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Analysing the opportunities and challenges for mitigating the climate impact of aviation: A narrative review

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ABSTRACT

Aviation accounts for approximately five percent of global greenhouse gas emissions through the combustion of fossil fuels. This paper analyses the opportunities and challenges of mitigation measures in limiting travel volume, energy and emission intensity to reduce the climate impact of aviation in Sweden. Several measures are in place that aim to reduce the climate impact of the aviation industry, ranging from regulations to technology alternatives to fossil-based jet fuel. These measures face several crosscutting challenges, many of which are of a socio-economic and political nature, and these aspects are often neglected in favour of focusing on technological solutions. The market creation for alternatives to fossil-based jet fuel is a major challenge, as most consumers today have a limited awareness of and willingness to pay for these innovations. Policy measures in place are proven ineffective in incentivising change. An understanding of the industry as a socio-technical system is required. The value of this review is its broader consideration of the pathways to reduce aviation's climate impact, offering new perspectives and pointing to areas for further research considering all components, their interactions and interdependence.

1. Introduction

Aviation contributes approximately 5 % to anthropogenic global greenhouse gas (GHG) emissions through the combustion of fossil fuels in aircraft [1]. Emissions from aircraft include carbon dioxide (CO_2), nitrogen oxides, sulphate aerosols, compounds, particulates, and water vapour leading to the formation of contrails, which contribute to radiative forcing and global warming [1,2]. In a world that increasingly aims for decarbonisation and limiting global temperature rise to below the two degree goal of the Paris Agreement [3], the aviation industry must take steps to reduce its emissions and climate impact. Although there exists a wide scope of research, ranging from proposals for air travel tax implementation [4–6], emission reduction schemes [7–9], alternative aviation fuels [10–12], novel aircraft types [13–15], and changes in travel behaviour [16–18], much of this literature is siloed with few studies taking a multidisciplinary approach in their analysis. In this study we adopt a comprehensive approach, considering the aviation industry as a socio-technical system, with a myriad of stakeholders and actors, in need of complex changes at multiple levels [19], including technology, regulation, markets, cultural meaning, infrastructure, science and networks etc. [20]. The aim of this paper is to analyse the challenges and opportunities for reducing the climate impact of aviation through mitigation measures, offering new perspectives and pointing to areas for further research.

We operationalise the work of Åkerman et al. [21], who identified three factors for limiting the climate impact of the consumption of air travel: the emissions per unit of energy used (emission intensity), energy unit per passenger kilometer (energy intensity), passenger kilometer per inhabitants and year (travel volume). We build on this work, applying it as a theoretical framework in our review. The three factors provide an entry point for our search and assessment of measures in terms of their individual and complementary challenges and opportunities for achieving each factor and limiting the overall climate impact of aviation.

This review focuses on Sweden. Whilst aviation is a globally operating industry, with international legislation governing operations,

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national rules and regulations vary from country to country and the implementation of measures is, to a certain extent, geographically bound. Sweden is an interesting case as the country has an ambitious climate agenda that aims to achieve net-zero GHG emissions by 2045 [22]. Achieving the goal will require the decarbonisation and lowering of emissions in the aviation industry which accounts for approximately 5% of national GHG emissions [23]. Despite its notable climate impact, aviation in Sweden is a key economic sector, contributing SEK 130 billion (US$ 15 billion) a year to the country's gross domestic product through revenue generated within the industry and through the access that air travel entails [24].

However, mitigating the GHG emissions from the aviation industry is a challenging endeavour. Firstly, aviation is not included in the Swedish Climate Act target for transport which aims to reduce transport emissions by 70% by 2030 compared with 2010 levels, indicating political ambiguity and a lack of direct policy [25]. Secondly, demand for international aviation has more than tripled over the last 30 years, with over 30 million passengers travelling by air from Swedish airports prior to the COVID-19 pandemic [26]. Emissions[1] from international aviation have more than doubled since the 1990s, increasing from 1354 ktCO_2e in 1990 to2826 ktCO_2e in 2018 and today account for nine percent of the Swedish transport sector's total emissions [27]. Although demand for domestic aviation has fallen slightly since the 1990s, from 8.7 million passengers in 1990 to 7.6 million passengers in 2018 [26], emissions from domestic aviation account for 2% of the national transport sector's total emissions (531ktCO_2e in 2018) [27]. The aviation industry itself has set a target to achieve fossil-free aviation for all flights departing from Swedish airports by 2045 [23]. To support this and the achievement of the Swedish target of net-zero GHG emissions by 2045 [22], measures must be implemented to limit the aviation industry's climate impact. In this paper, we analyse the current and potential measures for the Swedish aviation industry to do this, focusing on their multidisciplinary challenges and opportunities, offering new perspectives and pointing to areas for further research.

The rest of our paper is structured as follows. Section 2 describes the process of our literature review. Section 3 presents our findings, structured according to factors of travel volume, energy intensity and emission intensity. Section 4 discusses the opportunities and challenges of identified mitigation measures, highlighting areas for further research, and Section 5 concludes.

2. Material and methods

To analyse the challenges and opportunities of mitigation measures in place to limit the climate impact of aviation we undertook a narrative review, drawing on insights from a variety of perspectives and disciplines [28]. This allowed us to search for literature beyond the traditional fields of science, engineering and economics to include research from humanities and social sciences relevant for socio-technical transitions [29,30].

We departed from the three factors put forward by Åkerman et al. [21] that present possible ways to mitigate GHG emissions from aviation (Table 1). These factors are predominantly focused on aircraft operation and emissions due to the combustion of fossil-based jet fuel. Although this neglects indirect emissions attributed to the wider value chain (i.e., airport services, aircraft maintenance, fuel supply and distribution), emissions from aircraft operations account for the majority of emissions from the aviation industry [31].

We took a semi-systematic approach following the steps shown in Fig. 1 [32]. We used a variety of search terms considering literature from 2010 onwards in English or Swedish. We searched for academic literature in Web of Science, SCOPUS and Google Scholar using multiple

[1] GHG emissions are calculated based on domestic and bunker fuel emissions and reported by the Swedish Environmental Protection Agency [27].

Table 1
Definition of three factors to reduce overall GHG emissions from the aviation industry from Åkerman et al. [21].

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

combinations of keywords focusing on emissions-, climate- and aviation-related search terms. Although we had a geographic focus on Sweden, aviation is a global industry with international institutional structures and technical innovation influencing national development, operation and decision-making[2] [33]. We also directly searched grey literature relevant to the Swedish aviation industry including International Civil Aviation Organization (ICAO), European Commission, Swedish government and commercial publications from the Swedish aviation industry (e.g. airports, airlines, fuel suppliers).

The relevance of mitigation methods put forward by literature was determined by scanning abstracts and introductory texts, repeating each literature search with an alteration of search terms in an effort to fill knowledge gaps (see iterative loop in Fig. 1). We qualitatively assessed literature's relevance for mitigating emissions from aviation in Sweden, discussing within our co-authored team anddrawing on our multidisciplinary backgrounds and knowledge.[3] We sought to promote introspection and reflexivity throughout the research process, helping us avoid overconfidence on the labels in the keywords, titles and abstracts of publications and consider ambiguities and conflicting perspectives in review findings that crosscut social and technical sciences [34,35]. We report our findings according to each factor (travel volume, energy intensity, emission intensity) and critically analyse mitigation measures relevant to the Swedish aviation industry and the possible opportunities and challenges for their implementation.

3. Results

In this section we present the findings of our narrative review. We gather insights from a variety of perspectives and disciplines and discuss our findings according to the factors of travel volume, energy intensity and emission intensity (Table 1).

3.1. Travel volume

The demand for air travel has increased in the last decade, with revenue-passenger-kilometres growing over five percent a year [2]. Recent estimates suggest that the demand for air travel will continue to grow, despite the COVID-19 pandemic, with an estimated growth rate between 2.4 and 4.1% per year across the next 20 years [36]. Travel volume, defined as passenger kilometers travelled per inhabitant per year, is concerned with reducing the number of people travelling and is constrained by institutional factors, both formally through government-led regulations and informally through normative social obligations, leading to a change in individual travel behaviours [37].

One common regulative rule aimed at minimising travel volume is

[2] For example, technical developments for aircraft often occur at the international level, through the research and development efforts of multinational corporations, whilst national initiatives can influence the operation of airlines or the travel behaviour of consumers. International institutions, such as the ICAO and EASA, set safety standards and regulate operations in Swedish airspace.

[3] Members of our co-authorship team have various disciplinary backgrounds from social sciences, business research, environmental engineering, industrial economics and management, and political science.

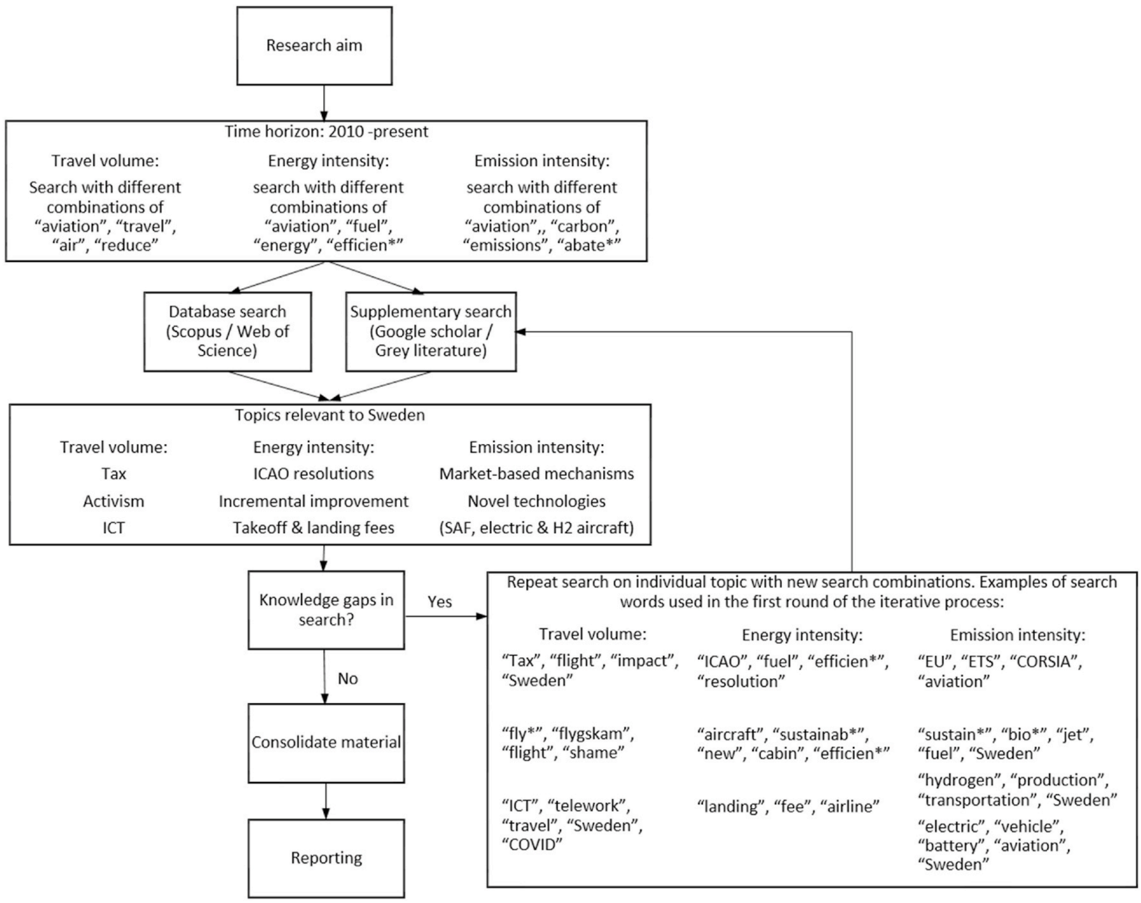

Fig. 1. Steps of semi-systematic literature review.

aviation ticket taxes; an indirect attempt to reduce aviation's environmental impact by utilising demand elasticity to reduce travel demand [4,38]. Sweden introduced such a tax in 2018 following a special investigation (SOU 2016:83) [39]. The tax is levied on each departing passenger and the cost differentiated depending on distance to travel destination [40]. Whilst the tax must be paid by airlines, the cost is most often borne by consumers through air ticket pricing [4,38]. In Europe, 14 countries have implemented this tax [41], yet there is limited evidence that national implementation of aviation ticket taxes translates to reduced travel volume or decreased aviation emissions [38,42]. Moreover, ticket taxes have been criticised for the relocation of air passengers to airports in neighbouring countries with lower taxes — as in the case of the Netherlands with travellers departing from Belgium and Germany [6,43]. Although Sweden is at the fringe of Europe, and air travel is capital-centric, with 62% of air passengers passing through Stockholm's airports [26], neighbouring Denmark currently has no ticket taxes [41]. Copenhagen Airport in Denmark is accessible to Swedish travellers who might otherwise depart from southern airports such as Gothenburg-Landvetter and Malmö. Moreover, aviation ticket taxes have also been criticised for failing to encourage innovation within the industry itself [6]. Although Sweden's ticket tax is projected to create 1.8 billion SEK per year, the revenue is returned to the general budget rather than earmarked for initiatives to reduce the environmental impact of the industry [44]. This lack of revenue "recycling" was found by Sonnenschien and Smedy [6] to lower consumers' willingness to pay if tax revenues were not allocated for climate change mitigation and sustainable transport projects.

Improvements to information and communications technologies (ICT) has allowed people to perform activities virtually instead of physically (i.e. telework, online learning and shopping, digital communication and video calls) offering a form of "virtual mobility" without the need for travel [45]. Previously considered to be a time and cost saving [46], the COVID-19 pandemic has highlighted the value of ICT in light of national lockdowns, travel bans and the closure of physical workplaces [45,47]. Several studies have considered the impact of the pandemic on travel behaviour, both globally [48–50] and nationally — US & Canada [48,51,52], the Netherlands [53,54], Greece [45], Sweden [55–57] — with discussion of the role of ICT and impact on business travel [52,55]. Sweden took a relatively liberal approach to restrictions during 2020, with voluntary measures and recommendations. Swedes were advised to work from home and avoid unnecessary travel. In a survey of over 700 employees from five Swedish public agencies, Hiselius and Arnfalk [55] found that during the pandemic only two percent of respondents took business trips during 2020 compared to over 75% in 2019. This was possible thanks to digital tools such as telework and virtual meeting offering a "backup collaboration solution" [55, p.9] when travel was no longer an option. Similarly Conway et al. [52], in their survey of over 1000 adults living in the US, found that air passenger numbers were down 95% in 2020 compared to 2019. Respondents anticipated changes in their future air travel post-pandemic, particularly for business trips, with 27% of business travellers expecting to reduce their air travel, thanks in part to an increased reliance on digital communication [52].

As COVID-19 pandemic is ongoing, the long-term impact on air travel behaviours is yet unknown. Previous disruptive events, such as 9/11 or SARs, have shown only minor lasting effects on decreased travel patterns [58]. In Sweden, air travel recovery is projected for 2022 and expected to reach 72% of the level of air traffic in 2019, with airlines reporting increasing numbers across Summer 2021 [59]. Nevertheless, there remains an expectation for a decrease in business travel, having been replaced by teleworking and remote online activities [45,47,55]. At the same time, ICT is less likely to reduce personal travel [52] and pre-pandemic trends indicated that, despite improvements to ICT, demand for air travel has continued to rise [60–62].

The consumer debate about the climate impact of aviation has been ongoing in Sweden, as the birthplace of the so-called “flight shame” movement [18]. Flight shame is not a “precise scientific description of a psychological reaction … but a click-friendly response to an emotional discourse” [64 p.315]. It has emerged as a phenomena associated with the social environment and individuals’ encounters with social norms [64–66]. In Sweden, 14% of Swedes have said they stopped flying because of the climate [67]. In their investigation of flight shame, involving the analysis of over 650 free text survey responses, Wormbs and Söderberg [63] found that knowledge of the climate impact of aviation plays the biggest role for individuals choosing to stop flying. Social media has, and will continue, to play a role in distributing and providing this information, once again highlighting the role of ICT in impacting travel behaviours [63,68,69]. However, there is diverging opinions on the potential impact of flight shame, with a call for more research considering the psychological and socio-cultural dynamics of general climate change discourse [66] and suggestions that, to successfully harness the movement, the influence of role models such as Greata Thunberg and the introspection of the pandemic requires well-designed environmental campaigns and policy measures to raise awareness amongst consumers [68,70].

3.2. Energy intensity

Historically driven by fuel costs, constraining the energy intensity of aircraft has predominantly been through technical means. Between 1968 and 2014, an average new aircraft achieved an annual fuel burn reduction of about 1.3% [71]. However, in the last 15 years, recognising the climate impact of aviation [72], policy regulations at an international level have sought to further improve aviation fuel efficiency and limit energy intensity.

In 2010, ICAO, a UN special agency that aims to “serve as the global forum for international aviation” [73], adopted the resolution to improve aviation’s global fuel efficiency by 2% per year until 2020, and an aspirational 2% global improvement per year from 2021 to 2050 [74]. As a further incentive for technology development and deployment, the ICAO Council adopted the CO_2 emission standard for new aircraft in 2017, regulating cruise fuel efficiency and thus CO_2 emission for future commercial aircraft and business jet delivery [75,76]. The ICAO resolutions have since instigated a vast range of options to improve energy intensity through airline operations modification, fleet retrofit, new aircraft introduction, and payload capacity expansion [77]. However, the high price tags attached to the improvement options [78], as illustrated in Table 2, could discourage airlines with limited budgets from partaking in these efficiency improvement efforts, and depending on factors such as aircraft age and fleet use patterns, the options may not be financially viable or technically feasible [78].

Table 3 presents the uptake of improvement measures from Swedish airlines (Table 3). As expected, airlines with stronger financial backing tend to have better pre-conditions to renew their aircraft fleet, which according to Yin et al. [77] and the International Air Transport Association (IATA) [79] is the most efficient way to improve energy intensity.

Increasing cabin density or load factor could lower an airline’s fuel use [77,94,100]. Based on Morrell’s [94] estimations, an 0.83% fuel saving could be achieved with every 1% increase in seat capacity in a short- and medium-haul aircraft. However, this option may no longer be taken as risk-free for public health post-pandemic. Through simulations and experiments, researchers have concluded that in-flight aerosol or particle transmission is probable [101–103] and risk of infection cannot be ruled out [104]. Instead, maintaining social distancing onboard appears to be necessary to regain travellers’ confidence in flying [105]. A study conducted by Song and Choi [106] indicated that travellers in Korea were less willing to fly in a cramped cabin space post-COVID-19.

Table 2
Energy intensity improvement options.

Improvement category	Improvement actions	References
Operations modification	• Optimise fuel uplift	[80]
	• Optimise cruise speed and altitude	[81,82]
	• Performance based descent and approach	[83] [84,85]
	• On-wing engine wash	[86]
	• No auxiliary power unit operations on ground	[87]
	• Reduce the number of engines used during taxiing	
Fleet retrofit	• Cabin modification	[88,89]
	• Electronic flight bags	[77]
	• New engines	[90,91]
	• Winglet installation	[90,91]
New aircraft introduction	• New and larger aircraft	[92–94]
Payload capacity expansion	• Increase in cabin density, seat quantity	[94]
	• Altering flight schedules	[77]
	• Code sharing	[77]

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 [95] • Operations modifications [95]
Braathens Regional Airlines (BRA)	Regular domestic and regional flights. Privately owned.	2018: • Operations modifications [96] • Fleet retrofit [96]
AirLeap	Regular domestic and regional flights. Privately owned.	2020: • Operations modifications [97]
Novair	International charter flights. Privately owned and part of Apollo group.	2019: • New aircraft introduction [98] • Operations modifications [98]
TUIfly Nordic	International charter flights. Privately owned and part of TUI group.	2018: • New aircraft introduction ongoing [99] • Operations modifications [99]

In addition to the ICAO global aspirational goal and CO_2 emission standard, the Swedish government proposed differentiated takeoff and landing fees at the Stockholm-Arlanda and Gothenburg-Landvetter airports from 2022 to intensify the climate impact mitigation effort [107]. The new fee structure would mean that individual flights performed by different aircraft types would be charged at a different rates based on their climate impact and fuel mix. Less energy efficient aircraft would be subject to higher takeoff and landing fees, indirectly serving as an incentive for airline to retrofit or renew their fleet with higher energy efficiency aircraft [107]. However, one of the conclusions drawn in Thelle and Mie la Cour’s [108] study on European airport competition was that airports opt to lower airport charges at times of crisis to stay competitive. Implementing climate-related takeoff and landing fees [107] in addition to the ICAO recommended landing charges [109] in the midst of the industry’s recovery from the pandemic might result in these airports losing traffic to no-charge competitors.

3.3. Emission intensity

Lee et al. [2] estimated that the overall aviation 20-year global warming potential could be three times higher than accounting CO_2 emissions alone. Aviation emission intensity, defined as emission per unit energy consumed during aircraft operation [21], is affected by policy measures, technology improvements including reduced fuel consumption and innovative technologies, and changes to travel volume.

In Sweden, aviation's emission intensity is regulated both nationally and internationally. As a member state of the ICAO and the European Union (EU), Sweden participates in the EU Emissions Trading System (ETS) and the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). These international schemes aim to create market-based platforms to curb the increase in GHG emissions, as well as triggering investments in climate mitigation initiatives. ETS operates by the cap-and-trade principle where aviation's annual CO_2 emissions are restricted through emission allowances allocated to airlines. Within the cap, 82% of the allowances are allocated to airlines without cost, 15% are auctioned, and 3% are reserved for new market entries or fast-growing operators [110]. Airlines are allowed to trade their allowances if needed [111]. Over time, the allowance budget will shrink, thus reducing CO_2 emission further [111]. In comparison, CORSIA aims to achieve global carbon neutral growth through offsetting the increase in total CO_2 emissions from international flights based on 2019 level[4] [112,113]. To offset the increased emissions, airline operators will collectively purchase the CORSIA eligible emissions units from certified offsetting programmes. This means that Swedish airlines, under the jurisdiction of the EU and ICAO, are obliged to purchase additional allowances from ETS if total emissions from their flights operating within the EU and EEA exceed the allocated limits in a calendar year. In addition, they are obliged to share the offsetting cost with other CORSIA participating airlines for their common routes outside of the EU and EEA in cases where the CO_2 emissions for that particular route exceed the 2019 baseline level. However, the effectiveness of both schemes is questioned. Firstly, ETS is criticised for handing out too many free allowances to the aviation industry, indirectly incentivising GHG emissions [114]. Secondly, with its emission baseline revised from 2020 to 2019 level due to the impact of the COVID-19 pandemic on aviation [112], CORSIA may neither deter emissions nor incentivise airlines to undertake climate mitigation actions as offsetting could be irrelevant for the slowly recovering industry [115]. Thirdly, offsetting emissions as a collective unit under the CORSIA scheme may not motivate the individual polluters to implement any abatement options [116]. Lastly, neither of the two schemes account for non-CO_2 emissions [117,118]. The global contributions of the two schemes in their current forms, operating side-by-side, are unlikely to reduce aviation emissions significantly [7]. Applying this reasoning to the Swedish context, Larsson et al. [119] estimated that the two schemes could account for an 0.8% annual CO_2 emissions reduction which is insufficient to meet the Swedish or the EU climate goals.

Innovative technologies - alternative fuels and propulsion systems - designed to abate aircraft emissions are being explored [120,121]. Whilst sustainable aviation fuels, including advanced biofuels and electrofuels, are identified as the immediate solution to reduce emissions, hydrogen fuels and electric propulsion systems are suggested to be the future for carbon-free aviation [121–123].

Advanced biofuels and electrofuels for aviation, collectively known as sustainable aviation fuels (SAF), are approved substitutes for fossil-based jet fuel [124,125]. Depending on the choice of feedstock and production pathways, SAF are permitted for blend-in with fossil-based jet fuel at a ratio between 5% and 50% [123]. The main difference between advanced biofuels and electrofuels is the feedstock used in fuel production. Advanced biofuels may be derived from biomass, provided they are not produced from food or feed crops, and residual oil feedstock [10,124], whereas electrofuels, or power-to-liquid fuels (PtL), are produced from green hydrogen and non-fossil CO_2 [126]. Hydrogen as a fuel is known for producing aircraft thrust either by direct-feed to a hydrogen combustion engine or through conversion to electricity in a fuel cell which drives an electric motor [127,128]. Unlike SAF, use of hydrogen fuels requires changes in aircraft and engine designs [127] as well as the development of accompanying infrastructure for hydrogen production, liquefaction, storage and transportation [122,129]. Similarly turboelectric, hybrid electric or all-electric aircraft [14,15,130] will also involve new designs of aircraft power and propulsion systems [130]. The use of electric aircraft would also entail an update of the current power supply network and development of necessary charging infrastructure [131].

In 2020, the Swedish government proposed a GHG emissions reduction obligation for jet fuel [132], mandating the blending of advanced biofuels into fossil-based jet fuel from an equivalency of 1% in volume in 2021 to 30% volume in 2030 [132]. As yet there are no commercial SAF production sites in Sweden and the country is reliant on imports from producers and suppliers such as NESTE and SkyNRG which primarily produce oil-based SAF [133]. Some researchers and industrial actors believe that the Swedish forest could potentially provide sufficient feedstock to enable large-scale national SAF production [134–136]. The technical feasibility of SAF production in Sweden is being showcased through demonstration projects like LTU greenfuels [137] and flying on forestry residues in Småland [138]. However, there is concern that large-scale SAF production in Sweden would induce by-product effects [11] or create negative externalities for sectors reliant on forestry in Sweden, such as paper and pulp [135], heat and power [11] and road transport [139] due to feedstock competition. Moreover, the recently proposed EU forest strategy, which urges EU member states to prioritise the use of forests as a carbon sink [140], may hinder the potential commercialisation of bio-based SAF in Sweden. Moreover, the high estimated production cost and unit price [122] could potentially weaken the commercial viability of national SAF production, especially when public funding is limited.

In Sweden, a non-profit initiative, Fly Green Fund, was established to acquire private funding to incentivise local SAF production [141]. Preliminary findings from Goding et al.'s [142] study on business travellers' preferences for bio jet fuel indicated that only 30% of the Swedish businesses surveyed were willing to pay for advanced biofuels for business travel. Otherwise, the Swedish consumers' willingness to pay for biofuel is largely unknown. In terms of sustainability, the majority of research investigating the life cycle environmental impacts of SAF [120, 143–145] are based on retrospective and conceptual cases, making them difficult to apply to the context of Sweden where the sustainability of future large-scale SAF production is under scrutiny. Moreover, the non-CO_2 effect of biofuels is still not widely understood, resulting in varying findings [146,147].

Electrofuels (PtL) for aviation is regarded by the EU as an alternative to biofuel-based SAF [148]. Operationalisation of electrofuels depends highly on the availability of CO_2, be it biogenic or directly captured from the air, and green hydrogen [126]. Hansson et al. [149], in their study of the potential for electrofuels in Sweden, found that the country has favourable conditions for production. If captured and used, the prospective biogenic CO_2 sources in Sweden could be sufficient to power the entire Swedish transport system. However, the absence of EU regulations, national policies or economic incentives disfavours the commercialisation of bioenergy carbon capture, utilisation or storage (BECCU/S) in Sweden [150–154]. Despite Sweden having the potential to be a market leader for direct air capture (DAC) [155], non-existent political strategies or technological development plans for capturing carbon in the air renders BECCU/S the only viable CO_2 source for electrofuels production for now. Availability of renewable electricity,

[4] The original sectoral baseline for CORSIA was designed to be the average of total CO_2 emissions of years 2019 and 2020. Given the decrease in global aviation traffic in 2020 due to COVID-19 pandemic, ICAO decided that 2019 emissions shall be used for 2020 during the CORSIA pilot phase from 2021 to 2023.

hence green hydrogen, is another limiting factor for electrofuels production [126]. To meet the potentially large-scale demand for electrofuels in Sweden, Hansson et al. [156] estimated a 60% increase in electricity generation is required. The latest prognosis from the Swedish Energy Agency [157] anticipates the increase in electricity use in the transport sector would be solely attributable to electrification of road transport, indicating that planning for electrofuels or hydrogen production is yet to be realised in the national energy strategy. The high initial production cost is yet another factor that could limit the potential commercial development of electrofuels in Sweden [156,158]. As with advanced biofuels, research has assessed the environmental sustainability of electrofuels [12,159,160] but none of them take sustainability of BECCS/U [161], the relevant CO_2 source for Swedish production, into account. Likewise, the non-CO_2 effects of electrofuels are relatively unexplored and its total climate impact remains uncertain [162].

Hydrogen production and utilisation is not new per se in Sweden, with chemical and metallurgical processes being the main users today [163]. The employment of green hydrogen in steel making [164–166] is one of the most recent low-carbon innovations developed in the country. Considering newly announced investment plans from diverse industrial actors, the potential demand for green hydrogen in Sweden could amount to 61 TW, corresponding to 81 TWh of renewable electricity —approximately half of the electricity production in Sweden in 2019 [167] — by 2045 [163]. Besides electricity, lacking an established pipeline network, unlike other countries such a Germany [168] or France [169], is seen as an impediment to the collaboration between Sweden and continental Europe in hydrogen development [163]. Meanwhile, industrial actors are emphasising the need for new policies and regulations to ensure a functional hydrogen economy [163].

High production costs, lack of fuel infrastructure and airport operational procedures are major obstacles to the deployment of hydrogen in aviation [127]. Limited general knowledge on the safety of hydrogen propulsion technology [170,171] could also become a hindrance for public acceptance of hydrogen powered aircraft. So far, no studies on Swedish public attitudes towards hydrogen fuelled aircraft have been conducted. With regard to sustainability, the few studies assessing environmental impacts of hydrogen propulsion [172,173] do not capture the wider sustainability impacts of required infrastructure including dedicated green electricity, storage and transportation. Although a study conducted by Ingenito [174] on the impact of hydrogen fuelled aircraft on ozone layer depletion suggested that the potential climate impact from water vapour emissions could be insignificant, consensus on the overall non-CO_2 effect of hydrogen powered aircraft has yet to be reached in the scientific community [162].

Sweden is an early supporter of electric aviation. In 2018, the Swedish innovation agency, Vinnova, funded the project Electric Aviation in Sweden (ELISE) with the aim to coordinate the development and deployment of electric aircraft in Sweden [175]. As a spin-off of the ELISE project, Heart Aerospace, an all-electric aircraft manufacturer, was founded in Gothenburg in the same year [176]. In order to harmonise isolated efforts and enhance collaboration between the Nordic countries, in 2019, a coordinating project, Nordic Network for Electric Aviation (NEA), was formed by Nordic Innovation [177]. Subsequently, the project Finding innovation to Accelerate Implementation of electric Regional aviation (FAIR) [178] was launched to investigate the potential for commercial electric flight routes in the Kvarken region of northern Sweden and Finland. However, the focus of ongoing research and projects is generally limited to the technical design of aircraft and flight routes, whilst subjects like battery handling or airport infrastructure optimisation have received little attention. Although knowledge from studies conducted on electric vehicle battery circularity [179] and second life business models [180,181] may be transferable to aviation, there is limited evidence that lithium battery recycling processes or supply chain networks for battery recovery are mature in Sweden [182]. From an operational point of view, electric aircraft battery swap and recharge strategies require planning and optimisation, not least in the adaptation of the existing electric grid [183,184]. The recent fossil-free collaboration between the Swedish Civil Aviation Administration (LFV) and electricity supplier Vattenfall at Örnsköldsvik airport [185] shows that planning and research on airport charging infrastructure is slowly materialising in Sweden.

Current projects and initiatives are highly technology oriented, with little exploration of consumer perspectives. Han et al. [186], in their study on consumers' willingness to travel on electric aircraft, suggested that green image, emotional attachments, attitudes, and moral norms could influence consumers' willingness to travel by electric aircraft. However, without knowledge and trust, Han et al. [187] believed it would be difficult to evoke consumers' acceptance or willingness to pay. Operations without direct CO_2 and non-CO_2 emissions have been a key factor in contributing to the low climate impact profile of all-electric aircraft [14,188,189]. Researchers, on the other hand, emphasised that low life cycle climate impact could only be attained if electric aircraft are charged with renewable electricity [14,189]. Based on estimates presented by Schäfer et al. [14], 0.6–1.7% of the worldwide electricity consumption in 2015 would be needed to power a global short-haul fleet of all-electric aircraft, implying a potential burden shifting[5] of environmental impact from the aviation industry to the energy sector. Building on the assessment of the automotive industry [191], potential burden shifting from global warming to other environmental impacts such as human toxicity, acidification or eutrophication could also be expected depending on battery handling processes. Nevertheless, the overall environmental performance of electric aviation, according to Lombardi et al. [191], is country specific and future assessments are necessary to determine the potential environmental impact of electric aviation in Sweden.

4. Discussion

Sweden has ambitions to achieve fossil-free aviation by 2045. To achieve this will require measures to limit emissions and thus reduce the climate impact of the aviation industry. In this paper, we reviewed current and potential mitigation measures, operationalising the factors that Åkerman et al. [21] previously identified as pathways to limit the climate impact of aviation. We took a multidisciplinary approach in our analysis of their opportunities and challenges relevant to our case study of Sweden.

Firstly, the long-lasting consequences of the COVID-19 pandemic are unknown, with both opportunities and challenges for the aviation industry. On the one hand, the pandemic provides an opportunity for businesses to test ICT's capability of conducting digital meetings, conferences etc., offering a new form of virtual mobility and reducing the need for travel. Preliminary results indicate that ICT may replace a significant share of future business travel following the pandemic in many countries, including Sweden. On the other hand, personal travel is likely to revert to pre-pandemic growth rates as national lockdowns ease; a trend exampled by travel patterns following previously disruptive events.

As aviation's growth is demand-driven, reducing travel volume is one pathway to limit the climate impact of the industry. However, the policy measures in place aimed at reducing travel demand may lead to aviation leakage, a term we have coined from carbon leakage, i.e., the transfer of production to other countries with laxer emission constraints leading to greater emissions. This is a potential impact of the aviation ticket tax as consumers, unwilling to pay a higher ticket price, may choose to depart from airports in a no- or low-tax neighbouring country. This may result in airlines shifting their operations to airports outside of Sweden, i.e., to Denmark. Similarly, differentiated takeoff and landing

[5] From the life cycle perspective, the phenomenon of shifting environmental problems between different impact categories, time or space is known as burden shifting [190, p.18 & 796].

fees may result in aviation leakage between airports, as well as countries, with airlines moving operations to airports without charges. This may not only be financially damaging for local airports but also limit consumer choices. Moreover, inefficient aircraft would still operate, departing from and landing at alternative airports, shifting GHG emissions rather than incentivising improvements in aircraft fuel efficiency.

Looking beyond reducing travel volume through policy measures, use of ICT or social norms such as flight shaming, consumer acceptance and willingness to pay may direct the future development of the industry. It is also worth noting that a reduction in air travel volume does not necessarily equate to a reduced climate impact of the total transport sector, should consumers switch to environmentally damaging transport modes, e.g., travelling long distances by road-based transport with combustion engines. Incremental improvements, as laid out in the ICAO resolutions, require investment and may be inaccessible to airlines with limited financial resources. As consumer awareness of the climate impact of aviation increases, airlines who maintain inefficient fleet may become unattractive to passengers, resulting in a loss of ticket sales, further constraining their financial resources and investment abilities.

Innovative technologies offer an alternative to fossil-based jet fuel yet each faces challenges, not only in terms of cost and investment, but also in market formation and gaining political support and consumer acceptance. Although forestry residues are a potential feedstock for the production of SAF, high cost, lack of production facilities, limited government interventions, concerns for the sustainability of and competitions for feedstock, and low willingness to pay amongst consumers are current bottlenecks for the upscale and uptake of advanced biofuels for aviation in Sweden. The role of forestry in Sweden's fossil-free future is politically controversial with debates surrounding its appropriateness as a fuel feedstock or as a natural carbon sink. Electrofuels offer an alternative to bio-based SAF, but similarly lack political incentives and commercial investments in biogenic carbon capture and use (CCU) facilities. Moreover, the use of captured biogenic carbon may be viewed as illogical by consumers and policymakers as the re-release of CO_2 during fuel combustion contradicts the very purpose of the carbon removal technology. Hydrogen fuels could play a significant role in the fossil-free future of Sweden with a potentially high demand from various industrial sectors. However, a hydrogen-based economy will require top-down coordination, regulation and long-term strategic planning with significant infrastructure investment. Electric aviation has strong proponents in Sweden and the technology has the potential to enable regional and industrial development in rural and semi-urban areas, particularly in the North. However, both hydrogen fuels and electric aviation face technical, operational and safety considerations, from the development of new aircraft to investments in infrastructure for refuelling and charging of aircraft. Moreover, little is known as to consumers' perspectives and awareness of these disruptive innovations, their confidence in the technology, and willingness to pay.

4.1. Directions for further research

The current and potential measures to reduce the climate impact of aviation face several challenges, emphasising the socio-technical nature of the aviation industry and calling for further research.

Firstly, the impact of the policy measures, both currently in place and in consideration, must be assessed in terms of their effectiveness to achieve their goals and reduce the climate impact of aviation. We must also understand the role of the consumer in the aviation industry, the influence of climate awareness on willingness to pay, the role of social media, and the long-term impact of the COVID-19 pandemic on travel behaviours.

Secondly, existing life cycle assessment studies that have considered the environmental sustainability of alternatives to fossil-based jet fuels have focussed on a limited number of predefined pathways. Few studies have considered potential environmental impacts induced by societal changes, political decisions and commercial strategies, overlooking potential burden shifting effects. Further studies need to account for the environmental sustainability of innovative technologies, beyond their technical considerations and encompass the socio-economic and socio-political perspectives. Moreover, future studies must also account for the non-CO_2 effects attributed to the combustion of fossil-based jet fuel, SAF, and hydrogen fuels to take stock of the overall environmental sustainability of aircraft operation.

Thirdly, further research must look beyond incremental improvements and innovations, which have characterised the historic development of aviation, to consider radical and disruptive solutions that can break the industry's carbon lock-in and path dependency. Improvements in turbine efficiency, flight path optimisation, operations modifications, retrofitting of aircrafts and other small-scale improvements will not be sufficient to decarbonise the aviation industry and to achieve the target of fossil-free aviation by 2045. The industry needs larger-scale, more radical and transformative change. This will require the development of alternatives to fossil-based jet fuels and there is a need to examine the socio-economic challenges currently inhibiting the development, diffusion and market creation of innovative technologies such as SAF, hydrogen fuels and electric aircraft.

4.2. Limitations

Every study has its limitations. Firstly, this review was undertaken in the midst of the COVID-19 pandemic, which had, and continues to have, a significant impact on the aviation industry at both a global and national level. Whilst previous disruptive events, such as the 2008 financial crisis, have had a marked short-term effect on aviation, past trends indicate that the industry recovers from such disruptions. It is not yet clear as to whether this will be the case following the COVID-19 pandemic, and literature reporting on and speculating about the long-term impacts of the pandemic is limited, which is reflected in our review.

Secondly, we chose to take a semi-structured approach in our search for literature in order to collect diverse findings from a range of research fields. Such an approach may mean that we may have overlooked certain literature or research areas. We took the case of Sweden as the focus of our research, but this may have led to geographic bias, overlooking research from other regions.

Thirdly, the three factors used as an entry point for this review — travel volume, energy intensity, emission intensity — have served as a structure for analysing our findings. These factors cover the climate impact attributed to the consumption of air travel, in other words direct emissions from aircraft operations [21]. Whilst this accounts for the majority of emissions from the overall sector, indirect emissions attributed to airport services, maintenance, supply chains or other aviation services fall outside the system boundaries of this study. This is a limitation of the review, and there is a need to consider the wider components of the aviation system beyond aircraft operation in future research.

5. Conclusion

The paper analysed the challenges and opportunities for reducing the climate impact of aviation through mitigation measures, taking a multidisciplinary approach and offering new perspectives and pointing to areas for further research. We departed from the three pathways, identified by Åkerman et al. [21], for limiting the climate impact from the consumption of air travel: reducing travel volume, energy intensity and emission intensity.

Several measures are in place that aim to reduce the climate impact of the aviation industry, ranging from regulations to technology alternatives to fossil-based jet fuel. These measures face several crosscutting challenges, many of which are of socio-economic and political nature, and these aspects are often neglected in favour of focusing on technological solutions. For example, our research finds that market creation is a major challenge, as most consumers of air travel today have limited willingness to pay for more expensive, but more sustainable flight technologies and fuels, be it through carbon taxation or biofuel-based flight options. Also, there is a lack of research at the systems perspective, for example analysing the long-term need for battery recycling from electric aviation, the need to include growing electricity demand from aviation in national electricity planning, and the potential competition for forestry products for biofuel production between the aviation industry, road-based transport, heat and power sector, and the pulp and paper industries.

Understanding the needs of aviation to reduce its climate impact requires a multidisciplinary perspective that takes into account the socio-technical nature of the industry and the crosscutting opportunities and challenges, going beyond the technical aspects to include the socio-economic and political dimensions of these potential transitions. Although this review has centered on Sweden as a case study, it can serve as an example for other countries, particularly Nordic other European countries which have similar conditions to Sweden, such as a low-carbon electricity supply and abundant forest resources for potential advanced biofuel production. The value of the review is its broader consideration of the pathways to reduce the climate impact of aviation and multididiciplinary analysis of their barriers and opportunities, offering new perspectives and pointing to areas for new research. A new research agenda for aviation must look beyond incremental improvements and analyse radical and disruptive innovations to replace fossil-based jet fuel to break the industry's carbon lock-in and lead to future of fossil-free aviation in line with many countries' mid-century decarbonisation targets.

Credit authorship contributions statement

Lai, Y.Y.: Conceptualisation, Methodology, Investigation, Writing – original draft, Writing – review & editing. Christley, E.: Conceptualisation, Methodology, Investigation, Writing – original draft, Writing – review & editing. Kulanovic, A.: Methodology, Investigation, Writing – original draft, Writing – review & editing. Teng, C.C: Conceptualisation, Methodology, Investigation, Writing – original draft. Björklund, A.: Conceptualisation, Supervision, Writing- Review &; Editing. Nordensvärd, J.: Supervision, Writing- Review &; Editing. Karakaya, E.: Supervision, Writing- Review &; Editing. Urban, F.: Supervision, Writing – original draft, Writing- Review &; Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Grewe V, Gangoli Rao A, Grönstedt T, Xisto C, Linke F, Melkert J, et al. Evaluating the climate impact of aviation emission scenarios towards the Paris agreement including COVID-19 effects. Nat Commun 2021;12:3841. https://doi.org/10.1038/s41467-021-24091-y.

[2] Lee DS, Fahey DW, Skowron A, Allen MR, Burkhardt U, Chen Q, et al. The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018. Atmos Environ 2021;244:117834. https://doi.org/10.1016/j.atmosenv.2020.117834.

[3] UNFCCC. Adoption of the Paris agreement. 2015.

[4] Faber J, Huigen T. A study on aviation ticket taxes. Netherlands: CE Delft; 2018.

[5] Faber J, O'leary A. Taxing aviation fuels in the EU. CE Delft; 2018.

[6] Sonnenschein J, Smedby N. Designing air ticket taxes for climate change mitigation: insights from a Swedish valuation study. Clim Pol 2019;19:651–63. https://doi.org/10.1080/14693062.2018.1547678.

[7] Scheelhaase J, Maertens S, Grimme W, Jung M. EU ETS versus CORSIA – a critical assessment of two approaches to limit air transport's CO2 emissions by market-based measures. J Air Transport Manag 2018;67:55–62. https://doi.org/10.1016/j.jairtraman.2017.11.007.

[8] Maertens S, Grimme W, Scheelhaase J, Jung M. Options to continue the EU ETS for aviation in a CORSIA-world. Sustainability 2019;11:5703. https://doi.org/10.3390/su11205703.

[9] Regeringskansliet. Remiss av Transportstyrelsens redovisning av regeringens uppdrag om miljöstyrande start- och landningsavgifter (Referral of the Swedish Transport Agency's report on the Government's assignment on environmental take-off and landing fees). Regeringskansliet; 2020. https://www.regeringen.se/remisser/2020/09/remiss-av-transportstyrelsens-redovisning-av-regeringens-uppdrag-om-miljostyrande-start–och-landningsavgifter/. [Accessed 20 October 2020].

[10] Wang M, Dewil R, Maniatis K, Wheeldon J, Tan T, Baeyens J, et al. Biomass-derived aviation fuels: challenges and perspective. Prog Energy Combust Sci 2019;74:31–49. https://doi.org/10.1016/j.pecs.2019.04.004.

[11] Bryngemark E. Second generation biofuels and the competition for forest raw materials: a partial equilibrium analysis of Sweden. For Pol Econ 2019;109:102022. https://doi.org/10.1016/j.forpol.2019.102022.

[12] Schmidt P, Batteiger V, Roth A, Weindorf W, Raksha T. Power-to-Liquids as renewable fuel option for aviation: a review. Chem Ing Tech 2018;90:127–40. https://doi.org/10.1002/cite.201700129.

[13] Epstein AH, O'Flarity SM. Considerations for reducing aviation's CO2 with aircraft electric propulsion. J Propul Power 2019;35:572–82. https://doi.org/10.2514/1.B37015.

[14] Schäfer AW, Barrett SRH, Doyme K, Dray LM, Gnadt AR, Self R, et al. Technological, economic and environmental prospects of all-electric aircraft. Nature Energy 2019;4:160–6. https://doi.org/10.1038/s41560-018-0294-x.

[15] Sahoo S, Zhao X, Kyprianidis K. A review of concepts, benefits, and challenges for future electrical propulsion-based aircraft. Aerospace 2020;7:44. https://doi.org/10.3390/aerospace7040044.

[16] Larsson J, Kamb A, Nässén J, Åkerman J. Measuring greenhouse gas emissions from international air travel of a country's residents methodological development and application for Sweden. Environ Impact Assess Rev 2018;72:137–44. https://doi.org/10.1016/j.eiar.2018.05.013.

[17] Gössling S, Hanna P, Higham J, Cohen S, Hopkins D. Can we fly less? Evaluating the 'necessity' of air travel. J Air Transport Manag 2019;81:101722. https://doi.org/10.1016/j.jairtraman.2019.101722.

[18] Jacobson L, Åkerman J, Giusti M, Bhowmik AK. Tipping to staying on the ground: internalized knowledge of climate change crucial for transformed air travel behavior. Sustainability 2020;12. https://doi.org/10.3390/su12051994. 1994.

[19] Kim Y, Lee J, Ahn J. Innovation towards sustainable technologies: a socio-technical perspective on accelerating transition to aviation biofuel. Technol Forecast Soc Change 2019;145:317–29. https://doi.org/10.1016/j.techfore.2019.04.002.

[20] Wittmer A, Bieger T, Müller R, editors. Aviation systems: management of the integrated aviation value chain. Berlin Heidelberg: Springer-Verlag; 2011. https://doi.org/10.1007/978-3-642-20080-9.

[21] Åkerman J, Larsson J, Elofsson A. Svenska handlingsalternativ för att minska flygets klimatpåverkan (The alternatives available to Sweden to reduce the aviation climate impact). 2016.

[22] Regeringskansliet. Sweden's climate policy framework - Government. 2021. https://www.government.se/articles/2021/03/swedens-climate-policy-framework/. [Accessed 7 June 2021].

[23] Färdplan Svensktflyg. För fossilfri konkurrens kraft - flybranschen (Roadmap for fossil-free competitiveness - the aviation industry). Fossilfritt Sverige; 2018.

[24] IATA. The importance of air transport to Sweden. IATA; 2019.

[25] The Ministry of Infrastructure. Sweden's integrated national energy and climate plan. 2020. https://ec.europa.eu/energy/sites/ener/files/documents/se_final_necp_main_en.pdf. [Accessed 15 February 2021].

[26] Trafikanalys. Luftfart 2019 (aviation 2019). 2020. https://www.trafa.se/globalassets/statistik/luftfart/2019/statistikblad-luftfart-2019.pdf?. [Accessed 15 February 2021].

[27] Naturvårdsverket. Greenhouse gas emission inventories 1990-2018. Stockholm: Naturvårdsverket; 2019.

[28] Sovacool BK, Axsen J, Sorrell S. Promoting novelty, rigor, and style in energy social science: towards codes of practice for appropriate methods and research design. Energy Res Soc Sci 2018;45:12–42. https://doi.org/10.1016/j.erss.2018.07.007.

[29] Sovacool BK. Diversity: energy studies need social science. Nature 2014;511:529–30. https://doi.org/10.1038/511529a.

[30] Köhler J, Geels FW, Kern F, Markard J, Onsongo E, Wieczorek A, et al. An agenda for sustainability transitions research: state of the art and future directions. Environ Innov Soc Trans 2019;31:1–32. https://doi.org/10.1016/j.eist.2019.01.004.

[31] Liljenström C, Åkerman J, Björklund A, Toller S. Direct and indirect climate impact and primary energy use of the Swedish transport system. 2018.

[32] Snyder H. Literature review as a research methodology: an overview and guidelines. J Bus Res 2019;104:333–9. https://doi.org/10.1016/j.jbusres.2019.07.039.

[33] Fuenfschilling L, Binz C. Global socio-technical regimes. Res Pol 2018;47:735–49. https://doi.org/10.1016/j.respol.2018.02.003.

[34] Tracy SJ. Qualitative quality: eight "big-tent" criteria for excellent qualitative research. Qual Inq 2010;16:837–51. https://doi.org/10.1177/1077800410383121.
[35] Alvesson M, Sandberg J. The problematizing review: a counterpoint to elsbach and van knippenberg's argument for integrative reviews. J Manag Stud 2020;57:1290–304. https://doi.org/10.1111/joms.12582.
[36] ICAO. Post-COVID-19 forecasts scenarios. 2021. https://www.icao.int/sustainability/Pages/Post-Covid-Forecasts-Scenarios.aspx. [Accessed 18 October 2021].
[37] Scott WR, Richard SCOTT. Institutions and organizations. Ideas, interests and identities. M@n@gement 2014 1995;17:136–40.
[38] Wild P, Mathys F, Wang J. Impact of political and market-based measures on aviation emissions and passenger behaviors (a Swiss case study). Trans Res Inter Perspect 2021;10:100405. https://doi.org/10.1016/j.trip.2021.100405.
[39] En svensk flygskatt (A Swedish air ticket tax). Stockholm: Wolters Kluwer; 2016.
[40] Skatteverket. Tax rate per country – tax on air travel. 2020. https://www.skatteverket.se/servicelankar/otherlanguages/inenglish/businessesandemployers/payingtaxesbusinesses/taxonairtravel/taxratepercountry.4.41f1c61d16193087d7f5472.html. [Accessed 9 December 2020].
[41] Schroten A, Nelissen D, Aalberts-Bakker J, Faber J, van der Veen R, Vergeer R. Taxes in the field of aviation and their impact: final report. LU: CE Delft; 2019.
[42] Falk M, Hagsten E. Short-run impact of the flight departure tax on air travel. Int J Tourism Res 2019;21:37–44. https://doi.org/10.1002/jtr.2239.
[43] Gordijn H, Kolkman J. Effects of the air passenger tax. KiM Netherlands Institute for Transport Policy Analysis: Ministry of Infrastructure and the Environment; 2011.
[44] Andersson M, Falck M. Lagrådsremiss - skatt på flygresor (refereral to the law Council - tax on air travel). Finansdepartmentet: Regeringen; 2017.
[45] Mouratidis K, Papagiannakis A. COVID-19, internet, and mobility: the rise of telework, telehealth, e-learning, and e-shopping. Sustain Cities Soc 2021;74:103182. https://doi.org/10.1016/j.scs.2021.103182.
[46] Räsänen M, Moberg Å, Picha M, Borggren C. Meeting at a distance: experiences of media companies in Sweden. Technol Soc 2010;32:264–73. https://doi.org/10.1016/j.techsoc.2010.10.002.
[47] Ahrendt D, Cabrita J, Clerici E, Hurley J, Leončikas T, Mascherini M, et al. Living, working and COVID-19. Luxembourg: Eurofound; 2020.
[48] Abu-Rayash A, Dincer I. Analysis of mobility trends during the COVID-19 coronavirus pandemic: exploring the impacts on global aviation and travel in selected cities. Energy Res Soc Sci 2020;68:101693. https://doi.org/10.1016/j.erss.2020.101693.
[49] van Wee B, Witlox F. COVID-19 and its long-term effects on activity participation and travel behaviour: a multiperspective view. J Transport Geogr 2021;95:103144. https://doi.org/10.1016/j.jtrangeo.2021.103144.
[50] Gössling S, Scott D, Hall CM. Pandemics, tourism and global change: a rapid assessment of COVID-19. J Sustain Tourism 2021;29:1–20. https://doi.org/10.1080/09669582.2020.1758708.
[51] Nguyen MH, Gruber J, Fuchs J, Marler W, Hunsaker A, Hargittai E. Changes in digital communication during the COVID-19 global pandemic: implications for digital inequality and future research. Social Media + Society 2020;6. https://doi.org/10.1177/2056305120948255. 2056305120948255.
[52] Conway MW, Salon D, da Silva DC, Mirtich L. How will the COVID-19 pandemic affect the future of urban life? Early evidence from highly-educated respondents in the United States. Urban Sci 2020;4:50. https://doi.org/10.3390/urbansci4040050.
[53] van der Drift S, Wismans L, Olde Kalter M-J. Changing mobility patterns in The Netherlands during COVID-19 outbreak. J Locat Based Serv 2021:1–24. https://doi.org/10.1080/17489725.2021.1876259. 0.
[54] Bezemer DJ. Seize the day: opportunities and costs in the COVID-19 crisis. Global Sustain 2021;4. https://doi.org/10.1017/sus.2021.9.
[55] Hiselius LW, Arnfalk P. When the impossible becomes possible: COVID-19's impact on work and travel patterns in Swedish public agencies. Eur Transp Res Rev 2021;13:17. https://doi.org/10.1186/s12544-021-00471-9.
[56] Bohman H, Ryan J, Stjernborg V, Nilsson D. A study of changes in everyday mobility during the Covid-19 pandemic: as perceived by people living in Malmö, Sweden. Transport Pol 2021;106:109–19. https://doi.org/10.1016/j.tranpol.2021.03.013.
[57] Jenelius E, Cebecauer M. Impacts of COVID-19 on public transport ridership in Sweden: analysis of ticket validations, sales and passenger counts. Trans Res Inter Perspect 2020;8:100242. https://doi.org/10.1016/j.trip.2020.100242.
[58] Van Cranenburgh S, Chorus C, Van Wee B. Substantial changes and their impact on mobility: a typology and an overview of the literature. Transport Rev 2012;32:569–97. https://doi.org/10.1080/01441647.2012.706836.
[59] Eurocontrol. COVID-19 impact on EUROCONTROL member states - Sweden. 2021. https://www.eurocontrol.int/publication/covid-19-impact-eurocontrol-member-states-sweden. [Accessed 18 October 2021].
[60] Mokhtarian P, Salomon I. Emerging travel patterns. In perpetual motion. 2002. p. 143–82. https://doi.org/10.1016/B978-008044044-6/50008-5.
[61] Mokhtarian PL. Telecommunications and travel: the case for complementarity. J Ind Ecol 2002;6:43–57. https://doi.org/10.1162/108819802763471771.
[62] Mokhtarian P. If telecommunication is such a good substitute for travel, why does congestion continue to get worse? Trans Lett 2009;1:1–17. https://doi.org/10.3328/TL.2009.01.01.1-17.
[63] Wormbs N, Söderberg MW. Knowledge, fear, and conscience: reasons to stop flying because of climate change. Urban Planning 2021;6:314–24. https://doi.org/10.17645/up.v6i2.3974.
[64] Doran R, Pallesen S, Böhm G, Ogunbode CA. When and why do people experience flight shame? Ann Tourism Res 2021. https://doi.org/10.1016/j.annals.2021.103254.
[65] Gössling S, Humpe A, Bausch T. Does 'flight shame' affect social norms? Changing perspectives on the desirability of air travel in Germany. J Clean Prod 2020;266:122015. https://doi.org/10.1016/j.jclepro.2020.122015.
[66] Mkono M. Eco-anxiety and the flight shaming movement: implications for tourism. J Tourism Futures 2020;6:223–6. https://doi.org/10.1108/JTF-10-2019-0093.
[67] Persson S. Den svenska miljö- och klimatopinionen 2019 (The Swedish environment and climate opinions, 2019). Gothenburg: University of Gothenburg; 2020.
[68] Mkono M, Hughes K, Echentille S. Hero or villain? Responses to Greta Thunberg's activism and the implications for travel and tourism. J Sustain Tourism 2020;28:2081–98. https://doi.org/10.1080/09669582.2020.1789157.
[69] Becken S, Friedl H, Stantic B, Connolly RM, Chen J. Climate crisis and flying: social media analysis traces the rise of "flightshame. J Sustain Tourism 2021;29:1450–69. https://doi.org/10.1080/09669582.2020.1851699.
[70] Árnadóttir Á, Czepkiewicz M, Heinonen J. Climate change concern and the desire to travel: how do I justify my flights? Travel Behav Soc 2021;24:282–90. https://doi.org/10.1016/j.tbs.2021.05.002.
[71] Kharina A, Rutherford D. Fuel efficiency trends for new commercial jet aircraft: 1960 to 2014. Washington DC: International Council on Clean Transportation; 2015.
[72] Lee DS, Fahey DW, Forster PM, Newton PJ, Wit RCN, Lim LL, et al. Aviation and global climate change in the 21st century. Atmos Environ 2009;43:3520–37. https://doi.org/10.1016/j.atmosenv.2009.04.024.
[73] ICAO. Vision and mission. ICAO uniting aviation - a united nations specialised agency. https://www.icao.int/about-icao/Council/Pages/vision-and-mission.aspx. [Accessed 18 October 2021].
[74] ICAO. Assembly resolutions in force (as of 8 October 2010). Montreal: International Civil Aviation Organization; 2011.
[75] ICAO., ICAO. Council adopts new CO2 emissions standard for aircraft. ICAO Newsroom; 2017. https://www.icao.int/newsroom/pages/icao-council-adopts-new-co2-emissions-standard-for-aircraft.aspx. [Accessed 20 October 2020].
[76] ICCT. ICAO's CO2 standard for new aircraft. International Council on Clean Transportation; 2017.
[77] Yin K, Dargusch P, Halog A. Study of the abatement options available to reduce carbon emissions from Australian international flights. Int J Sustain Trans 2016;10:935–46. https://doi.org/10.1080/15568318.2016.1190882.
[78] Yin K, Ward A, Dargusch P, Halog A. The cost of abatement options to reduce carbon emissions from Australian international flights. Int J Sustain Trans 2018;12:165–78. https://doi.org/10.1080/15568318.2017.1341575.
[79] IATA. Technology. Roadmap for environmental improvement fact sheet. 2019. https://www.iata.org/contentassets/8d19e716636a47c184e7221c77563c93/fact-sheet-technology-roadmap-environment.pdf. [Accessed 20 October 2020].
[80] Tang N, Wu C-L, Tan D. Evaluating the implementation of performance-based fuel uplift regulation for airline operation. Faculty of Business - Papers (Archive); 2020. p. 47–61. https://doi.org/10.1016/j.tra.2019.12.028.
[81] Jensen L, Hansman RJ, Venuti J, Reynolds T. Commercial Airline Altitude Optimization Strategies for Reduced Cruise Fuel Consumption. 14th AIAA Aviation Technology, Integration, and Operations Conference, American Institute of Aeronautics and Astronautics; n.d. https://doi.org/10.2514/6.2014-3006.
[82] Dalmau R, Prats X. Fuel and time savings by flying continuous cruise climbs: estimating the benefit pools for maximum range operations. Transport Res Transport Environ 2015;35:62–71. https://doi.org/10.1016/j.trd.2014.11.019.
[83] Errico A, Di Vito V. Performance-based navigation (PBN) with continuous descent operations (CDO) for efficient approach over highly protected zones. In: 2017 24th saint petersburg international conference on integrated navigation systems (ICINS); 2017. p. 1–8. https://doi.org/10.23919/ICINS.2017.7995612.
[84] Chen D, Sun J. Fuel and emission reduction assessment for civil aircraft engine fleet on-wing washing, vol. 65. Transportation Research Part D: Transport and Environment; 2018.
[85] Technik Lufthansa. Cyclean engine wash -efficient engine cleaning - aircraft engines. Cyclean engine wash -efficient engine cleaning. 2015. https://www.lufthansa-technik.com/cyclean. [Accessed 22 September 2021].
[86] Postorino MN, Mantecchini L. A transport carbon footprint methodology to assess airport carbon emissions. J Air Transport Manag 2014;37:76–86. https://doi.org/10.1016/j.jairtraman.2014.03.001.
[87] Deonandan I, Balakrishnan H. Evaluation of Strategies for Reducing Taxi-out Emissions at Airports. 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, American Institute of Aeronautics and Astronautics; n.d. https://doi.org/10.2514/6.2010-9370.
[88] Tsai W-H, Chang Y-C, Lin S-J, Chen H-C, Chu P-Y. A green approach to the weight reduction of aircraft cabins. J Air Transport Manag 2014;40:65–77.
[89] Gubisch M. New Lufthansa seat saves nearly 30% in weight. Flight Global 2010. https://www.flightglobal.com/new-lufthansa-seat-saves-nearly-30-in-weight/97485.article. [Accessed 18 October 2021].
[90] Cansino JM, Román R. Energy efficiency improvements in air traffic: the case of Airbus A320 in Spain. Energy Pol 2017;101:109–22. https://doi.org/10.1016/j.enpol.2016.11.027.
[91] Müller C, Kieckhäfer K, Spengler TS. The influence of emission thresholds and retrofit options on airline fleet planning: an optimization approach. Energy Pol 2018;112:242–57. https://doi.org/10.1016/j.enpol.2017.10.022.
[92] Setlak L, Kowalik R. Modern technological solutions in generation, transmission and distribution of electricity in "conventional" vs. "More Electric" Aircrafts. In:

2017 progress in applied electrical engineering (PAEE); 2017. p. 1–6. https://doi.org/10.1109/PAEE.2017.8009008.
[93] Marsh G. Airbus takes on Boeing with reinforced plastic A350 XWB. Reinforc Plast 2007;51:26–9. https://doi.org/10.1016/S0034-3617(07)70383-1.
[94] Morrell P. The potential for European aviation CO2 emissions reduction through the use of larger jet aircraft. J Air Transport Manag 2009;15:151–7. https://doi.org/10.1016/j.jairtraman.2008.09.021.
[95] SAS. SAS annual and sustainability report fiscal year 2020. 2020. https://www.sasgroup.net/files/documents/Corporate_governace/annual-reports/SAS_AST19-20_ENG2.pdf.
[96] BRA. hallbarhetsrapport-2018 (sustainability report 2018). 2018. https://falco-prod-facelift-cdnendpoint.azureedge.net/media/1554/hallbarhetsrapport-2018.pdf. [Accessed 18 October 2021].
[97] AirLeap. Miljöarbete (environmental work). 2020. https://www.airleap.se/AirLeap/PDF/air_leap_miljo_201027.pdf. [Accessed 18 October 2021].
[98] Novair. Hållbarhetsrapport nova airlines AB 2019 (sustainability report nova airlines AB 2019). 2019. https://upload-prod-www.novair.se/upload/Nova%20Airlines%20AB%20%20-%20H%C3%A5llbarhetsrapport%202019.pdf. [Accessed 18 October 2021].
[99] TUI Group. Sustainability Report 2018, https://www.tuigroup.com/damfiles/default/tuigroup-15/de/nachhaltigkeit/berichterstattung-downloads/2019/nachhaltigkeitsbericht-de-en/TUI_CSR18_EN.pdf-5940a155fe7c4eb56170bf97e3b69ec6.pdf. [Accessed 18 October 2021].
[100] Miller EL, Lapp SM, Parkinson MB. The effects of seat width, load factor, and passenger demographics on airline passenger accommodation. Ergonomics 2019;62:330–41. https://doi.org/10.1080/00140139.2018.1550209.
[101] Desai PS, Sawant N, Keene A. On COVID-19-safety ranking of seats in intercontinental commercial aircrafts: a preliminary multiphysics computational perspective. Build Simul 2021;14:1585–96. https://doi.org/10.1007/s12273-021-0774-y.
[102] Talaat K, Abuhegazy M, Mahfoze OA, Anderoglu O, Poroseva SV. Simulation of aerosol transmission on a Boeing 737 airplane with intervention measures for COVID-19 mitigation. Phys Fluids 2021;33:033312. https://doi.org/10.1063/5.0044720.
[103] Li X, Zhang T (Tim), Fan M, Liu M, Chang D, Wei Z, Daniel. Experimental evaluation of particle exposure at different seats in a single-aisle aircraft cabin. Build Environ 2021;202:108049. https://doi.org/10.1016/j.buildenv.2021.108049.
[104] Wang Z, Galea ER, Grandison A, Ewer J, Jia F. Inflight transmission of COVID-19 based on experimental aerosol dispersion data. J Trav Med 2021;28. https://doi.org/10.1093/jtm/taab023.
[105] Khatib AN, Carvalho A-M, Primavesi R, To K, Poirier V. Navigating the risks of flying during COVID-19: a review for safe air travel. J Trav Med 2020;27. https://doi.org/10.1093/jtm/taaa212.
[106] Song K-H, Choi S. A study on the behavioral change of passengers on sustainable air transport after COVID-19. Sustainability 2020;12:9207. https://doi.org/10.3390/su12219207.
[107] Transportstyrelsen. Författningsförslag om miljöstyrande start- och landningsavgifter (Constitutional proposal on environmental take-off and landing fees). Transportstyrelsen; 2020.
[108] Thelle MH, Sonne M la C. Airport competition in Europe. J Air Transport Manag 2018;67:232–40.
[109] ICAO. ICAO's policies on charges for airports and air navigation services. Montreal: ICAO; 2012.
[110] European Commission. EU emissions trading system (EU ETS). Climate action - European commission. 2016. https://ec.europa.eu/clima/policies/ets_en. [Accessed 14 October 2020].
[111] Efthymiou M, Papatheodorou A. EU Emissions Trading scheme in aviation: policy analysis and suggestions. J Clean Prod 2019;237:117734. https://doi.org/10.1016/j.jclepro.2019.117734.
[112] ICAO. CORSIA and COVID-19. 2020. https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-and-Covid-19.aspx. [Accessed 15 October 2020].
[113] ICAO. Climate change mitigation. CORSIA; 2019.
[114] Nava CR, Meleo L, Cassetta E, Morelli G. The impact of the EU-ETS on the aviation sector: competitive effects of abatement efforts by airlines. Transport Res Pol Pract 2018;113:20–34. https://doi.org/10.1016/j.tra.2018.03.032.
[115] Zhang J, Zhang S, Wu R, Duan M, Zhang D, Wu Y, et al. The new CORSIA baseline has limited motivation to promote the green recovery of global aviation. Environ Pollut 2021;289:117833. https://doi.org/10.1016/j.envpol.2021.117833.
[116] Winchester N. A win-win solution to abate aviation CO2 emissions. J Air Transport Manag 2019;80:101692. https://doi.org/10.1016/j.jairtraman.2019.101692.
[117] Scheelhaase JD. How to regulate aviation's full climate impact as intended by the EU council from 2020 onwards. J Air Transport Manag 2019;75:68–74. https://doi.org/10.1016/j.jairtraman.2018.11.007.
[118] Forster PM de F, Shine KP, Stuber N. It is premature to include non-CO2 effects of aviation in emission trading schemes. Atmos Environ 2006;40:1117–21. https://doi.org/10.1016/j.atmosenv.2005.11.005.
[119] Larsson J, Elofsson A, Sterner T, Åkerman J. International and national climate policies for aviation: a review. Clim Pol 2019;19:787–99. https://doi.org/10.1080/14693062.2018.1562871.
[120] Pinheiro Melo S, Barke A, Cerdas F, Thies C, Mennenga M, Spengler TS, et al. Sustainability assessment and engineering of emerging aircraft technologies—challenges, methods and tools. Sustainability 2020;12:5663. https://doi.org/10.3390/su12145663.
[121] Bauen A, Bitossi N, German L, Harris A, Leow K. Sustainable Aviation Fuels : status, challenges and prospects of drop-in liquid fuels, hydrogen and electrification in aviation. Johnson Matthey Technology Review 2020;64:263–78. https://doi.org/10.1595/205651320X15816756012040.
[122] Dahal K, Brynolf S, Xisto C, Hansson J, Grahn M, Grönstedt T, et al. Techno-economic review of alternative fuels and propulsion systems for the aviation sector. Renew Sustain Energy Rev 2021;151:111564. https://doi.org/10.1016/j.rser.2021.111564.
[123] Soone J. Sustainable aviation fuels. European Parliamentary Research Service; 2020.
[124] European Union. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (Text with EEA relevance. 2018.
[125] Pavlenko N, Searle S. Fueling flight: assessing the sustainability implications of alternative aviation fuels. ICCT; 2021.
[126] Goldmann A, Sauter W, Oettinger M, Kluge T, Schröder U, Seume JR, et al. A study on electrofuels in aviation. Energies 2018;11:392. https://doi.org/10.3390/en11020392.
[127] Baroutaji A, Wilberforce T, Ramadan M, Olabi AG. Comprehensive investigation on hydrogen and fuel cell technology in the aviation and aerospace sectors. Renew Sustain Energy Rev 2019;106:31–40. https://doi.org/10.1016/j.rser.2019.02.022.
[128] McKinsey, Company. Hydrogen-powered aviation: a fact-based study of hydrogen technology, economics, and climate impact by 2050. Luxembourg: European Union; 2020.
[129] Ratnakar RR, Gupta N, Zhang K, van Doorne C, Fesmire J, Dindoruk B, et al. Hydrogen supply chain and challenges in large-scale LH2 storage and transportation. Int J Hydrogen Energy 2021;46:24149–68. https://doi.org/10.1016/j.ijhydene.2021.05.025.
[130] Bowman CL, Marien TV, Felder JL. Turbo- and hybrid-electrified aircraft propulsion for commercial transport. In: 2018 AIAA/IEEE electric aircraft technologies symposium, American institute of aeronautics and astronautics; 2018. https://doi.org/10.2514/6.2018-4984.
[131] Trainelli L, Salucci F, Riboldi CED, Rolando A, Bigoni F. Optimal sizing and operation of airport infrastructures in support of electric-powered aviation. Aerospace 2021;8:40. https://doi.org/10.3390/aerospace8020040.
[132] Regeringskansliet. Reduktionsplikt ska minska flygets klimatpåverkan (The reduction obligation shall reduce the climate impact of aviation). Regeringskansliet; 2020. https://www.regeringen.se/pressmeddelanden/2020/12/reduktionsplikt-ska-minska-flygets-klimatpaverkan/. [Accessed 19 February 2021].
[133] Kousoulidou M, Lonza L. Biofuels in aviation: fuel demand and CO2 emissions evolution in Europe toward 2030. Transport Res Transport Environ 2016;46:166–81. https://doi.org/10.1016/j.trd.2016.03.018.
[134] Di Gruttola F, Borello D. Analysis of the EU secondary biomass availability and conversion processes to produce advanced biofuels: use of existing databases for assessing a metric evaluation for the 2025 perspective. Sustainability 2021;13:7882. https://doi.org/10.3390/su13147882.
[135] Jåstad EO, Bolkesjø TF, Trømborg E, Rørstad PK. Large-scale forest-based biofuel production in the Nordic forest sector: effects on the economics of forestry and forest industries. Energy Convers Manag 2019;184:374–88. https://doi.org/10.1016/j.enconman.2019.01.065.
[136] Al-Ghussein Norrman N, Talalasova E. Fossil-free aviation 2045. Actions, obstacles and needs. RISE; 2021.
[137] O'Malley J, Pavlenko N, Searle S. Estimating sustainable aviation fuel feedstock availability to meet growing European Union demand. ICCT; 2021.
[138] RISE. Från Flis till flygplan i småland (FFS) - en genomförbarhetsstudie (From flis to aircraft in Småland, a feasibility study). 2020. https://www.ri.se/sites/default/files/2021-03/Final%20report%20FFS_public_low%20resolution_0.pdf. [Accessed 9 April 2021].
[139] Soam S, Börjesson P. Considerations on potentials, greenhouse gas, and energy performance of biofuels based on forest residues for heavy-duty road transport in Sweden. Energies 2020;13:6701. https://doi.org/10.3390/en13246701.
[140] European Commissions. New EU forest strategy for 2030 - to improve the quantity and quality of EU forests. Forest Strategy. 2021. https://ec.europa.eu/environment/strategy/forest-strategy_en. [Accessed 18 October 2021].
[141] Green Fund Fly. Reduce the carbon emissions from your flights. Fly Green Fund. n.d. https://flygreenfund.se/en/about-us/. [Accessed 19 February 2021].
[142] Goding L, Andersson-Franko M, Lagerkvist CJ. Preferences for bio jet fuel in Sweden: the case of business travel from a city airport. Sustain Energy Technol Assessments 2018;29:60–9. https://doi.org/10.1016/j.seta.2018.06.015.
[143] Siddiqui O, Dincer I. A comparative life cycle assessment of clean aviation fuels. Energy 2021;234:121126. https://doi.org/10.1016/j.energy.2021.121126.
[144] Resurreccion EP, Roostaei J, Martin MJ, Maglinao RL, Zhang Y, Kumar S. The case for camelina-derived aviation biofuel: sustainability underpinnings from a holistic assessment approach. Ind Crop Prod 2021;170:113777. https://doi.org/10.1016/j.indcrop.2021.113777.
[145] Kolosz BW, Luo Y, Xu B, Maroto-Valer MM, Andresen JM. Life cycle environmental analysis of 'drop in' alternative aviation fuels: a review. Sustain Energy Fuel 2020;4:3229–63. https://doi.org/10.1039/C9SE00788A.
[146] Sundararaj RH, Kumar RD, Raut AK, Sekar TC, Pandey V, Kushari A, et al. Combustion and emission characteristics from biojet fuel blends in a gas turbine combustor. Energy 2019;182:689–705. https://doi.org/10.1016/j.energy.2019.06.060.

[147] Krammer P, Dray L, Köhler MO. Climate-neutrality versus carbon-neutrality for aviation biofuel policy. Transport Res Transport Environ 2013;23:64–72. https://doi.org/10.1016/j.trd.2013.03.013.

[148] EU. European aviation environmental report 2019. Eurocontrol: EASA, EEA; 2019.

[149] Hansson J, Hackl R, Taljegard M, Brynolf S, Grahn M. The potential for electrofuels production in Sweden utilizing fossil and biogenic CO2 point sources. Frontiers Energy Res 2017;5:4. https://doi.org/10.3389/fenrg.2017.00004.

[150] Bellamy R, Fridahl M, Lezaun J, Palmer J, Rodriguez E, Lefvert A, et al. Incentivising bioenergy with carbon capture and storage (BECCS) responsibly: comparing stakeholder policy preferences in the United Kingdom and Sweden. Environ Sci Pol 2021;116:47–55. https://doi.org/10.1016/j.envsci.2020.09.022.

[151] Christiansen KL, Carton W. What 'climate positive future'? Emerging sociotechnical imaginaries of negative emissions in Sweden. Energy Res Soc Sci 2021;76:102086. https://doi.org/10.1016/j.erss.2021.102086.

[152] Fuss S, Johnsson F. The BECCS implementation gap–A Swedish case study. Frontiers Energy Res 2021;8:385. https://doi.org/10.3389/fenrg.2020.553400.

[153] Fridahl M, Bellamy R, Hansson A, Haikola S. Mapping multi-level policy incentives for bioenergy with carbon capture and storage in Sweden. Frontiers Clim 2020;2:25. https://doi.org/10.3389/fclim.2020.604787.

[154] Rodriguez E, Lefvert A, Fridahl M, Grönkvist S, Haikola S, Hansson A. Tensions in the energy transition: Swedish and Finnish company perspectives on bioenergy with carbon capture and storage. J Clean Prod 2021;280:124527. https://doi.org/10.1016/j.jclepro.2020.124527.

[155] Meckling J, Biber E. A policy roadmap for negative emissions using direct air capture. Nat Commun 2021;12:2051. https://doi.org/10.1038/s41467-021-22347-1.

[156] Hansson J, Hackl R, Taljegard M, Brynolf S, Grahn M. The potential for electrofuels production in Sweden utilizing fossil and biogenic CO2 point sources. Frontiers Energy Res 2017;5:4. https://doi.org/10.3389/fenrg.2017.00004.

[157] Swedish Energy Agency. Scenarier över Sveriges energisystem 2020 (Scenarios of Swedish energy system 2020). Bromma: Sweish Energy Agency; 2021.

[158] Larsson M, Grönkvist S, Alvfors P. Synthetic fuels from electricity for the Swedish transport sector: comparison of well to wheel energy efficiencies and costs. Energy Procedia 2015;75:1875–80. https://doi.org/10.1016/j.egypro.2015.07.169.

[159] Isaacs SA, Staples MD, Allroggen F, Mallapragada DS, Falter CP, Barrett SRH. Environmental and economic performance of hybrid power-to-liquid and biomass-to-liquid fuel production in the United States. Environ Sci Technol 2021;55:8247–57. https://doi.org/10.1021/acs.est.0c07674.

[160] Freire Ordóñez D, Shah N, Guillén-Gosálbez G. Economic and full environmental assessment of electrofuels via electrolysis and co-electrolysis considering externalities. Appl Energy 2021;286:116488. https://doi.org/10.1016/j.apenergy.2021.116488.

[161] Fajardy M, Dowell NM. Can BECCS deliver sustainable and resource efficient negative emissions? Energy Environ Sci 2017;10:1389–426. https://doi.org/10.1039/C7EE00465F.

[162] Penke C, Falter C, Batteiger V. Pathways and environmental assessment for the introduction of renewable hydrogen into the aviation sector. In: Albrecht S, Fischer M, Leistner P, Schebek L, editors. Progress in life cycle assessment 2019. Cham: Springer International Publishing; 2021. p. 41–52. https://doi.org/10.1007/978-3-030-50519-6_4.

[163] Fossil Free Sweden. Strategy for fossil free competitiveness - hydrogen. Fossil free Sweden; 2021.

[164] Pei M, Petäjäniemi M, Regnell A, Wijk O. Toward a fossil free future with HYBRIT: development of iron and steelmaking technology in Sweden and Finland. Metals 2020;10:972. https://doi.org/10.3390/met10070972.

[165] Toktarova A, Karlsson I, Rootzén J, Göransson L, Odenberger M, Johnsson F. Pathways for low-carbon transition of the steel industry—a Swedish case study. Energies 2020;13:3840. https://doi.org/10.3390/en13153840.

[166] Karakaya E, Nuur C, Assbring L. Potential transitions in the iron and steel industry in Sweden: towards a hydrogen-based future? J Clean Prod 2018;195:651–63. https://doi.org/10.1016/j.jclepro.2018.05.142.

[167] SCB. Elektricitet i sverige (electricity in Sweden). Statistiska centralbyrån. 2021. http://www.scb.se/hitta-statistik/sverige-i-siffror/miljo/elektricitet-i-sverige/. [Accessed 18 October 2021].

[168] Cerniauskas S, Jose Chavez Junco A, Grube T, Robinius M, Stolten D. Options of natural gas pipeline reassignment for hydrogen: cost assessment for a Germany case study. Int J Hydrogen Energy 2020;45:12095–107. https://doi.org/10.1016/j.ijhydene.2020.02.121.

[169] André J, Auray S, De Wolf D, Memmah M-M, Simonnet A. Time development of new hydrogen transmission pipeline networks for France. Int J Hydrogen Energy 2014;39:10323–37. https://doi.org/10.1016/j.ijhydene.2014.04.190.

[170] Benson CM, Ingram JM, Battersby PN, Mba D, Sethi V, Rolt AM. An analysis of Civil aviation industry safety needs for the introduction of liquid hydrogen propulsion technology. American Society of Mechanical Engineers Digital Collection; 2019. https://doi.org/10.1115/GT2019-90453.

[171] Benson CM, Holborn PG, Rolt AM, Ingram JM, Alexander E. Combined hazard analyses to explore the impact of liquid hydrogen fuel on the Civil aviation industry. American Society of Mechanical Engineers Digital Collection; 2021. https://doi.org/10.1115/GT2020-14977.

[172] Bicer Y, Dincer I. Life cycle evaluation of hydrogen and other potential fuels for aircrafts. Int J Hydrogen Energy 2017;42:10722–38. https://doi.org/10.1016/j.ijhydene.2016.12.119.

[173] Gambino C, Reddy TA. Sustainability assessment of aviation fuel blends. American Society of Mechanical Engineers Digital Collection; 2021. https://doi.org/10.1115/ES2021-60617.

[174] Ingenito A. Impact of hydrogen fueled hypersonic airliners on the O3 layer depletion. Int J Hydrogen Energy 2018;43:22694–704. https://doi.org/10.1016/j.ijhydene.2018.09.208.

[175] Chalmers. Electric aviation in Sweden (elise part 2). 2020. https://www.chalmers.se/en/projects/Pages/Elise—Electric-Aviation-in-Sweden.aspx. [Accessed 18 October 2021].

[176] Heart Aerospace. Heart Aerospace is one step closer to building an electric plane, closing $35M Series A round led by Breakthrough Energy Ventures. United Airlines and Mesa Air Group; 2021. https://heartaerospace.com/wp-content/uploads/2021/07/Heart-Aerospace-Series-A-Press-Release-July-13-2021.pdf. [Accessed 18 October 2021].

[177] Nordic Innovation. Nordic network for electric aviation (NEA). Nordic innovation. 2019. https://www.nordicinnovation.org/programs/nordic-network-electric-aviation-nea. [Accessed 18 October 2021].

[178] Mäenpää A, Kalliomäki H, Ampuja V. Potential impacts of electric aviation in the kvarken region: stakeholder views in 2020. Vaasa, Finland: University of Vaasa; 2021.

[179] Kurdve M, Zackrisson M, Johansson MI, Ebin B, Harlin U. Considerations when modelling EV battery circularity systems. Batteries 2019;5:40. https://doi.org/10.3390/batteries5020040.

[180] Olsson L, Fallahi S, Schnurr M, Diener D, Van Loon P. Circular business models for extended EV battery life. Batteries 2018;4:57. https://doi.org/10.3390/batteries4040057.

[181] Gur K, Chatzikyriakou D, Baschet C, Salomon M. The reuse of electrified vehicle batteries as a means of integrating renewable energy into the European electricity grid: a policy and market analysis. Energy Pol 2018;113:535–45. https://doi.org/10.1016/j.enpol.2017.11.002.

[182] Tadaros M, Migdalas A, Samuelsson B, Segerstedt A. Location of facilities and network design for reverse logistics of lithium-ion batteries in Sweden. Oper Res Int J 2020. https://doi.org/10.1007/s12351-020-00586-2.

[183] Salucci F, Trainelli L, Faranda R, Longo M. An optimization model for airport infrastructures in support to electric aircraft. In: 2019 IEEE milan PowerTech; 2019. p. 1–5. https://doi.org/10.1109/PTC.2019.8810713.

[184] Justin CY, Payan AP, Briceno SI, German BJ, Mavris DN. Power optimized battery swap and recharge strategies for electric aircraft operations. Transport Res C Emerg Technol 2020;115:102605. https://doi.org/10.1016/j.trc.2020.02.027.

[185] LFV. LFV and Vattenfall in collaboration on the fossil-free airport. 2021. https://www.lfv.se/en/news/news-2021/lfv-and-vattenfall-in-collaboration-on-the-fossil-free-airport. [Accessed 18 October 2021].

[186] Han H, Lho LH, Al-Ansi A, Ryu HB, Park J, Kim W. Factors triggering customer willingness to travel on environmentally responsible electric airplanes. Sustainability 2019;11:2035. https://doi.org/10.3390/su11072035.

[187] Han H, Yu J, Kim W. An electric airplane: assessing the effect of travelers' perceived risk, attitude, and new product knowledge. J Air Transport Manag 2019;78:33–42. https://doi.org/10.1016/j.jairtraman.2019.04.004.

[188] Gnadt AR, Speth RL, Sabnis JS, Barrett SRH. Technical and environmental assessment of all-electric 180-passenger commercial aircraft. Prog Aero Sci 2019;105:1–30. https://doi.org/10.1016/j.paerosci.2018.11.002.

[189] Baumeister S, Leung A, Ryley T. The emission reduction potentials of first generation electric aircraft (FGEA) in Finland. J Transport Geogr 2020;85:102730. https://doi.org/10.1016/j.jtrangeo.2020.102730.

[190] Hauschild MZ. Introduction to LCA methodology. In: Hauschild MZ, Rosenbaum RK, Olsen SI, editors. Life cycle assessment: theory and practice. Cham: Springer International Publishing; 2018. p. 59–66. https://doi.org/10.1007/978-3-319-56475-3_6.

[191] Lombardi L, Tribioli L, Cozzolino R, Bella G. Comparative environmental assessment of conventional, electric, hybrid, and fuel cell powertrains based on LCA. Int J Life Cycle Assess 2017;22:1989–2006. https://doi.org/10.1007/s11367-017-1294-y.