Aviation and the Environment: An Analysis of the Environmental Implications of Aviation and the Interplay Between Society and Practical Mitigation Strategies

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

As society has begun to place a growing emphasis on sustainability and the environmental implications of our day to day operations, few industries have faced greater scrutiny than the aviation industry. As reported by the EPA, commercial airplanes and large business jets contribute 10 percent of U.S transportation emissions and account for 3 percent of the nation's total greenhouse gas (GHG) emissions (Overton, 2022). In terms of the global CO_2 emissions, aviation contributed 2.4 percent of the total in 2018. Though this contribution may seem insignificant, if global commercial aviation had been its own country in the 2019 GHG emissions standings, the industry would rank number 6 in the world (Overton, 2022). Consequently, though the current design of commercial aircraft has gained substantial technological momentum within our society, considerable pressure has been placed on the aviation industry to produce new aircraft with greater consideration of their environmental implications. To address these sustainability concerns, analysis has indicated that substantial reductions in emissions will require the introduction of new and radical technologies (Lee et al., 2009).

While I agree with this conclusion, I will show through my research that even the most technical of mitigation strategies must be implemented within and thus will be dependent upon a society comprising myriad relevant social groups, each with differing values and perspectives. This interdependency between the technology and the society requires an understanding not just of the technical challenges within this issue but also of the social dynamics surrounding it. It has been found that the development of a sustainable aviation industry has become a contested issue, leading to a growing and ongoing debate between various social groups over which mitigation strategies, if any, should be employed. As a result, it has been concluded that the reframing of aviation policy must by necessity be fraught with political and technical difficulties that merit a wider dialogue to address a complex set of interconnected political and social challenges (Budd et al., 2013).

To reinforce this conclusion, my research utilizes the framework of the social construction of technology (SCOT) to explore how the values of various groups in society including but not limited to the aviation industry, environmentalists, governmental stakeholders, and passengers both interact with the primary mitigation strategies being considered and conflict with one another in the development of a sustainable aviation industry. SCOT is especially convenient in this discussion because it emphasizes the understanding of how human behavior shapes the development of technology (Klett, 2018). Through this application of SCOT, I will employ a sociotechnical analysis of the most prominent mitigation strategies being pursued to assess the practicality and consequences of each based upon the values of these social groups.

Relevant Social Groups in the Social Construction of Sustainable Aviation

To successfully mitigate the harmful effects of the aviation industry on the environment, it is essential to understand the social dynamics surrounding the strategies that could potentially be implemented. As explained by Budd et al. (2013), the issue of sustainable aviation is considered to have been transformed from a “tame” to a “wicked” policy issue, where “wicked” policy issues are “characterized by conflicting policy frames, each informed by competing evidence bases, rival definitions of problems and solutions, and antagonistic beliefs and values" (Budd et al., 2013, p. 5). In the application of SCOT to this issue, the following social groups within society best illustrate the contested nature of sustainable aviation: industry representatives, environmentalists, governmental stakeholders, and passengers.

Each of these groups possess uniquely different definitions of both the problem of sustainability in aviation and its solution. In fact, even the mere idea of “sustainable aviation” itself is considered a contested concept (Budd et al., 2013). These conflicting policy frames are derived from a contested set of perspectives and distinctly different values. For instance, representatives of the aviation industry may concede that there is a problem of environmental sustainability in society as a whole but will likely value economic growth to an equal or higher degree as sustainability within their particular industry. Consequently, industry representatives will likely value mitigation strategies that are less antagonistic to the growth of the industry such as the implementation of sustainable aviation fuels (SAF) or new innovative designs over strategies such as green taxes. Conversely, environmentalists are likely to be far less concerned with industry growth and more interested in strategies that, when implemented, can provide almost immediate benefits to the environment. These contrasting values are summarized in the following excerpt from McManners (2016), “At the core of the environmentalist's demand is reduction in emissions. At the core of the industry demands is to be allowed to continue flying” (McManners, 2016, p. 4). Moreover, governmental stakeholders may also be concerned with economic growth in addition to regulatory policies and international agreements whereas aviation passengers may be most concerned with the affordability and convenience of air travel. It are these conflicting values that contribute to the “wicked” policy issue of sustainable aviation.

Green-Growth vs Degrowth

In assessing the social dynamics surrounding the social construction of sustainable aviation, it is necessary to understand any power dynamics that may be present between the four groups being discussed; namely, industry representatives, environmentalists, governmental stakeholders, and passengers. In the consideration of policy strategies pertaining to environmental sustainability, two theoretical perspectives have emerged: the perspectives of green-growth and degrowth. The key distinction between these two perspectives is that green growthists believe that economic growth and environmental protection are compatible whereas degrowthists believe the two are incompatible. Though research through critical social theory has suggested that degrowth has a stronger normative justification than green growth, the most widely accepted solution continues to be green growth (Sandberg et al., 2019). As will become evident throughout subsequent sections, this concept of green growth has dominated the exploration of mitigation strategies in aviation, giving social groups that value economic growth such as industry representatives and governmental stakeholders considerable power in the social construction of sustainable aviation.

Technical Mitigation Strategies

In light of the established social dynamics surrounding the issue of sustainable aviation such as the disparate sets of values between groups within society and the power imbalances present due to the perspective of green growth, the practicality of many proposed technical mitigation strategies can now be considered within the context of society. There are currently numerous proposed technical strategies to mitigate the environmental implications of aviation such as electric and hybrid-electric aircraft propulsion technologies (EAP), sustainable aviation fuels (SAF), and innovations in the fields of aerodynamics, propulsion, and aeropropulsive coupling. All of these strategies reflect the concept of green growth, the ability to preserve economic growth of the industry while still working towards the development of a sustainable aviation industry. A key metric considered in technical innovations is technology readiness level

(TRL). TRL ranges from 1-9 and is assigned based on the stage of development for a technology, with 1 being the lowest where research is only just beginning and 9 being the highest where the actual technology is "flight proven" through successful missions (Tzinis, 2015). This metric will be particularly useful in the proceeding discussion because it provides a means to qualitatively assess a technology's entry into service date (EIS); in other words, when the proposed mitigation strategy could actually be implemented.

To discuss the implementation of the most prominently considered technical mitigation strategies, I will categorize all design innovations pertaining to the various research fields such as aerodynamics and propulsion into a single broad group and will consider the following three strategies: EAP, SAF, and broad design innovations such as blended wing body configurations, boundary layer ingestion techniques, etc. The practicality of these technical strategies will be assessed by considering any likely TRL values, design implementation requirements, and societal issues or concerns regarding a particular strategy.

Electric Aircraft Propulsion

With regards to EAP, extensive research and development has gone towards the implementation of both hybrid-electric propulsion systems and fully electric propulsion systems on aircraft. This particular strategy is intended to substantially reduce the GHG emissions resulting from aviation, particularly CO_2 emissions. A strategy often coupled with the implementation of EAP is an increased reliance on turboprop aircraft for regional transportation, as current research suggests this shorter ranged sector of aviation could be most benefited from the implementation of EAP. In considering the use of turboprop aircraft vs jet aircraft in this sector, analysis from researchers working in the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology has shown that an increased fuel efficiency is derived from the use of turboprop engines relative to jet engines in regional aviation (Babikian et al., 2002). Thus the coupling of regional turboprop aircraft with EAP systems has the potential to yield substantial benefits in the mitigation of harmful emissions from aviation. This coupling is discussed in further detail in my technical report.

However, though extensive research has gone towards EAP, the TRL of the constituent components of EAP systems is still only moderate at best. A particular challenge associated with EAP is derived from the design of effective thermal management systems as unusually high heat loads relative to conventional aircraft are expected due to the presence of batteries and other electric equipment (Affonso et al., 2021). Furthermore, the current performance of this technology limits the overall capabilities of aircraft, making the present implementation of these systems confined to only a small portion of the aviation sector such as small regional and general aviation aircraft. Consequently, the effective implementation of this technology to the aviation sector as a whole to develop a sustainable aviation industry is unlikely to be feasible as of today, though in the coming years it will likely become more practical.

In considering the social dynamics surrounding EAP technology, this strategy seems relatively attractive. Since this type of technology has already begun to be implemented in the automobile industry, it can be seen as a relatively trustworthy solution to the harmful emissions produced by the aviation industry. Furthermore, though the current performance of EAP systems is limited, it will likely improve substantially in the near future and will allow the design of aircraft to continue without major changes to the entire aircraft system. Thus from the industry and governmental perspectives, the implementation of EAP systems could continue to allow industry growth without the need to establish significantly new manufacturing architectures and regulatory practices. However, due to the lack of present feasibility, EAP technology as a stand alone mitigation strategy is unlikely to succeed in producing significant progress in the present issue of sustainability in aviation. In addition, in the cases where EAP could be implemented today, the relative novelty of the technology and overall limited performance will likely necessitate both an increase in prices and slower air travel, which would reduce the affordability and convenience associated with air travel in these sectors.

Sustainable Aviation Fuels

With regards to SAF, numerous assessments have been conducted to consider its implementation as a replacement to current jet fuels. Like EAP, this particular strategy is intended to substantially reduce the GHG emissions resulting from aviation and has even been shown to potentially reduce SOx emissions and contrails as well (Kramer et al., 2022). Furthermore, with the increasing depletion of fossil fuels, use of SAF could have economic benefits as well and reduce reliance on petroleum supplying countries (Yilmaz & Atmanli, 2017). The key to the implementation of this strategy is to develop SAF that has properties within the accepted range for those associated with current jet fuels.

In the assessment of the implementation of SAF, research indicates relatively high values of TRL. According to Kramer et al. (2022), the definition and qualification process for the replication of all Jet A/A-1 properties in a single fuel has already been pioneered by SASOL and could be achievable in the next two years. Furthermore, the process for replicating these properties in a blended fuel could follow a year or two behind. Following these assessments, the use of SAF to help mitigate the environmental implications of the aviation industry seems to be highly practical. However, questions have been raised about the current scalability of this strategy, particularly in a global context.

From these considerations, the use of SAF seems to be highly attractive within the context of the contrasting values present in society. Like EAP, the implementation of SAF shouldn't be antagonistic to the economic growth of the aviation industry. However, unlike EAP, because SAF is being designed with the properties of current aviation fuels in mind, its use shouldn't limit the current performance of aircraft and could be utilized throughout the entire aviation sector. It also possesses the potential to be implemented in the very near future, allowing for the immediate mitigation of some of the harmful environmental effects of the aviation industry without jeopardizing the convenience of air travel. In fact, the United States has already set a target of producing about 10% of anticipated annual jet fuel consumption in SAF by 2030 and targets complete replacement by 2050 (The White House, 2021). However, as mentioned in Kramer et al. (2022), it should be noted that the sustainability certification of SAF as presently considered doesn't fully address important societal choices such as "interactions among economies… and how these considerations should be valued both locally and internationally" (Kramer et al., 2022, p. 5). In addition, as previously discussed, studies have concluded that biofuels in particular among SAF may have issues of overall scalability if deployed globally (Kramer et al., 2022). As discussed briefly in Rathore et al. (2020), the current high cost associated with SAF makes it unacceptable for the developing Indian aviation industry; a concern likely shared by most developing economies. Thus though the use of SAF presents as an attractive strategy to mitigate the environmental implications of the aviation industry, it too is unlikely to produce a significant change to the issue of sustainability in the aviation industry by itself.

Broad Design Innovations

Lastly, there are numerous additional innovations being considered to help mitigate the environmental implications of the aviation industry. Some of these strategies represent new and radical changes in technology and aircraft configurations such as those identified in Lee et al. (2009), including blended wing body aircraft and unducted-propfan engines. Others represent unique changes to be implemented in specific aviation sectors such as transonic truss-braced wings, variable geometry wing planforms, and boundary layer ingestion techniques to name a few. Each of these strategies are intended to improve the efficiency of future aircraft, which will subsequently reduce fuel consumption and overall aircraft emissions. The TRLs of each of these broad design innovations vary but each strategy has and continues to undergo extensive research for future implementation. Like EAP and SAF, these innovations are likely to contribute to the growth of the aviation industry and shouldn't significantly compromise the convenience and affordability of air travel, if at all. However, from an environmental sustainability perspective, all of these proposed technical strategies, which adhere to the concept of green growth, seem unlikely to fully establish a sustainable aviation industry in the absence of political and economic strategies. As such, political and economic strategies, some of which constitute the concept of de-growth, must also be discussed.

Political & Economic Mitigation Strategies

After discussing both the social dynamics surrounding the issue of sustainable aviation and possible technical mitigation strategies for the current environmental implications of the aviation industry, the social context regarding the most widely proposed political and economic mitigation strategies can now be effectively discussed. As a result of the contested nature of sustainable aviation, particularly with regards to the contrast between economic concerns such as growth and environmental concerns such as harmful emissions, McManners (2016) concluded that "fundamental change to the process of crafting policy is required if sustainability is to fulfill its potential to reconcile environmental and economic objectives" (McManners, 2016, p. 1). To discuss the implementation of sustainable aviation policy, I will consider both national and international government policies and will focus on two types of policies: green taxes and international policy agreements. These strategies will be considered in light of the differing perspectives and concerns inherent to the different relevant groups in society.

Green Taxes

In the consideration of green taxes, the intent is to incentivise and de-incentivise environmentally sustainable and less environmentally sustainable activities respectively. Since the current aviation industry model contributes substantially to the negative environmental implications of our society, the application of green taxes would likely lead to increased costs for air travel and may be established through the taxing of aviation fuels to provide commercial incentive for low-carbon aviation or other means of travel altogether. In the view of an industry representative who was opposed to this type of policy, this could have catastrophic effects on the aviation industry and all industries that directly and indirectly depend on it; anything that might interrupt with growth should be resisted (McManners, 2016). This is also a concern of governmental stakeholders, particularly those representing developing economies that rely heavily on aviation. However, the view of an environmentalist who participated in this study was substantially different. In his view, growth in the aviation industry should be resisted and people should ultimately be persuaded to fly less.

As previously discussed, a key result of the implementation of green taxes to the aviation industry would likely be an increase in overall price. This would affect the general affordability of air travel, which could become a concern for passengers. However, as discussed in Ryley et al. (2010), a study pertaining to the public sentiment regarding aviation taxes in the UK, research has suggested a gradual shift in public opinion towards policies that increase the price of flying to reflect environmental damage. Thus the potential increase in price resulting from the implementation of green taxes may not experience significant resistance from passengers. However, passengers were only willing to pay a green tax if they had evidence and governmental transparency that the revenue raised would be used to reduce the impact of aviation on the environment. Nonetheless, this indicates that passengers may be willing to accept the implementation of green taxes to air travel.

International Policy Agreements

In the consideration of international policy agreements, the governmental stakeholders group must now be considered to be comprised of two separate groups: governmental stakeholders representing developed economies and governmental stakeholders representing developing economies. This is due to the fact that aviation industries are often vital to economic growth in developing economies. This further complicates the implementation of international policy agreements to mitigate the role aviation plays in the harmful effects of society on the environment. As discussed by Ryley et al. (2010), at the time of the study, international aviation was excluded from international agreements that address targets for GHG reductions due to the absence of an internationally agreed upon methodology for allocating emissions at a national level. Furthermore, because the aviation industry is vital to the global economy, connecting markets, facilitating international trade, and supporting tourism, there is often little appetite to address its sustainability concerns (McManners, 2016).

Nonetheless, policies such as the European Union-Emission Trading Scheme (EU-ETS), discussed briefly in Rathore et al. (2020), have been established to help curb carbon emissions by creating various mechanisms of control and trade within multiple industries. However, this policy along with others like it tend to be opposed by developing economies such as India, China, South Africa, and Brazil due to government apprehensions that they will adversely affect their aviation markets (Rathore et al., 2020). Though Rathore et al. (2020) argues that concerns that measures like these and carbon taxes would adversely affect growth are far-fetched, they remain prominent in the ongoing debate regarding attempts to establish a sustainable aviation industry globally. This demonstrates the inherent difficulty in the implementation of international policy agreements between developing economies and developed economies: developing economies rely significantly on their aviation industries for their ongoing economic development. For the implementation of international policy agreements to succeed as a strategy to mitigate the harmful environmental effects of the aviation industry, further consideration to help address these concerns will be required.

Conclusion

In the consideration of the issue of sustainable aviation, there exists an interdependency between the technology and the society that requires an understanding not just of the technical challenges within this issue but also of the social dynamics surrounding it. Consequently, the successful implementation of strategies to address sustainability in aviation must consider the differing perspectives between relevant groups in society. Though none of the technical mitigation strategies considered, EAP, SAF, and broad design innovations, are likely to fully mitigate the environmental implications of the aviation industry alone, each of these strategies when implemented together, where feasible to do so, may substantially reduce and help mitigate the current sustainability issues associated with the aviation industry. When successfully combined with political and economic strategies such as green taxes and international policy agreements, the potential to significantly reduce the harmful implications of the current aviation industry model is immense. Though the issue of sustainable aviation remains a contested concept, fraught with differing perspectives and values, I believe a balanced approach employing each of the strategies I have discussed, perhaps in conjunction with others such as emissions trading schemes and more universally accepted international policy agreements, can help address the issue of sustainability in aviation in light of the social dynamics surrounding it. Following this kind of approach, the issue of sustainability in aviation may be effectively resolved.

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