reports are verified and assured independently, but this is not true of all sections of these reports, or all airlines. There is nevertheless a degree of peer review for some parts of some of these reports via company auditors or other independent third parties. Nine of the reports and plans were published in either 2023 or 2024, but China Southern Airlines' CSR report was published in 2021. Although there were only ten airline companies (of which just one is a low-cost airline) in this phase of the research, the authors felt that the findings—based on the largest airline companies—represented a fair picture of how the major players in the industry are looking to tackle climate change. As pointed out by Islam & Aldaihani [10], qualitative research often does not include a large sample of a population because the collected data is not easily quantifiable.

The information on climate change and net zero posted on the Internet by the airlines provided the empirical information for this paper. The reports and plans were well structured and clearly signposted, and the authors took the view that a detailed content analysis would be unnecessary in an exploratory study. As the reports are in the public domain, on the selected companies' websites, the authors felt that it was unnecessary to seek formal permission to use them. In the following sections, a general narrative style is used, designed to capture the airlines' general approaches to climate change and net zero, using both specific illustrative examples and explicit quotations drawn from material posted on the airlines' websites. In using quotations, the aim was to add authenticity to the findings by exploring how the selected airlines publicly expressed, and looked to evidence, how they addressed the challenges of climate change and net zero in their own words.

3. Literature Review

This literature review looks to explore the two main overlapping themes featured in the RQs set out above, namely airlines and climate change, and airlines and net zero, and in both cases, the aim is to provide a brief picture of work in the field rather than a comprehensive coverage. A growing volume of work has been published on how the aviation industry is looking to adapt to climate change, and more specifically, on how the industry is looking to address net zero.

Focusing on climate change issues, Ryley et al. [11] claimed that, although the aviation sector had long been referred to as contributing to the causes of climate change, the need for the sector

to adapt to the consequences of climate change had not been as well researched. However, Burbidge et al. [12] looked to present a systematic review of the growing, but dispersed, academic literature on climate change impacts and adaptation in the aviation sector. The authors identified a number of areas for action to address knowledge, awareness and implementation gaps. These action areas included widening the geographical coverage of studies of climate risks and responses, extending knowledge of physical impacts, addressing the risks associated with unprecedented or extreme events, extending knowledge of adaptation to embrace cost-benefit analysis and integrated mitigation and adaptation, and enhancing collaboration between researchers and practitioners.

Leamon et al. [13] provided an overview of the ways airlines are both impacting and are impacted by the climate, and made recommendations on how industry leaders might create a more sustainable future for aviation. The authors suggest that, if aviation is to reduce carbon dioxide emissions into the environment, then it must focus on technological improvements, notably the development of sustainable alternative fuels. At the same time, the authors suggest that in crafting their response to climate change, airline companies must view the issue from a political, social, technological and economic perspective. In conclusion, the authors claim that the airlines should place increasing emphasis on sustainability programmes, but even then, they call into question the industry's ability to pave a pathway to a low-carbon future.

Hasan et al. [14] recognised that while the aviation sector made a notable contribution to the global economy, it had also contributed to climate change. With this in mind, the authors looked to examine a range of issues, including mitigation pathways and challenges, achievements in mitigating emissions, barriers hampering mitigation, and overcoming these barriers. In focusing on achievements in mitigating emissions, for example, the authors claim that a range of individual measures, including the development of fuel-efficient technologies, and the promotion of less carbon-intensive alternative fuels, could play an important role in reducing greenhouse gas emissions, but that an integrated solution had not yet been developed. At the same time, the authors argued that the challenge of financing the mitigation of climate change was one of the major barriers that nations and companies faced. By way of conclusion, the authors highlighted the challenges involved in the development of sustainable aircraft fuels and the costs associated with changes in design and technological innovation and drew attention to the time constraint companies had to develop and introduce new technologically advanced airplanes into their fleets.

Paraschi [15] recognised that the challenges posed by climate change called for urgent action by the policymakers and the airline industry. More specifically, she identified a series of adaptation measures, namely, the development of risk-assessment frameworks and stakeholder action plans, technological advancements to deal with gas emissions and oil depletion, long-range infrastructure planning and investment, the introduction of climate-related regulations, awareness raising, and collaboration, as key steps in building climate change resilience into the global aviation sector. In her conclusions, the author also identified several major obstacles to adaptation, including scientific uncertainty surrounding climate change. The author notes that "some industry stakeholders are extremely concerned about the scientific uncertainty surrounding climate change, and there is low confidence in the current comprehension of how climate change will impact tourism" (p. 94). Here, the author refers not just to the link between aircraft emissions and climate change, which is still contested by some far-right individuals and political groups, but also the fact that long timescales of climate change impacts are seen to be incompatible with corporate planning, thus relegating adaptation to a low priority, and a lack of technical, human and financial capacity to tackle climate change effectively.

A growing volume of work has been published on the possible drive to net zero within the aviation industry. Bergero et al. [16] suggested that the aviation industry will find it very difficult to achieve net-zero carbon dioxide emissions by 2050, because of the industry's need for kerosene liquid fuels that lack commercially competitive substitutes and are difficult to abate carbon dioxide radiative forcing. Nevertheless, the authors look to systematically assess pathways to net-zero aviation. This assessment reveals that ambitious reductions in demand for air transport and improvements to the efficiency of aircraft might in total avoid up to 88% of projected business-as-usual in 2050. However, they also argued that further reductions will depend on replacing fossil jet fuel with large quantities of net-zero emissions biofuels or synthetic fuels which may be substantially more expensive, while large quantities of carbon dioxide may also need to be removed from the atmosphere, in order to compensate for non-carbon dioxide forcing if the sector is to achieve net-zero radiative forcing. The difference between these fuel types is not always clear.

Paraschi et al. [17] note "there is not a single international definition of sustainable aviation fuel (SAF) but it is generally agreed that they refer to bio-based fuels which are obtained from sources other than petroleum, such as woody biomass, hydrogenated fats and oils, recycled waste, or other renewable sources", but "significant interest also exists for non-bio-based feedstocks, in particular the so-called drop-in Power-to-Liquids 'electrofuels'" (p. 3).

Gossling & Humpe [18] suggested that if the aviation industry's current business model, namely volume growth with very small profit margins is continued, then aviation's contribution to climate change will continue to grow. However, in proposing a new business model for a credible and reliable net-zero pathway for the aviation industry, the authors looked to model the cost of biomass-based and non-biogenetic synthetic fuels in combination with carbon taxes. Further, it is argued that if the industry is to achieve net zero by 2050, it will have to reassess capacity and possibly embrace an alternative business model.

More recently, Gossling & Humpe [19] suggested that while air transport decarbonization was theoretically feasible, limited attention had been paid to the complexity of a variety of the transition barriers, namely contested and unresolved issues that potentially undermine the success of net-zero strategies, and which act as roadblocks to net-zero goals. The authors identified a total of 40 barriers related to mitigation, management, technology and fuel transition, finance and governance, but argued that low profitability makes it unlikely that the industry can finance the required fuel transition costs. The paper develops four alternative scenarios for the aviation industry, which have as their starting point a reduction in growth rates and include internalizing the cost of carbon dioxide, the introduction of low-carbon biofuels, the replacement of jet fuels by sustainable biofuels or synthetic fuels, and limiting future capacity to 2019 levels.

Looking to a specific geographical area, Jensen et al. [20] investigated the potential pathways and associated requirements to meet the goal of net-zero greenhouse gas emissions from the US commercial aviation sector by 2050. The authors' analysis revealed that the replacement of older aircraft, the introduction of advanced aircraft technologies, and operational efficiencies might contribute 30% of the total 2050 net-zero target. However, the remaining 70% of emissions would have to be addressed through sustainable fuels and market-based measures, for example, emissions-based trading and carbon credits. The authors suggest that meeting a net-zero emissions goal by 2050 with sustainable aviation fuel would require an increase of 57% per annum in its production from 2022 to 2030 and a 135% annual increase thereafter, and that market-based measures might fill the gap between residual lifecycle emissions and the target.

To date, 25 airlines have signed up to the Science-based Targets initiative (SBTi) [21]. These targets provide organizations with a clearly defined path to reduce greenhouse gas (GHG) emissions, in line with the Paris Agreement goals (closely related to the United Nations Sustainable Development Goals). In this context, "science-based" implies alignment with the latest scientific indicators necessary to meet the goals of the Paris Agreement. These 25 airlines are mainly European or American, and have set (or are in the process of setting) science-based targets for the drive to net zero. McKinsey estimates this accounts for more than 30 per cent of global passenger traffic [22]. Maslin & Hanson [4], in their review of decarbonization in the aviation sector, put forward five specific measures for addressing the issue: optimize flight planning and airspace; make operations more sustainable; switch to sustainable fuels; make airports more eco-friendly—by which they meant "using renewable energy, such as solar or wind energy, for airport operations"; and smart travel, which involves "redefining the passenger experience from door to door, not just the time spent at the airport or on a plane. This could include luggage pickup from your home and incentives to use public transport to the airport".

The above examples and debate in the current literature highlight the multi-dimensionality of the issues in play and the wide range of obstacles facing the airlines in addressing climate change and net zero (Figure 2). This provides a basis for the examination of airline company statements and perspectives, analysed in Section 4 below.

4. Results

The search revealed considerable variation in the amount of information the airlines publicly presented on climate change and net zero. Rather than looking to describe how each of the airlines was addressing these issues in detail, the authors looked to identify, and draw out a number of key themes to provide a narrative account to address the two RQs noted above, and more specifically, assess WHAT are the airlines are committing to do (RQ1), and HOW they plan to do it (RQ2).

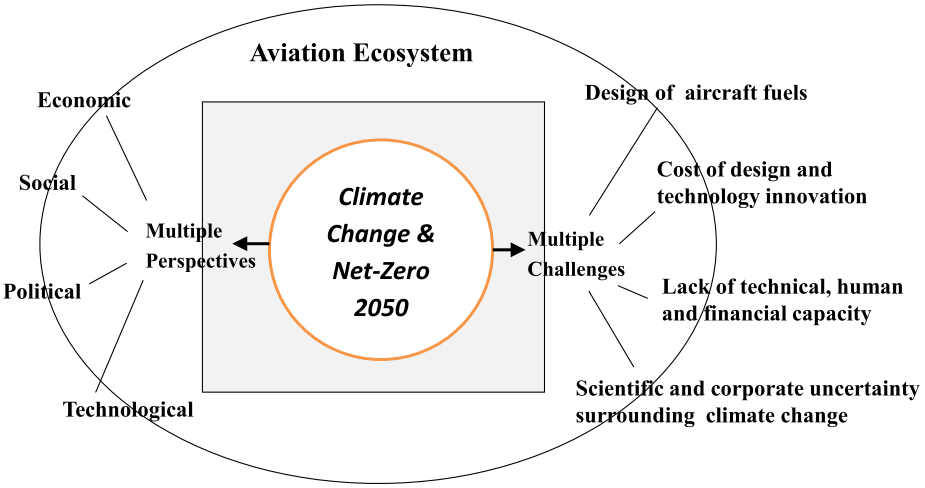

Figure 2. Aviation and climate change/net zero: an illustrative overview from a scoping literature review.

4.1. RQ1. What is the general approach of airlines in addressing climate change and net zero?

All the selected airlines recognized the importance of climate change and expressed their concern about its impact on their business. Under the banner "Climate and Environment", Delta ([23], p. 27), for example, reported that the global aviation sector currently contributes 2–3% of total greenhouse gas emissions and it is among the most difficult to decarbonize, "which only strengthens our resolve to innovate and advance a new future of flight", and that "addressing the challenges posed by climate change is of particular importance" (p. 29). At the same time, Delta clearly had an eye to the commercial importance of air travel, as evidenced by its belief that "addressing the climate impact of aviation is essential to helping meet global emissions goals while preserving the vital role that air travel plays in global connectivity and commerce" (p. 29). China Southern Airlines ([24], p. 27) explicitly recognized "the harm from climate change, and global warming impacts everyone". American Airlines ([25], p. 11) reported its belief that "being a competitive, resilient airline—and one that will continue to care for people on life's journey for generations to come—requires helping to drive the operational, policy and technological changes needed to advance the transition to a low-carbon aviation future".

The selected airlines certainly emphasised their corporate and strategic commitment to address climate change, albeit often in different ways. American Airlines [25] reported that the management of its climate change strategy has been formally assigned to the airline's Chief Executive Officer, and responsibility for specific climate-related issues was embedded in senior roles across the company. Turkish Airlines [26] "claimed we are committed to developing climate change-focused strategies to make our business and our world sustainable", the airline reported that "climate change is not addressed as a separate topic in our business development processes but instead is integrated into the workflows of all our business units". China Southern Airlines ([14], p. 27) emphasised that the company attached "great importance to the construction of environmental systems to actively respond to climate change through the reduction of energy and resource consumption". Air France-KLM [27] argued that "given the climate challenges facing society today, we feel that it is our responsibility to accelerate our environmental transition and become the leader of a more sustainable aviation industry". Lufthansa ([28], p. 8) claimed to have "set ambitious climate protection goals".

More specifically, the majority of the selected airlines reported their commitment to achieving net-zero emissions. Lufthansa ([28], p. 8), for example, claimed it would "achieve carbon neutrality by 2050". While the airlines' headline commitment was to net-zero emissions by 2050, some of the selected airlines published interim targets. The International Airlines Group [29] claimed that by 2030 its gross carbon dioxide emissions would be 15% lower than in 2019. American Airlines ([25], p. 11) claimed "our aim is to achieve net-zero greenhouse gas emissions by 2050. To drive progress, we have set an intermediate target to reduce greenhouse gas emissions intensity by 45% by 2035, relative to a 2019 baseline. This includes both direct emissions (Scope 1)—primarily from the combustion of jet fuel used in flight—and the indirect emissions (Scope 3) from the production of the jet fuel we use and the consumption of jet fuel used by our contracted regional carriers". However, such interim targets were sometimes relative, rather than

absolute. Air France-KLM [27] emphasised that its decarbonization strategy "is primarily centred around reducing our direct and indirect carbon dioxide emissions, with a targeted reduction of 30% per passenger kilometre by 2030 compared to 2019".

4.2. RQ2. How do the airlines envisage meeting their commitments to climate change and net zero?

In terms of HOW the airlines plan to realize these commitments, several options and possibilities were put forward. As a prerequisite to action (rather than a climate strategy in itself for achieving net zero), many of the selected airlines focused on the risks associated with climate change and put emphasis on the need to adequately manage these risks. Delta ([23], p. 41), for example, claimed that its climate strategy "was informed and guided by the continuing identification and assessment of climate-related risks and opportunities relevant to our business". For Southwest Airlines [30] "assessing climate-related risk is a part of building organizational resilience in the face of climate change".

The Emirates Group ([31], p. 54) reported identifying several "climate related risks". These risks included incremental costs from introducing a carbon pricing scheme, operational disruption and increasing costs from increased severity and frequency of extreme weather events, such as cyclones and floods, and the costs associated with transitioning to sustainable aviation fuel, using biofuels for fleet operations and the electrification of the ground handling fleet. At the same time, Emirates was also keen to identify a series of climate-related opportunities, namely cost reductions achieved through efficiency measures and the use of renewable resources, and becoming an industry leader in the battle against climate change. Southwest Airlines [30] also identified a number of physical risks, including coastal flooding, drought, extreme tropical storms, heatwaves, and a series of transitional risks, including enhanced reporting obligations, increased cost of raw material, changing customer behaviour, increased stakeholder concern, and transitioning to new aircraft technology.

More specifically, several of the airlines provided details of the measures planned to achieve their climate strategies and goals, including fleet modernization, improving the efficiency of flight operations, eco-responsible piloting, increasing the use of sustainable fuels, providing alternative means of transport to their hubs, and offsetting (Table 1).

Air France/KLM [27] identified "three main levers to help us reduce our emissions: renewal of our fleet; use of sustainable aviation fuel; [and] adopting eco-piloting methods". United Airlines Holdings [32] claimed to be "the first global airline to commit to achieving net zero greenhouse gas emissions by 2050, without relying on the use of voluntary carbon offsets". Some airlines claim eco-responsible piloting offers a way forward. Air France-KLM [27], for example, claim that eco-responsible piloting immediately reduces the fuel consumption of aircraft, both in flight and on the ground, without any impact on flight safety or punctuality. Lufthansa [28] claimed that the long-term key to making aviation more climate-friendly was to increase their use of sustainable aviation fuels, while fleet modernization provided the best means of tackling climate change in the short term. In a similar vein, Delta [23] claimed that its integrated climate change strategy includes increasing the number of efficient aircraft in its fleet, enhancing the efficiency of its operations, and increasing its use of sustainable aviation fuel. American Airlines Group ([25], p. 11), having set "externally validated, science-based 2035 greenhouse gas (GHG) reduction targets", stated "our strategy to reach these targets focuses on running an ever more fuel-efficient operation, primarily by operating more fuel-efficient aircraft that are increasingly powered by low-carbon fuel". China Southern Airlines ([33], p. 49) in "coping with climate change" noted that they are aiming "to optimize the green and low-carbon measures such as flight fuel saving, ground consumption reduction and passenger emission reduction" and had "promoted the utilization of recyclable resources" and "tried all out to practice the green full-journey service".

American Airlines Group [25], under the strategy banner of "emitting less by using less", looked to reduce fossil jet fuel consumption and GHG emissions by "introducing more efficient aircraft, operational efficiency and investments in lower carbon alternative propulsion technologies". Rather similarly, International Airlines Group ([34], p. 4), as part of their "Flightpath net zero" strategy, noted they were "investing in new aircraft and applying laser-focus to operational fuel efficiency", whilst also "using high quality carbon offsets to fund CO2 reduction initiatives around the world such as solar energy and reforestation projects".

Table 1. Net zero measures pursued by the airlines.

Measure/Airline	Air France-KLM [27]	Lufthansa [28]	Delta [23]	United Airline Holdings [32]	American Airlines Group [25]	Emirates Group [31]	International Airlines Group [29,34]	Turkish Airlines [26]	China Southern Airlines [33]	Southwest Airlines [30]
Fleet modernization	Gradual replacement of current fleet with new-generation models	Largest-ever fleet modernization programme. The best short-term measure.	Improving fuel efficiency through ongoing renewal.		Fleet renewal/next-generation airlines	Investing in the most modern, eco-efficient air-craft technology	Investing in new aircraft	Fleet modernization and improvement is a core element of sustainability strategy		
Flight operation efficiencies		Intelligent route planning, modern approach procedures, and the latest technologies.	Continually maximizing the efficiency of existing fleet and operations		Jet fuel reduction targets	New flight planning system	Applying laser-focus to operational fuel efficiency			Fuel conservation programme
Eco-responsible piloting	Enables an average saving of 4% to 5% on fuel consumption									
Sustainable Aviation Fuels (SAFs)	One of the most promising levers for emissions reduction	One of the world's biggest SAF customers. SAFs are the long-term key	Addressing barriers to increase the availability and affordability of SAF	The airline will help to scale, commercialize and adopt SAF	Purchase and help scale SAF production	Monitoring biofuel technology development	Key solution in the airline's transition plan to net zero	Signatory to Global SAF declaration		Replace 10% of total jet fuel consumption with SAF by 2030
Hub-transport options		Introduced alternative transport to hubs.	Reducing climate impacts of ground service equipment and facilities	Reduce GHG emissions by embedding more sustainability across the enterprise		Minimizing the environmental footprint of road operations			Ground consumption reduction	Ground support electrification programme
Offsetting		High-quality, certified offset projects			Utilize offsets and removals		Smart carbon pricing to fund carbon reductions in other sectors	Passengers offered the opportunity to offset their carbon emissions	Plans to carry out carbon asset management	

International Airlines Group [29] recorded that "SAF is a key solution in IAG's transition plan to net zero" and that the airline was "on track to deliver a 100-fold increase in its SAF volumes between 2022 and 2030 and expects to use SAF for 70% of total fuel in 2050". Turkish Airlines ([26], p. 4) claimed to have "expanded the boundaries of our efforts to increase the use of Sustainable Aviation Fuels" by becoming a signatory to the Global SAF Declaration. Air France-KLM [27] identified SAF as "one of the most promising levers that will help us to reduce our CO_2 emissions", noting "we already plan to use more than 10% sustainable aviation fuel on board our aircraft by 2030, exceeding the obligations set by the European Commission. United Airlines Holdings [32] claimed that one of its objectives was to help scale, commercialise, and adopt sustainable aviation fuel, which will be produced from biomass sources through a variety of biological, thermal and chemical processes, and which can be used in conventional engines, and that it will be vital in meeting the airline's climate ambitions. However, the airline also explicitly recognized that the current supply of sustainable aviation fuel is constrained and that it currently accounts for less than 1% of commercial aviation fuel usage. American Airlines [20] similarly concluded: "while we expect that certain technologies—such as SAF and new aircraft propulsion—may be able to reduce emissions to a greater extent than others, the future development and availability of these technologies is not something we can predict with precision. Their contribution to our decarbonization will depend on the pace at which new technologies are developed and the willingness of stakeholders to invest in them, as well as the implementation of public policies that will help drive the trajectory toward their adoption" (p. 12).

Despite this, the use of SAF is seen by the airlines studied as the favoured route to decarbonization. Indeed, United Airlines Holdings [32] concluded: "we believe SAF is the most promising technology solution in development today that can abate emissions from our flight operations on a lifecycle basis and will be a critical component in meeting our climate ambitions". This is understandable, in that the widespread availability and use of SAF would arguably result in the least disruption of current business models when compared with other possible measures, such as fleet modernization, operational efficiencies gain, and eco-responsible piloting. The development of SAFs arguably offers the most potential for the future decarbonization of the industry. The International Air Transport Association (IATA) [35], in cooperation with aircraft manufacturers and airlines, has committed to cut CO_2 emissions in half by 2050 through the deployment of innovative technologies, and the use of sustainable aviation fuels, as well as through improved operations and infrastructure; but as Maslim & Hanson [4] noted earlier this year "the aviation industry has been slow to engage with the climate change agenda and new technology that could help it decarbonize is still being developed".

5. Discussion

The findings reported above reveal a complex picture of interrelated and overlapping issues crossing different disciplines and spheres of activity—technological, socio-economic and industrial/political (Figure 3). The leading international airlines all clearly state that they are looking to address the challenge of climate change, but detail on how they will achieve this remains largely directional. For the time being, the airline industry is looking to continue to pursue growth strategies, as part of its commitment to "business as usual" approaches, but at the same time is looking to harness both technological and bioeconomic solutions to the problems of climate change. In a wider context, there are arguments that technological and bioeconomic initiatives can help to achieve sustainable solutions, for example, by reducing energy consumption, reliance on fossil fuels, and greenhouse gas emissions, and by improving productivity and efficiency, as well as nature and biodiversity. However, both types of solutions are not without their problems and two specific examples being pursued by the airlines, namely the development and increasing use of sustainable aviation fuels, and carbon offsetting, provide illustrations of these types of solutions, and of their problems.

Sustainable aviation fuelis produced from sustainable feedstocks, including cooking oils and non-palm waste oils and solid waste from homes and businesses, forestry waste, and fast-growing plants and algae. It can be used in existing aircraft and lifecycle emissions are up to 70% lower when compared with traditional jet fuel. However, there are a number of barriers to increasing the use of SAF, not least the high cost of production and the lack of sufficient feedstock. There is only a limited infrastructure for the collection of feedstocks, which results in low availability and

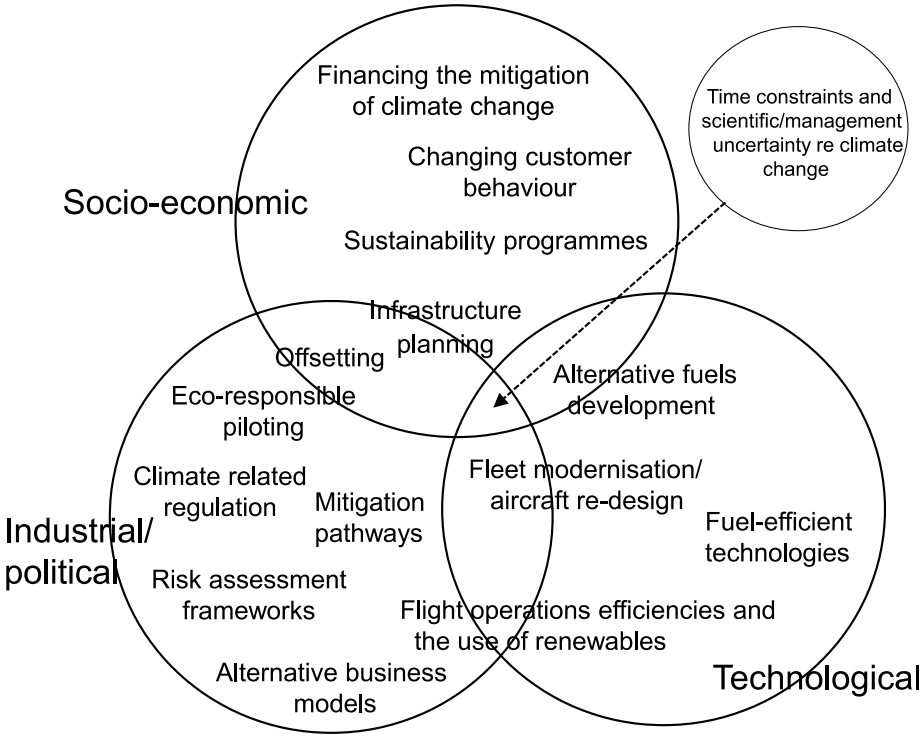

Figure 3. Aviation, climate change and net zero: key issues and considerations.

high prices. At the same time switching agricultural land use to the growing of crops for biofuels may affect food production and food prices, which may have damaging consequences for people in less developed economies, while a switch to biofuels may lead to deforestation that will have a negative impact on carbon dioxide emissions. It is also important to remember that the airline industry is not the only one looking to increase its use of sustainable fuel. The motor vehicle industry is particularly keen to increase its use of sustainable fuels, and other sectors such as chemicals, pulp and paper, and cement production are looking to use a range of sustainable fuels, including biofuels, hydrogen, and synthetic fuels.

Carbon offsetting is seen to offer the airlines a means of compensating for the carbon emissions produced by their aircraft through their investment in initiatives that reduce or remove carbon dioxide, or other greenhouse gas emissions from the atmosphere. However, offsetting schemes face several challenges. While carbon offset schemes may offer some environmental benefits, the emission reductions they achieve can be difficult to quantify, and such schemes can not only lead to greenwashing, but they can also allow customers to think their journeys are effectively emission-free and thus can be seen to detract from the pressing need to reduce emissions. More positively, Becken & Mackey [36] proposed five principles of best practice, including careful selection and reporting, and third-party auditing, which they claim offer a credible basis on which they can develop their approach to carbon offsetting.

The circular economy is seen to offer solutions to some of the most pressing sustainable development challenges, but Lanate et al. [37] suggest that it has not been fully explored within the airline industry. Circular practices that can help to reduce carbon emissions include reducing waste, using biofuels, reusing and recycling materials, and more fully exploiting the potential of digital technologies to support circularity [38], but waste management is the only measure currently being employed at scale within the industry. Emirates Group [39], for example, had invested in a "huge closed loop recycling programme to reduce waste and give our plastic items new life". Southwest Airlines ([30], p. 9) aims to "eliminate single-use plastics from inflight service where feasible by 2030" The recycling of cabin waste, and the introduction of new catering systems that involve recycling are thus in evidence, but the overall rate of adoption of circular models within the airline industry is at a low level at present.

In summary, whilst the airline industry is more or less unanimous on what it needs to do, exactly how it is to achieve these objectives is less clear. Airlines are increasingly looking to use more efficient aircraft, reduce fuel consumption, and employ carbon removal technologies, but

the challenges they face in successfully implementing such strategies are significant. The uncertainty about how these challenges will be overcome is striking. Esqué et al. [22], writing under the McKinsey & Company banner, recently noted, as regards the aviation industry achieving decarbonization, that "while the ambitions are clear, actors in the aviation sector are highly dependent on each other to achieve their decarbonization commitments. …. this interdependency has strengthened the industry's unified ambition to decarbonize, but it also highlights the role that actors such as commercial aviation lessors, OEMs, and suppliers need to play to support airlines and offer solutions".

6. Conclusions

All the selected airlines reported their concern, albeit often differently expressed, about climate change, and all expressed their commitment to tackle climate change and move to net-zero emissions by 2050. However, the airlines' commitments can be seen to be largely aspirational. On the one hand, few of the selected airlines published interim targets, which would have provided a means of assessing, if, and how well, the airlines were on the way to achieving their 2050 goals. On the other hand, while the airlines reported on a number of measures, they would be employing to tackle climate change and to meet their net-zero targets, many of these measures are *terra incognita* for the industry, and it remains to be seen how successful they will be.

More generally, in exploring how the major airlines are addressing climate change, it is important to recognize that their commitment to move to net zero is explicitly and publicly expressed, but it is not easy to escape the conclusion that in looking to fulfil these commitments, the airlines are putting their trust in undeveloped and uncertain technologies. As such, there seem to be parallels between their approach and that of many governments, who have been accused of double standards in that they do not practice what they preach, and that they are not introducing nor funding policies and measures that will begin to move to net zero. As recently noted by the CEO of American Airlines ([25], p. 3), "aviation is widely recognized as one of the most difficult sectors to decarbonize. Getting there is going to require action and investment across the public and private sectors and, quite frankly, that's not happening at the pace or scale we need".

This paper has its limitations, not least in that its empirical material is drawn exclusively from the selected airlines' websites on the Internet. However, the authors believe that the paper uses accessible sources to offer a valuable exploratory picture of the complex series of challenges airlines are facing in tackling climate change and that it can provide a platform for future research. Looking to the future, such research agendas might include detailed empirical studies of how specific airlines are progressing in their attempts to achieve net-zero emissions, and of the barriers constraining progress to net-zero targets. This could include an analysis of which measures the airlines are adopting to reach net zero by 2050 (fleet renewal, operational efficiencies, SAF, market-based measures, and carbon removals), and how the airline interim targets align with SBTi targets. Equally, research into how customers' perceptions of airlines' commitment to tackling climate change, and into how such perceptions may change their patronage behaviour, may also pay dividends.

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Data Availability

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Author Contributions

Conceptualization: M.W., & P.J.; Data curation: M.W., & P.J.; Formal analysis: M.W., & P.J.; Investigation: P.J.; Methodology: M.W., & P.J.; Project administration: M.W.; Supervision: M.W., & P.J.; Validation: M.W.; Visualization: M.W., & P.J.; Writing – original draft: M.W., & P.J.; Writing – review & editing: M.W., & P.J.

Conflicts of Interest

The authors have no conflict of interest to declare.

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