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Examining Opportunities and Challenges for Addressing the Climate Impact of Aviation: A Narrative Review

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Abstract

Aviation is responsible for about five per cent of global greenhouse gas emissions through the burning of fossil fuels. This analysis explores the potential and obstacles of measures to reduce travel, energy use, and emissions in order to lessen aviation's impact on the climate in Sweden. Various efforts have been made to decrease aviation's climate impact, from regulations to alternative technologies for jet fuel. These efforts face multiple challenges, many rooted in social and political issues that are often overlooked in favour of technological fixes. One major hurdle is creating a market for alternatives to traditional jet fuel as consumer awareness and willingness to invest in these innovations remain limited. Current policy measures have proven ineffective at driving change; an understanding of aviation as a socio-technical system is essential moving forward. The significance of this review lies in its comprehensive examination of ways to diminish aviation's climate impact, presenting new perspectives and identifying areas for further research by considering all components, their interactions, and interdependence.

Keywords: Aviation, Climate impact, Air travel, Emissions reduction, Policymaking

1. INTRODUCTION

Aviation accounts for about 5% of human-caused global greenhouse gas emissions by burning fossil fuels in airplanes (Grewe et al., 2021). Aircraft emissions consist of carbon dioxide, nitrogen oxides, sulfate aerosols, various compounds, particles, and water vapor. These contribute to the creation of contrails that contribute to radiative forcing and global warming ((Grewe et al., 2021),(Lee et al., 2021)). In an increasingly decarbonizing world, the focus is on limiting the global temperature increase to meet the Paris Agreement's goal of staying below two degrees, The aviation sector needs to implement measures to decrease its carbon emissions and environmental footprint. While a broad range of research exists, including suggestions for introducing air travel taxes (Sonnenschein & Smedby, 2018), schemes for reducing emissions (Scheelhaase et al., 2018), alternative options for aviation fuel (Wang et al., 2019), novel aircraft types (Epstein & O'Flarity, 2019), and alterations in travel habits (Gößling et al., 2019)(Schäfer et al., 2018), There is a lot of existing research that is isolated, with only a few studies approaching their analysis from various disciplines. In this study, we take an all-encompassing approach by viewing the aviation industry as a socio-technical system with numerous stakeholders and factors. This perspective highlights the need for intricate changes at several levels(Kim et al., 2019), including technology, regulations, markets, cultural significance, infrastructure, scientific advancements and networks etc (Aviation Systems, 2011). The purpose of this paper is to examine the obstacles and possibilities for decreasing the environmental effects of air travel through measures to mitigate them, presenting fresh insights and highlighting areas that warrant additional research. We put into action the work of (Sovacool et al., 2018), who identified three elements that restrict the climate impact of air travel consumption: emissions per unit of energy used (emission intensity), energy usage per passenger kilometer (energy intensity), and passenger kilometers traveled per inhabitants and year (travel volume). We utilized this research as a theoretical framework in our review. These three factors serve as a starting point for identifying and evaluating measures aimed at addressing the individual challenges and opportunities, as well as achieving each factor to limit aviation's overall climate impact.

This evaluation centers on Sweden. While aviation is a worldwide industry with global regulations, each country has its own specific rules and guidelines for implementation. Sweden stands out due to its ambitious climate agenda aiming to reach net-zero GHG emissions by 2045(Evaluating the climate impact of aviation emission scenarios towards the Paris agreement including COVID-19 effects - Nature Communications, 2021) . Achieving the objective will involve reducing carbon emissions in the aviation sector, which currently represents about 5% of national greenhouse gas emissions (Larsson et al., 2019). Aviation plays a significant role in Sweden's economy, contributing SEK 130 billion (US$ 15 billion) annually to the country's GDP through industry-generated revenue and the accessibility provided by air travel.

However, reducing the GHG emissions from the aviation sector is a formidable task. To begin with, the Swedish Climate Act target for transport does not encompass aviation and focuses on decreasing transport emissions by 70% by 2030 in comparison to 2010 levels. This highlights political uncertainty and a deficiency of specific policy measures(Sovacool et al., 2018). Demand for international air travel has increased by more than three times in the past 30 years, with over 30 million passengers flying from Swedish airports before the COVID-19 outbreak (Sovacool et al., 2018). Emissions from global air travel have more than doubled since the 1990s, rising from 1354 ktCO2e in 1990 to 2826 ktCO2e in 2018. Currently, they make up around nine percent of total emissions from the Swedish transport sector. Demand for domestic air travel has experienced a slight decrease since the 1990s, dropping from 8.7 million passengers in 1990 to 7.6 million passengers in 2018 (Luftfart, 2020), Emissions from domestic air travel make up 2% of the total emissions from the national transportation sector, amounting to 531ktCO2e in 2018 (2017). The aviation sector has established a goal to accomplish carbon-neutral aviation for all flights leaving Swedish airports by 2045 (IATA, 2019). To support this and achieve the Swedish goal of reaching net-zero greenhouse gas emissions by 2045 (Climate policy, 2018), measures need to be put in place to reduce the environmental impact of the aviation industry. This paper examines the existing and possible actions that can be taken by the Swedish aviation sector, addressing its interdisciplinary challenges and opportunities, presenting fresh insights, and identifying areas for additional study.

The remaining part of our document is organized as follows. In Section 2, we outline the process of conducting our literature review. Section 3 outlines our discoveries categorized by travel volume, energy intensity, and emission intensity. Section 4 addresses the potential and difficulties related to the mitigation methods identified, emphasizing areas that require further investigation. Finally, in Section 5, we provide a conclusion.

2. MATERIAL AND METHODS

To assess the difficulties and potential benefits of mitigation strategies implemented to reduce the environmental impact of aviation, we conducted a narrative review that incorporated perspectives from diverse disciplines (Sovacool et al., 2018). This enabled us to explore sources beyond the usual areas of science, engineering, and economics to encompass studies from the humanities and social sciences that are pertinent to socio-technical transitions (Sovacool, 2014),(Köhler et al., 2019).

We started from the three factors proposed by(Alkemen, 2016) presenting potential methods to reduce greenhouse gas emissions from air travel. These factors mainly concentrate on how aircrafts operate and the emissions resulting from burning fossil fuel for jet propulsion. While this overlooks indirect emissions linked to the broader supply chain (such as airport services, airplane upkeep, fuel procurement, and distribution), operational aircraft activities contribute the most to overall emissions in the aviation sector (Transport system, 2018).

We employed a semi-structured method guided by the procedures. Our search encompassed diverse terms and covered literature from 2010 onwards in both English and Swedish. We conducted searches for scholarly works on Web of Science, SCOPUS, and Google Scholar using various combinations of keywords related to emissions, climate, and aviation. Even though our focus was primarily geographical with regard to Sweden, it is important to note that aviation is a worldwide industry with international institutional frameworks and technological advancements impacting national progress, operations, and decision-making processes2 (Fuenfschilling & Binz, 2018). We also conducted direct searches for unpublished materials related to the Swedish aviation industry from sources such as the International Civil Aviation Organization, European Commission, Swedish government, and commercial publications of companies within the Swedish aviation sector (e.g. airports, airlines, fuel suppliers).

The relevance of mitigation techniques proposed in literature was evaluated by reviewing abstracts and introductory texts. We repeated each search with modified terms to ensure comprehensive coverage and fill knowledge gaps. Our team qualitatively assessed the literature's applicability to emissions reduction in Sweden's aviation industry through discussions among co-authors drawing on our diverse backgrounds and expertise.

Throughout the research process, we placed an emphasis on introspection and reflexivity to guard against overreliance on keywords or predetermined labels found in publication titles or abstracts. We carefully considered ambiguities and conflicting perspectives that cut across social and technical sciences when interpreting review findings((Tracy, 2010);(Alvesson & Sandberg, 2020)). We present our results based on individual factors (such as travel volume, energy intensity, and emission intensity) and conduct a thorough evaluation of potential actions to reduce the impact for the Swedish aviation sector. We also discuss the potential opportunities and challenges associated with their implementation.

Table 1 Definition of three factors to reduce overall GHG emissions from the aviation industry

Factor	Definition
Travel Volume	Passenger kilometers travelled per inhabitant per year
Energy Intensity	Energy consumption per passenger kilometer over the aircraft operation cycle
Emission Intensity	GHG emission per unit energy consumed during aircraft operation

3. RESULTS

In this section, we outline the results of our narrative review. We collect perspectives from diverse fields and viewpoints, and analyze our findings based on travel volume, energy usage, and emission levels. (Table 1).

3.1. Volume of travel

Air travel has seen a rise in demand over the past ten years, with revenue-passenger-kilometers increasing by more than five percent annually(Lee et al., 2021). Recent projections indicate that there will be a continued increase in the demand for air travel, even in the aftermath of the COVID-19 pandemic. It is estimated to grow at a rate ranging from 2.4% to 4.1% annually over the next two decades(Wild et al., 2021). Travel volume, which measures the distance traveled by passengers per person each year, aims to decrease the amount of people traveling. It is influenced by institutional factors such as government regulations and social norms, resulting in shifts in individual travel patterns(Wild et al., 2021).

An example of a common rule used to decrease travel volume is the imposition of aviation ticket taxes. This indirect approach aims to reduce the environmental impact of air travel by leveraging demand elasticity to lessen the demand for travel. Sweden implemented such a tax in 2018 after conducting a special inquiry (SOU 2016:83)(Swedish Air, 2016). The tax is imposed on every traveler leaving, and the fee varies based on the distance to their destination (Tax on Travel, 2020). Airlines are required to pay the tax, but consumers typically end up bearing the cost through air ticket pricing((Faber, 2018),(Wild et al., 2021)). This tax has been implemented in 14 European countries(Delft, 2019), However, there is little proof that enforcing aviation ticket taxes at a national level leads to lower travel volume or reduced aviation emissions(Wild et al., 2021),(Falk & Hagsten, 2018). Moreover, there has been criticism of ticket taxes for causing air passengers to use airports in neighboring countries with lower taxes. This is evident in the situation of the Netherlands, where travelers depart from Belgium and Germany(Sonnenschein & Smedby, 2018),(Gordijn, 2020). Sweden is located on the outskirts of Europe, and air transportation primarily revolves around the capital city. Approximately 62% of air travelers pass through airports in Stockholm (Akermen, 2016), Denmark's neighboring country currently does not impose any ticket taxes (Delft, 2019).

Travellers from Sweden can easily reach Copenhagen Airport in Denmark instead of using southern airports like Gothenburg-Landvetter and Malmo. Additionally, there has been criticism that aviation ticket taxes do not effectively promote innovation within the industry itself (Sonnenschein & Smedby, 2018). Sweden's aviation tax is expected to generate 1.8 billion SEK annually, but instead of being allocated for efforts to minimize the industry's environmental footprint, the revenue goes into the general budget(Andersen, 2017). This inability to generate "revenue from recycling" was discovered by (Sonnenschein & Smedby, 2018) to reduce the amount consumers are willing to spend if tax revenues were not used for climate change mitigation and sustainable transport initiatives.

Advancements in information and communications technologies have enabled individuals to carry out tasks virtually rather than in person (such as telecommuting, virtual learning, online shopping, digital communication, and video calls), providing a type of "virtual mobility" without the requirement for physical travel(Mouratidis & Papagiannakis, 2021). Formerly regarded as a method to save time and money (Räsänen et al., 2010),The importance of ICT has been underscored by the COVID-19 pandemic due to national lockdowns, travel restrictions, and the closure of traditional offices (Mouratidis & Papagiannakis, 2021). Several research works have explored the effects of the pandemic on travel patterns, both worldwide (Abu-Rayash & Dinçer, 2020)(Wee & Witlox, 2021) nationally, such as in the US and Canada (Abu-Rayash & Dinçer, 2020),(Nguyen et al., 2020),(Conway et al., 2020)], the Netherlands (Drift et al., 2021),(Bezemer, 2021), Greece(Mouratidis & Papagiannakis, 2021), Sweden (Jenelius & Cebecauer, 2020)(Bohman et al., 2021) discussing the role of ICT and its influence on corporate travel (Nguyen et al., 2020),(Hiselius & Arnfalk, 2021). Sweden adopted a relatively lenient strategy for limitations in 2020, employing voluntary measures and suggestions. Swedes were encouraged to engage in remote work and refrain from non-essential travel. In a study involving more than 700 workers from five Swedish public organizations conducted by (Hiselius & Arnfalk, 2021) During the pandemic, just two percent of participants went on business travels in 2020, a significant drop from over 75% in 2019. This was made feasible by the availability of digital tools like telecommuting and virtual meetings, which provided an alternative solution for collaboration [(Hiselius & Arnfalk, 2021), p.9] when travel was no longer possible. (Conway et al., 2020), In a survey of more than 1000 US residents, it was discovered that air travel numbers decreased by 95% in 2020 compared to the previous year. Survey participants indicated expectations for changes in their future air travel habits post-pandemic, particularly among business travelers. Approximately 27% of those who travel for business anticipate reducing their air travel due to an increased dependence on digital communication technologies (Conway et al., 2020).

The long-term effects of the COVID-19 pandemic on air travel habits remain uncertain. Previous major events like 9/11 or SARS have demonstrated only minimal and temporary impacts on reduced travel behaviors(Cranenburgh et al., 2012). Air travel in Sweden is anticipated to make a recovery by 2022, with airlines seeing an uptick in numbers throughout the summer of 2021. It is expected to reach around 72% of the air traffic level seen in 2019(Kim & Salomon, 2002). Nevertheless, there is an anticipation of reduced business travel as telecommuting and remote online activities take its place (Mouratidis & Papagiannakis, 2021),(Hiselius & Arnfalk, 2021) ICT is unlikely to decrease personal travel, according to(Conway et al., 2020) Before the pandemic, there were indications that demand for air travel continued to increase despite improvements in ICT (Kim & Salomon, 2002);(Mokhtarian, 2009).

The discussion among consumers regarding the environmental effects of air travel has been ongoing in Sweden, as it is where the "flight shame" movement originated(Jacobson et al., 2020). The concept of flight shame is not an exact scientific description of a psychological response, but rather a catchy way to respond to an emotional conversation." (Doran et al., 2022) p.315]. It has become a phenomenon linked to the social environment and people's interactions with societal standards (Doran et al., 2022);(Gößling et al., 2020);(Mkono, 2020). 14% of Swedish individuals have reported ceasing air travel due to environmental concerns (Pearson, 2020). Investigating the concept of flight shame, which involved analyzing more than 650 survey responses in free text format Wormbs and So ̈derberg (Wormbs & Söderberg, 2021) The understanding of the environmental effects of air travel significantly influences people's decision to stop flying. Social media has and will continue to be instrumental in sharing and providing this knowledge, emphasizing the influence of technology on travel choices (Wormbs & Söderberg, 2021),(Mkono et al., 2020),(Becken et al., 2020). However, there are contrasting views on the potential effects of flight shame, prompting a need for further research into the psychological and socio-cultural aspects of broader discussions about climate change(Mkono, 2020) successful utilization of the movement will involve well-crafted environmental campaigns and policy measures to increase consumer awareness, building on the influence of role models like Greata Thunberg and the reflection brought about by the pandemic (Mkono et al., 2020),(Árnadóttir et al., 2021).

3.2. Intensity of energy use

Historically, the energy intensity of aircraft has mainly been restricted by fuel expenses, leading to a focus on technical methods. From 1968 to 2014, new aircraft consistently achieved an approximately 1.3% reduction in annual fuel consumption(Kharina, 2014). However, over the past 15 years, acknowledging the environmental influence of a ir travel(Lee et al., 2009), Policy regulations at a global level have aimed to enhance aviation fuel efficiency and restrict energy intensity.

Table 2 Energy intensity improvement options.

Improvement category	Improvement actions
Operations modification	Optimise fuel uplift
	Optimise cruise speed and altitude
	Performance based descent and approach
	On-wing engine wash
	No auxiliary power unit operations on ground
	Reduce the number of engines used during taxiing
Fleet retrofit	Cabin modification
	Electronic flight bags
	New engines
	Winglet installation
New aircraft introduction Payload capacity	New and larger aircraft
	Increase in cabin density, seat quantity
	Altering flight schedules
	Code sharing

Table 3 Measures to reduce energy intensity incorporated by some Swedish airlines.

Airlines	Descriptions	Improvement
Scandinavia Airlines System (SAS)	Regular domestic, regional and international flights. Partially government owned.	2020:
		New aircraft introduction
		Operations modifications
Braathens Regional Airlines (BRA)	Regular domestic and regional flights. Privately owned.	2018:
		Operations modifications
		Fleet retrofit
AirLeap	Regular domestic and regional flights. Privately owned.	2020:
		Operations modifications
Novair	International charter flights Privately owned and part of Apollo group.	2019:
		New aircraft introduction
		Operations modifications
TUIfly Nordic	International charter flights.	2018:
	Privately owned and part of TUI group.	New aircraft introduction

In 2010, the International Civil Aviation Organization, a specialized agency of the United Nations focused on being the primary platform for global aviation discussions” (Lee et al., 2009), The decision was made to enhance worldwide fuel efficiency in the aviation industry by 2% annually up to 2020, followed by a target of achieving a 2% global improvement each year from 2021 to 2050 (ICAO, 2016). As an additional motivation for the advancement and implementation of technology, the ICAO Council approved the CO2 emission standard for new aircraft in 2017. This standard regulates cruise fuel efficiency, which affects future commercial aircraft and business jet emissions (ICAO, 2017). ICAO resolutions have led to a wide variety of choices for enhancing energy efficiency through changes in airline operations, retrofitting fleets, introducing new aircraft, and expanding payload capacity (Yin et al., 2016).

The costly nature of the improvement choices, as shown in Table 2, may deter airlines with limited budgets from participating in efficiency enhancement efforts. Additionally, depending on factors like aircraft age and fleet usage patterns, some options may not be financially feasible or technically viable (Yin et al., 2017).

Table 3 displays the adoption of enhancement initiatives by airlines in Sweden. It is evident that carriers with more robust financial support are better positioned to upgrade their aircraft fleet, aligning with expectations to (Yin et al., 2016). The most effective method to reduce energy intensity is through the International Air Transport Association(Yin et al., 2016). Enhancing cabin density or load factor has the potential to decrease an airline's fuel consumption. (Yin et al., 2016),(Morrell, 2009),(Miller et al., 2019). Based on Morrell’s (Morrell, 2009) Based on estimates, a 0.83% reduction in fuel consumption could be attained for every 1% rise in seat capacity within a short- and medium-haul airplane. However, this alternative might no longer be considered risk-free for public health after the pandemic. Research using simulations and experiments has led to the conclusion that the potential transmission of aerosols or particles during flights is likely (Desai et al., 2021)(Li et al., 2021)(Talaat et al., 2021) and the possibility of infection cannot be discounted. Therefore, adhering to social distancing measures while on board is essential in order to restore travelers' trust in air travel (Khatib et al., 2020). A research carried out by Song and Choi found that after the COVID-19 pandemic, travelers in Korea showed reduced willingness to fly in a confined cabin space(Song & Choi, 2020). Alongside the ICAO's global aspirational goal and CO2 emission standard, the Swedish government has suggested implementing varied takeoff and landing fees at Stockholm-Arlanda and Gothenburg-Landvetter airports from 2022 as part of its intensified climate impact mitigation effort.

The updated pricing system will result in varied charges for individual flights operated by different types of aircraft, based on their environmental impact and fuel composition. Aircraft with lower energy efficiency will incur higher fees for takeoff and landing, creating an indirect incentive for airlines to upgrade their fleet with more energy-efficient models (Song & Choi, 2020). However, according to a study on European airport competition, airports may reduce their airport charges during times of crisis in order to maintain competitiveness. Introducing climate-related takeoff and landing fees alongside the ICAO recommended landing charges (ICAO, 2012) while the industry is recovering from the pandemic could lead these airports to lose traffic to competitors that do not impose such fees.

3.3. Intensity of emissions

(Lee et al., 2021) The overall global warming potential of aviation over a 20-year period is estimated to be potentially three times higher than just accounting for CO2 emissions. Aviation emission intensity is defined as the emissions per unit of energy consumed during aircraft operation (Sovacool et al., 2018), Policy measures, advancements in technology leading to reduced fuel consumption and the implementation of innovative technologies, as well as changes in travel volume, all play a role in impacting aviation emissions. In Sweden, aviation's emission intensity is regulated at both national and international levels. As a member state of the ICAO and the European Union, Sweden takes part in the EU Emissions Trading System and the ICAO Carbon Offsetting and Reduction Scheme for International Aviation. These global initiatives are designed to establish market-based platforms aimed at curbing the rise of greenhouse gas emissions while also encouraging investments in climate mitigation efforts. The ETS functions on a cap-and-trade principle where annual CO2 emissions from aviation are limited through allocated emission allowances for airlines. Under this system, 82% of allowances are provided to airlines without cost, 15%

are auctioned off, and 3% are reserved for new market entrants or rapidly expanding operators (EU-ETS, 2016). Airlines have the option to exchange their allowances as necessary. As time passes, the allowance budget will decrease, leading to a further reduction in CO2 emissions. In contrast, CORSIA seeks to attain global carbon neutral growth by offsetting any rise in total CO2 emissions from international flights based on 2019 levels(CORSIA, 2019). Airline operators will need to purchase CORSIA eligible emissions units from certified offsetting programmes in order to counteract the increased emissions. Swedish airlines, operating within the EU and ICAO's jurisdiction, are required to buy additional allowances from ETS if their flights' total emissions surpass allocated limits in a calendar year. They also have an obligation to share offsetting costs with other CORSIA participating airlines for common routes outside of the EU and EEA where CO2 emissions exceed the 2019 baseline level. However, there are doubts about the effectiveness of both schemes due to criticisms aimed at ETS for providing too many free allowances to the aviation industry, indirectly encouraging greenhouse gas emissions (Nava et al., 2018). Secondly, after adjusting its emission baseline from the 2020 level to that of 2019 in response to the impact of the COVID-19 pandemic on aviation industry(CORSIA, 2020), CORSIA might not discourage emissions or provide airlines with incentives to take climate mitigation actions, as offsetting may be inconsequential for the slowly rebounding industry (Zhang et al., 2021). Thirdly, the collective offsetting of emissions under the CORSIA scheme may not provide individual polluters with motivation to pursue emission reduction options(Winchester, 2019). Finally,,both schemes fail to consider non-CO2 emissions (Scheelhaase, 2019),(Forster et al., 2006).

The combined impact of the current versions of both programs, working alongside each other, is not expected to result in a significant reduction in aviation emissions (Scheelhaase et al., 2018). Applying this reasoning to the Swedish context, (Larsson et al., 2019) The two plans were predicted to result in a 0.8% decrease in annual CO2 emissions, which falls short of meeting the climate objectives set by Sweden and the EU. Innovative technologies are being investigated to reduce aircraft emissions, including alternative fuels and propulsion systems (Melo et al., 2020),(Bauen et al., 2020).

Sustainable aviation fuels, such as advanced biofuels and electrofuels, are seen as the current solution for lowering emissions. However, hydrogen fuels and electric propulsion systems are being proposed for future carbon-free aviation. (Bauen et al., 2020)(Bauen et al., 2020).

Sustainable aviation fuels, which include advanced biofuels and electrofuels, have been approved as alternatives to fossil-based jet fuel for aviation (EU Directive, 2018)SAF can be blended with fossil-based jet fuel at a ratio ranging from 5% to 50%, depending on the feedstock and production pathways chosen (2014). Advanced biofuels and electrofuels differ mainly in the raw materials utilized for fuel production. While advanced biofuels can be derived from non-food or feed crops biomass, as well as residual oil feedstock, electrofuels have a different source altogether (Wang et al., 2019),(Mkensy, n.d), Electrofuels, also known as power-to-liquid fuels, are generated from green hydrogen and non-fossil CO2 (Goldmann et al., 2018). Hydrogen is recognized for its use as a fuel in generating aircraft propulsion, either by supplying directly to a hydrogen combustion engine or by converting it into electricity in a fuel cell that powers an electric motor (Baroutaji et al., 2019). Hydrogen fuel demands adjustments in aircraft and engine designs, unlike SAF (Baroutaji et al., 2019) as well as establishing the necessary infrastructure for producing, storing, and transporting hydrogen. (Dahal et al., 2021),(Ratnakar et al., 2021). Similarly, aircraft with turboelectric, hybrid electric, or all-electric propulsion systems (Schäfer et al., 2018),(Bowman et al., 2018)] new technologies will also require advancements in aircraft power and propulsion systems (Bowman et al., 2018). The implementation of electric airplanes would also require an upgrade to the existing power supply system and the establishment of essential charging infrastructure(Trainelli et al., 2021).

In 2020, the Swedish government suggested a requirement to reduce greenhouse gas emissions in jet fuel , mandating the requirement to mix advanced biofuels with fossil-based jet fuel from 1% volume in 2021 to 30% volume in 2030 (Kousoulidou & Laura, 2016). To date, Sweden has no operational SAF production facilities and depends on imports from companies like NESTE and SkyNRG, which mainly manufacture oil-derived SAF (Kousoulidou & Laura, 2016). Some researchers and industry experts believe that the Swedish forest has the potential to supply enough feedstock for significant national production of SAF (Gruttola & Borello, 2021).Demonstration projects such as LTU Greenfuels are illustrating the technical viability of producing SAF in Sweden (Gruttola & Borello, 2021) flying using forest waste in the Småland region. However, there is worry that significant production of SAF in Sweden could lead to unintended impacts (Bryngemark, 2019) create adverse effects for industries depending on forestry in Sweden, like the paper and pulp sector(Jåstad et al., 2019), heat and power (Bryngemark, 2019) and road transport (Soam & Börjesson, 2020) due to competition for resources. Additionally, the EU forest strategy recently suggested prioritizing the role of forests as a carbon sink for EU member states , may impede the potential for commercializing bio-based SAF in Sweden. Additionally, the projected high production costs and unit prices (Dahal et al., 2021) potentially undermine the economic feasibility of domestic SAF production, especially in cases where there is limited public funding. In Sweden, an organization called Fly Green Fund was set up as a non-profit effort to secure private investments aimed at stimulating local SAF production. Initial results from (Goding et al., 2018) A research on the preferences of business travelers for bio jet fuel found that just 30% of the businesses surveyed in Sweden were open to paying for advanced biofuels for their travel. The willingness of Swedish consumers to pay for biofuel is mostly unclear. When it comes to sustainability, most studies focus on investigating the life cycle environmental impacts of SAF (Melo et al., 2020);(Siddiqui & Dinçer, 2021);(Kolosz et al., 2020) Based on historical and theoretical instances, these findings pose a challenge when applied to the Swedish context, where the viability of future widespread SAF production is being questioned. Furthermore, there is still limited understanding of the non-CO2 impact of biofuels, leading to diverse conclusions (Sundararaj et al., 2019),(Krammer et al., 2013). Electrofuels (PtL) aviation is considered by the EU as a substitute for biofuel-based SAF(Krammer et al., 2013). The successful implementation of electrofuels relies heavily on the presence of CO2, whether biogenic or directly obtained from the atmosphere, and sustainable hydrogen production (Goldmann et al., 2018). (Hansson et al., 2017), A research on electrofuel potential in Sweden discovered that the country has advantageous conditions for production. If harnessed, the potential biogenic CO2 sources in Sweden could generate enough power for the entire Swedish transport system. Nonetheless, due to the lack of EU regulations, national policies, or economic incentives, it is challenging to promote bioenergy carbon capture, utilization, or storage (BECCU/S) commercially in Sweden ((Bellamy et al., 2021);(Fridahl et al., 2020);(Rodriguez et al., 2021)). Sweden has the ability to emerge as a prominent player in direct air capture. However, due to the lack of political strategies or technological development plans for capturing carbon from the air, BECCU/S currently remains the only feasible CO2 source for electrofuels production. Renewable electricity availability, and therefore green hydrogen, is a further constraint for electrofuels production (Goldmann et al., 2018). To address the possible high-level need for electrofuels in Sweden, (Hansson et al., 2017) a 60% rise in electricity production is needed. The most recent forecast from the Swedish Energy Agency, The expected rise in electricity consumption within the transportation industry is predicted to result primarily from the shift towards electric-powered road transport. This suggests that there has been little focus on incorporating plans for electrofuels or hydrogen production into the national energy strategy. Additionally, the initial high cost of production presents another obstacle that may restrict the potential commercial advancement of electrofuels in Sweden (Larsson et al., 2015). Research has evaluated the environmental sustainability of electrofuels, similar to advanced biofuels (Schmidt et al., 2018),(Isaacs et al., 2021),(Ordóñez et al., 2021) but they do not consider the sustainability of BECCS/U, which is the relevant CO2 source for Swedish production. Similarly, little research has been done on the non-CO2 effects of electrofuels, and its overall climate impact remains uncertain (Penke et al., 2020).

In Sweden, the production and utilization of hydrogen is not a recent development. Currently, chemical and metallurgical processes are the primary applications for hydrogen (Pei et al., 2020). Green hydrogen's application in the steel production industry (Pei et al., 2020);(Toktarova et al., 2020)(Karakaya et al., 2018) One of the latest sustainable advancements created in the nation is green hydrogen. With various industrial players announcing new investment plans, the potential need for green hydrogen in Sweden could reach 61 TW, equivalent to 81 TWh of renewable electricity—approximately half of Sweden's electricity production in 2019 (2016)— by 2045 (Pei et al., 2020). In addition to the absence of a well-developed pipeline network, unlike countries like Germany and France, Sweden's lack of infrastructure is viewed as a barrier to collaboration with continental Europe in hydrogen development (Fossle Free Sweeden, 2021).

Industrial stakeholders are highlighting the necessity for updated policies and regulations to support a viable hydrogen economy. Significant barriers, such as high production costs, limited fuel infrastructure, and airport operational procedures, continue to hinder the adoption of hydrogen in aviation(Baroutaji et al., 2019). Limited general knowledge on the safety of hydrogen Propulsion technology (Benson et al., 2019),(Benson et al., 2020) could potentially impede the public's acceptance of hydrogen-powered aircraft. To date, there have been no surveys on the attitudes of the Swedish public towards aircraft fueled by hydrogen. With regard to sustainability, the few studies assessing environmental impacts of hydrogen propulsion (Biçer & Dinçer, 2017),(Ingenito, 2018) The broader sustainability effects of necessary infrastructure, such as specific green energy, storage, and transportation, are not fully considered. Despite research carried out by Ingenito studies on the effects of hydrogen-powered aircraft on ozone layer depletion found that the potential climate impact from water vapor emissions might be minimal. However, there is still no consensus in the scientific community regarding the overall non-CO2 effect of hydrogen-powered aircraft (Penke et al., 2020).

Sweden has been a pioneer in promoting electric aviation. In 2018, the Swedish innovation agency Vinnova provided funding for the Electric Aviation in Sweden project, which aims to facilitate the advancement and utilization of electric aircraft in Sweden (Ingenito, 2018). Heart Aerospace was established in Gothenburg in the same year as a result of the ELISE project, focusing on all-electric aircraft manufacturing(Ingenito, 2018). In 2019, Nordic Innovation established the Nordic Network for Electric Aviation to coordinate and improve collaboration among the Nordic countries' efforts in electric aviation (NEA, 2019). Subsequently, the FAIR project aims to discover innovations to expedite the implementation of electric regional aviation (Kurdve et al., 2019)The project was initiated to explore the possibility of establishing commercial electric flight routes in the Kvarken region of northern Sweden and Finland. Current research and projects mainly concentrate on the technical aspects of aircraft design and flight routes, with little emphasis on areas such as battery management or airport infrastructure improvement. Insights from studies related to electric vehicle battery circularity may provide valuable knowledge for this purpose (Kurdve et al., 2019) and second life business models (Olsson et al., 2018),(Gur et al., 2018) it's possible that the findings could apply to aviation as well. However, there is little proof that lithium battery recycling methods or supply chain networks for battery recovery are well-established in Sweden (Gur et al., 2018). From an operational perspective, strategies for swapping and recharging batteries in electric aircraft require careful planning and optimization, particularly when it comes to adjusting the current electric grid (Salucci et al., 2019),(Salucci et al., 2019). A new partnership between the Swedish Civil Aviation Administration and electricity supplier Vattenfall at Örnsköldsvik airport demonstrates that Sweden is making progress in planning and researching airport charging infrastructure.

Highly technology-driven projects and initiatives currently lack thorough consideration of consumer viewpoints (Han et al., 2019), The researchers' study on the factors affecting consumers' willingness to travel by electric aircraft revealed that perceptions of environmental friendliness, emotional connections, attitudes, and ethical considerations may impact this willingness. However, lack of awareness and confidence, Han et al. (Han et al., 2019) It was thought to be challenging to elicit consumer acceptance or willingness to make a payment. The absence of both direct CO2 and non-CO2 emissions has played a significant role in creating the low climate impact profile of electric aircraft ((Schäfer et al., 2018),(Gnadt et al., 2019)). On the flip side, experts stressed that achieving a low life cycle climate impact would only be possible by using renewable electricity to charge electric aircraft (Schäfer et al., 2018),(Baumeister et al., 2020). Based on the presented estimations by (Schäfer et al., 2018), In 2015, approximately 0.6–1.7% of the global electricity consumption would have been necessary to operate a worldwide fleet of short-haul all-electric aircraft, suggesting a potential transfer of environmental impact from the aviation sector to the energy industry. Expanding on the analysis conducted in the automotive sector (Lombardi et al., 2017), Potential changes in environmental impact, such as increased human toxicity, acidification, or eutrophication, could occur due to battery handling processes. However, the overall environmental effects of electric aviation are specific to each country and require future assessments to determine their potential impact on Sweden's environment.

4. DISCUSSION

Sweden aims to accomplish fossil-free air travel by 2045, necessitating steps to minimize emissions and mitigate the environmental impact of the aviation sector. This study examined existing and prospective strategies for reducing emissions in order to achieve this goal (Sovacool et al., 2018) Previously recognized as ways to reduce the environmental impact of air travel. Our study of Sweden considered a wide range of perspectives to analyze their potential benefits and obstacles.

The enduring impacts of the COVID-19 pandemic remain uncertain, presenting both advantages and disadvantages for the aviation industry. On one hand, the pandemic allows businesses to test the capability of ICT in conducting digital meetings and conferences, introducing a new form of virtual mobility that reduces the necessity for travel. Initial findings suggest that ICT could replace a substantial portion of future business travel post-pandemic in numerous countries, including Sweden. Conversely, personal travel is expected to return to pre-pandemic growth rates as national lockdowns are lifted; mirroring previous disruptive events' impact on travel patterns.

As the aviation industry's expansion is driven by demand, one way to mitigate its climate impact is by reducing travel volume. However, policy measures designed to decrease travel demand may result in aviation leakage, a concept we have derived from carbon leakage. This refers to the shift of production to other countries with less strict emission regulations, ultimately causing higher emissions. The implementation of an aviation ticket tax could potentially lead consumers to opt for departure from neighboring countries with little or no taxation rather than paying a higher ticket price.

This could lead to airlines relocating their activities to airports in other countries, such as Denmark. Additionally, having different takeoff and landing fees could cause air traffic leakage between airports and countries, with airlines moving their operations to fee-free airports. This not only has financial implications for local airports but also restricts choices for consumers. Furthermore, less efficient aircraft may continue operating from alternative airports without promoting improvements in aircraft fuel efficiency or reducing GHG emissions. In addition to policies aimed at reducing travel volume, the use of ICT or social norms like flight shaming will likely influence consumer acceptance and willingness to pay in shaping the future of the aviation industry. It's important to consider that a decrease in air travel doesn't necessarily mean a reduced overall climate impact on transportation if travelers start using environmentally harmful modes such as long-distance road-based transport with combustion engines. The incremental improvements outlined in ICAO resolutions require investment and may not be accessible to airlines with limited financial resources. As consumer awareness of aviation's climate impact grows, airlines operating inefficient fleets could lose appeal to passengers, leading to decreased ticket sales and further limiting their financial resources for investments.

Innovative technologies provide alternative options to fossil-based jet fuel, but they face various challenges including cost, investment requirements, market formation difficulties, political support issues, and gaining consumer acceptance. While forestry residues have potential as feedstock for sustainable aviation fuel production; high costs; lack of production facilities; limited government interventions; concerns about sustainability and competition for feedstock; plus low consumer willingness-to-pay are current hurdles for the advancement of advanced biofuels in Swedish aviation. Forestry's role in Sweden’s transition toward a fossil-free future is politically contentious due to debates over its suitability as a fuel source or carbon sink.

Electrofuels provide an alternative to bio-based SAF, but they also lack the same political incentives and commercial investments in biogenic carbon capture and use facilities. Additionally, using captured biogenic carbon may be perceived as contradictory by consumers and policymakers since it involves re-releasing CO2 during fuel combustion, which contradicts the purpose of carbon removal technology. Hydrogen fuels could have a significant impact on Sweden's fossil-free future with potentially high demand from various industrial sectors. However, transitioning to a hydrogen-based economy will require coordinated top-down regulation and long-term strategic planning along with substantial infrastructure investment. Electric aviation has strong support in Sweden and has the potential to drive regional and industrial development in rural areas, especially in the North. But both hydrogen fuels and electric aviation present technical, operational, safety considerations as well as challenges such as developing new aircrafts or investing in refuelling and charging infrastructure for aircrafts. Furthermore, there is limited understanding about consumer perspectives on these disruptive innovations - their confidence levels regarding this technology or willingness to pay for them remains unknown.

4.1. Directions for further research

Measures to mitigate the climate impact of aviation encounter various challenges, underscoring the complex nature of the industry and highlighting the need for further study. Evaluating both current and proposed policy measures is crucial to determine their efficacy in reducing aviation's climate impact. Additionally, it's important to examine consumer behavior within the industry, including the influence of environmental awareness on willingness to pay, as well as factors such as social media and long-term effects of COVID-19 on travel patterns.

Additionally, current research on life cycle assessments focusing on the environmental sustainability of alternatives to fossil-based jet fuels has concentrated on a limited set of predetermined pathways. Few studies have taken into account potential environmental impacts resulting from societal changes, political decisions, and business strategies, thus failing to consider potential burden shifting effects. Further research needs to take into consideration the environmental sustainability of innovative technologies beyond their technical aspects and encompass socio-economic as well as socio-political perspectives. Furthermore, future studies should also address the non-CO2 effects associated with the combustion of fossil-based jet fuel, SAF (sustainable aviation fuel), and hydrogen fuels in order to assess the overall environmental impact of aircraft operation.

Further research should move beyond small improvements and innovations that have characterized aviation's development. Instead, it should focus on radical solutions to break the industry's reliance on carbon and established paths. Incremental changes like turbine efficiency improvements and operations modifications will not be enough to decarbonize the industry by 2045. Larger-scale, transformative change is necessary, including developing alternatives to fossil-based jet fuels and addressing socio-economic challenges hindering innovative technology adoption such as SAF, hydrogen fuels, and electric aircraft.

4.2. Limitations

This review was conducted during the COVID-19 pandemic, which has had a significant impact on the global and national aviation industry. Previous disruptive events like the 2008 financial crisis have had a short-term effect on aviation, but the industry has shown resilience in recovering from such disruptions. However, it is uncertain whether this will be the case following the COVID-19 pandemic. Literature reporting on and speculating about its long-term impacts is limited, as reflected in our review.

Secondly, we opted for a semi-structured method to explore the literature. This allowed us to gather a wide range of findings from various research fields. However, this approach may have caused us to miss out on certain literature or areas of research. While our focus was on Sweden, it's possible that this led to a bias towards geographic information and resulted in overlooking valuable research from other regions.

Thirdly, the review starts by considering three key factors - travel volume, energy intensity, and emission intensity - as a framework for analyzing our discoveries. These elements address the climate effects associated with air travel consumption including direct emissions from aircraft operations (Sovacool et al., 2018). This represents the largest portion of emissions from the entire sector, but indirect emissions associated with airport services, maintenance, supply chains, or other aviation services are not included in this study's system boundaries. This review is limited by this factor and underscores the importance of examining the broader elements of the aviation system beyond just aircraft operation in future research.

5. CONCLUSION

This paper offers a thorough exploration of the complex landscape surrounding the mitigation of environmental impacts associated with air travel, providing nuanced insights into both the formidable challenges and promising opportunities inherent in implementing mitigation strategies. Through a meticulous examination, novel perspectives have been introduced, and avenues for further investigation have been elucidated. Departing from the multifaceted pathways delineated by Åkerman et al. and (Sovacool et al., 2018)), efforts to mitigate the environmental effects of air travel are anchored in a multifaceted approach aimed at reducing travel frequency, optimizing energy usage, and minimizing emissions. The aviation industry has demonstrated a commendable commitment to addressing its climate impact through a variety of initiatives, including regulatory measures and the exploration of alternative technologies for jet fuel. However, the journey towards sustainability is fraught with challenges that extend far beyond technological innovation, encompassing deeply entrenched socio-economic and political dynamics. Indeed, our analysis underscores the significant hurdle posed by the creation of a viable market for eco-friendly flight technologies and fuels. Despite an increasing awareness of environmental concerns among air travel consumers, there remains a palpable reluctance to shoulder the additional costs associated with these alternatives, whether through carbon taxes or biofuel-based options.

Furthermore, our meticulous investigation has not only highlighted critical gaps in existing research but also underscored the pressing need for a more expansive and interdisciplinary inquiry into the myriad dimensions of sustainable aviation. This imperative extends to several key areas that demand rigorous examination and analysis. Firstly, there is a compelling necessity to delve into the future requirements for recycling batteries utilized in electric aviation. As the industry increasingly pivots towards electrification to reduce emissions, understanding the lifecycle implications of these batteries and devising efficient recycling mechanisms are paramount. Additionally, the integration of aviation's escalating electricity demands into national power planning frameworks warrants meticulous consideration. With the advent of electric aircraft and the growing adoption of electric ground support equipment, the aviation sector's electricity consumption is poised to surge. Consequently, a strategic and coordinated approach to integrating these demands into national energy policies is imperative to ensure sustainable energy supply and grid stability. a nuanced exploration of potential competition for forest products utilized in biofuel production across various industries is essential. As biofuels gain traction as a viable alternative to traditional jet fuels, concerns regarding resource competition, land use, and environmental sustainability come to the forefront. Understanding the intricate dynamics of this competition and its implications for forest ecosystems, biodiversity, and socio-economic development is crucial for devising effective and equitable biofuel policies.

Despite the commendable strides made in addressing the environmental ramifications of air travel, it remains evident that substantial hurdles lie ahead on the journey towards sustainability. As we navigate the path forward, it is imperative that concerted efforts are directed towards surmounting entrenched socio-economic barriers, cultivating broad acceptance of eco-friendly alternatives, and propelling forward holistic research agendas that comprehensively address the diverse facets of sustainable aviation. Only through collaborative and interdisciplinary approaches can the aviation industry successfully traverse the intricate landscape towards a more environmentally conscious and sustainable future—a future characterized by robust environmental stewardship, while simultaneously nurturing ongoing growth and innovation within the sector.

Delving into the imperative task of comprehending aviation's requirements to mitigate its environmental footprint, it becomes evident that a multidisciplinary approach is paramount. Such an approach necessitates the consideration of a plethora of disciplines, encompassing social, technical, economic, and political domains, all of which intersect to shape the trajectory of potential changes. While this review centers on Sweden as a case study, its insights hold the potential to serve as a blueprint for other nations grappling with similar conditions and challenges. The exhaustive analysis presented within this review traverses diverse pathways aimed at curbing aviation's climate impact, meticulously identifying both barriers and opportunities that could serve as guiding beacons for future research endeavors. However, to realize the ambitious goal of achieving fossil-free aviation in alignment with the decarbonization targets espoused by numerous countries, it becomes evident that a paradigm shift is indispensable. There emerges a compelling need for a novel research agenda that transcends incremental improvements, instead embarking on a quest to explore radical and disruptive innovations poised to supplant traditional jet fuel. Such a research agenda must be characterized by its boldness and ambition, pushing the boundaries of conventional wisdom and embracing pioneering approaches that challenge the status quo. By venturing into uncharted territory and fostering an environment conducive to experimentation and innovation, the aviation industry can pave the way for transformative change. Moreover, this necessitates a collaborative and interdisciplinary effort, harnessing the collective expertise and insights of stakeholders across various sectors and disciplines. While the road to achieving fossil-free aviation may be fraught with challenges, it is also replete with boundless opportunities for innovation and progress. By embracing a forward-thinking mindset and embarking on a journey of exploration and discovery, the aviation industry can chart a course towards a greener and more sustainable future—one that not only mitigates environmental impact but also catalyzes a paradigm shift in the way we conceive of air travel.

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