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HOW DO SUSTAINABLE AVIATION FUELS SHAPE THE CONDITIONS FOR AVIATION GROWTH?

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ABSTRACT: According to forecasts, the aviation market will be characterised by dynamic growth. At the same time, a reduction in GHG emissions from transport is postulated. One of the proposed solutions is sustainable aviation fuels (SAF). The aim of this article is to analyse the impact of sustainable aviation fuels on the development of the aviation market. Economic and environmental criteria will be considered. The paper uses an approach based on an analysis of foundational data, including academic articles, industry reports and sustainability reports presented by carriers. Given the dynamics of the market, it seems difficult at this point to secure the right quantities of SAF. Larger aerospace companies are seeking to secure supply by, among other things, signing memoranda and co-funding innovation activities to develop supply. The main added value of the presented research is that it highlights the need for cooperation between several stakeholders in the aviation market who are committed to the growth of air transport.

KEYWORDS: aviation, sustainable aviation fuel, emissions, European airlines, development of air transport market

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Introduction

Air transport is one of the key instruments of the global economy. During the COVID-19 2020 pandemic crisis, there has been a decrease (vs 2019) in the number of passengers (60%), seats offered by airlines (50%) and the revenue (371 billion USD loss) generated by air transport companies (ICAO, 2021). In the post-pandemic period and during the war in Ukraine, there was a change in the socio-economic environment, resulting in an uncontrolled process of price increases and inflation. Despite the unfavourable economic situation, air transport is recovering from the COVID-19 pandemic, as evidenced by operational data. In 2022, the share of cargo traffic in total airline revenues was 17%, 5 pct more than in 2019. Global GDP grew by 3.4% in 2022, while a moderate forecast calls for a further growth of 2.8% in 2023, which should be read as economic development. Passenger kilometre revenue (PRK) also increased from 41.7% in 2019 to 68.5% in 2022 (IATA, 2024b).

International Air Transport Association (IATA, 2023a) estimates that demand for air transport services will continue to grow, but at a slower pace than in the past three years. Forecasts indicate an annual growth rate of 4.2% per year between 2023 and 2040, bringing the number of passengers travelling by air in 2040 to 7.8 billion passengers. There are a number of uncertainties around such forecasts related to the operation of the market. Such insecurities include changes in demand under macroeconomic conditions as well as changes in the supply chain and environmental requirements. However, increased air traffic will be accompanied by increased pollution.

In this context, air transport is one of the transport sectors that pollutes the environment to a large extent. According to the European Environment Agency (EEA, 2022), air transport was responsible for around 5% of global carbon dioxide emissions, which consequently contributes to the greenhouse effect, but already in 2022, according to the EEA, the share has decreased to 2%. In the European Union (European Commission, 2020), air transport accounted for 13.9% of greenhouse gas emissions in 2017, much less than road transport.

In pursuit of zero emissions in air transport, the ICAO (IATA, 2024c) has identified three main environmental goals: to reduce or limit the number of people affected by significant aircraft noise, to reduce or limit the impact of aviation emissions on local air quality, and to reduce or limit the greenhouse gas impact of air transport on the global climate. In addition, ICAO has developed an environmental toolkit:

- Carbon Calculator,
- Green Meetings Calculator,
- ICAO tool for estimating aviation fuel savings,
- Environmental Benefits Tool,
- Marginal abatement cost curve tool,
- E-learning course on State Action Plans,
- Eco-airport toolkit,
- ICAO CORSIA CO_2 Estimation and Reporting Tool.

In addition to ICAO activities, similar actions are also being taken by the Air Transport Action Group (ATAG), IATA and representatives of continental organisations (in Europe: the European Union). The Air Transport Action Group aims to reduce annual net emissions in 2050 to half of 2005 levels (EASA et al., 2019). (EC, 2019) in its Green Deal Policy, it set out the need to reduce emissions from the transport sector by 90 percent by 2050. European air transport will also be forced to take action to move towards low-carbon transport. In addition to market-based measures (Larsson et al., 2019) (EU ETS – the EU's emission trading system), the European Commission will also aim for European airports to carry out strictly operational activities, e.g. modernisation and improvement of technology, in terms of procedures, air traffic management systems and promotional, public awareness activities (European Commission, 2020). As a result of environmental awareness, there has been a 21.5% reduction in CO_2 emissions/pkm over the last few years, new aircraft delivered to the market meet requirements to reduce environmental impact, are more efficient, and aircraft engines use less aviation fuel. One of the solutions identified is the use of sustainable jet fuel (SAF). Based on the above considerations, we have identified the scientific objective of the paper. The aim of this article is to analyse the impact of sustainable aviation fuels on the development of the aviation market. In realising the scientific aim, we formulated the main hypothesis:

- H: SAF requirements presented by IATA, the EU and CORSIA may be a barrier to growth for the air carriers, which we formulated three research problems addressed in this paper:
    - RP1: At present, SAF supply is significantly lower than the limits announced by the EU and IATA. Due to the short time to comply with the regulations, the imposed limits may be a problem.
    - RP2: In view of the guidance issued by international aviation organisations and European authorities, aviation fuel producers are implementing joint activities to contribute to the availability of SAF.
    - RP3: Currently, there is no single leading technology in the production of sustainable aviation fuels.

In pursuing the main objective and research problems, in order to verify the hypothesis, we conducted a literature review, research from which we drew conclusions and discussed them scientifically, taking into account our insights from the literature review. In the final part of the research, we formulated recommendations for the development of the SAF market.

An overview of the literature

Bio-based fuels offer an alternative to fossil fuels. Research into the suitability of fuels to reduce the negative environmental impact of air transport has shown that, as a result of the use of different feedstocks and technologies in the production of biofuels, their negative environmental impact will be lower than that of traditional fossil fuels. It is important to agree (Kolosz et al., 2020; Staples et al., 2018) that sustainable aviation fuel is an alternative to the traditional fuels previously used by carriers, and with the research, the use of sustainable fuels will help the aviation sector meet its targets by 2050.

Sustainable aviation fuels are drop-in fuels that do not require mechanical modification to aircraft engines or infrastructure (Ng et al., 2021). The main factor needed to produce sustainable fuels is waste biomass components (Staples et al., 2018). The feedstock for obtaining biomass from which it is possible to create SAF fuel may be municipal solid waste, straw, used cooking oil, forestry residues, sugar and starch, agricultural residues, wood waste and energy crops, such as halophytes and algae, rapeseed, sugarcane, corn, palm oil (Ahmad & Xu, 2021). Raw materials that have a less harmful environmental impact are used to produce SAF. From the chemical point of view and depending on the use of biomass, different SAF production paths are possible and belong to them:

Fischer-Tropsch synthetic paraffinic kerosene (FT-SPK), in which 1 ton of FT fuel can be obtained from approximately 5-6 tons of biomass. In the process of FT formation, hydrocarbons with different numbers of C-atoms (carbon chain lengths) are produced. Here, we can distinguish light hydrocarbons (C_1–C_4), naphtha (C_5–C_{10}), kerosene (C_{10}–C_{16}), distillate (C_{14}–C_{20}), and waxes (C_{20+}). The FT liquid is completely sulfur-free and contains a minimal amount of aromatic compounds compared to gasoline and diesel oil, which consequently causes less environmental pollution (IATA, 2015; Ng et al., 2021),

Hydroprocessed esters and fatty acids (HEFA), in which approximately 1.2 tons of biomass are needed to produce 1 ton of HEFA fuel. This process involves a series of reactions, starting with the extraction of free fatty acids (FFA) from the biomass, followed by molecular rearrangement and reactions that reduce the carbon chain length of the molecules to obtain jet fuel (Ng et al., 2021),

Alcohol-to-jet (ATJ), which involves the conversion of short-chain alcohols, for example, methanol, ethanol and butanol, into longer-chain hydrocarbons (8-16 C-atoms). Alcohol can be produced from biomass via thermochemical processes such as gasification, pyrolysis, or fermentation. The most common methods of obtaining fuel from alcohol are processing routes methanol-to-olefins followed by Mobil's olefin-to-gasoline/distillate and processing ethanol/isobutanol/butanol/other alcohols processing via dehydration, oligomerisation and hydrogenation (Ng et al., 2021; Ng & Sadhukhan, 2011),

Hydroprocessing of fermented sugars (HFS) involves the direct conversion of sugars into hydrocarbons. The process begins by separating the sugars from the lignin, then conversion of sugars to farnesene ($C_{15}H_{24}$) by enzymatic hydrolysis and fermentation, separation of solid and liquid substances and recovery of farnesene and hydroprocessing to farnesan ($C_{15}H_{32}$), which is the biofuel (Ng et al., 2021), and new and other ways of receiving SAF such as hydroprocessing of fermented sugar, Synthetic iso-paraffins (HFS–SIP) hydrothermal liquefaction (HTL), aqueous phase reforming (APR) or Co-processing (Davis et al., 2018; Farooq et al., 2020; Ng et al., 2021; Perkins et al., 2019; Tzanetis et al., 2017)regional resource and carbon footprint assessment are conducted on three different HTL configurations, i.e. a base case without energy and resource recovery; an HTL with heat integration; and an HTL with energy and resource recovery. Three different feedstocks (algae, food waste and sewage sludge. SAF can be produced synthetically through a process that captures carbon directly from the air, and as a sustainable fuel, it does not compete with food crops water resources, nor is it responsible for forest degradation (IATA, 2024a).

The biomass, which includes agricultural residues, hardwood, wheat straw, and energy crops can be processed in FT process and biomass, such as forest residues, wood chips, sugarcane, agricultural residues, energy crops and others) in the ATJ process, while the oils (used cooking oil, palm oil soya oil, palm fatty acid distillate and others) constitute biomass for the HEFA process. The HFS process uses fructose, sugarcane, C_5 and C_6 sugars, agricultural residue and other) (Ng et al., 2021).

The environmental impact of SAF on air transport in the global transport literature is analysed in both indirect and direct ways. Indirect relates to exhaust emissions and cirrus clouds that lead to climate change through biochemical processes, while the direct effect results from the combustion of jet fuel and the formation of CO_2, SO_2 and NO_x (Lee et al., 2009; Myhre et al., 2011)$_{\text{nitrogen oxides (NOx.}}$ Exhaust emissions resulting from the combustion of fossil fuel during flight, per 1 l. of JET fuel emits approx. 2.5 kg of CO_2, making aircraft such as the Airbus A320 consume about 2,700 l of fuel per hour of flight, resulting in emissions of about 6750 kg of CO_2 during that time (Andruleit et al., 2018; Mensen, 2013). Therefore, the main point for sustainable development is that depending on the feedstock and technological path, the GHG emissions can be up to 94% lower than emissions from conventional fuels (the CO_2-equivalent emission of the base fossil fuel is 89 g CO_2e MJ−1). The CO_2e emissions of SAF range from 5.2 to 73.4 g CO_2e MJ−1 (Teoh & Khoo, 2016)the environmental sustainability of air transport is receiving greater concern nowadays owing to its critical impact on climate change. This paper provides an overview of the environmental (green. Direct the greenhouse gas (GHG) emissions [g CO_2e MJ−1] for different SAF production pathways are 3.06-22.0 for Fischer-Tropsch (FT) synthesis, from 13.0 to 55.0 for hydroprocessed esters and fatty acids (HEFA) process from 1.6 to 65.0 for alcohol-to-jet (ATJ) process and 15.0-61.5 for hydroprocessing of fermented sugars (HFS) (Ng et al., 2021). The SAF solutions can significantly reduce the CO_2 emissions affecting the environment. Moreover, according to (Bhatt et al., 2023)there is a lack of understanding of how the synergistic effects of key performance variables could hinder or help the deployment of aviation fuels on a regional scale. Here, we assess the implications of key variables–including type and quantity of waste/biomass feedstock availability near the airport, cost of SAF production, life cycle greenhouse gas (GHG the volume of PM2.5 emissions can decrease by 30%, depending on the type of feedstock used.

Methodology

Based on the literature review, the state of the art (and research) in SAF to the present, as well as empirical data from airlines and guidance from legislation and documents from industry organisations, were presented. The comparison of the three different dimensions made it possible to find that air transport-related companies perform a number of activities related to the development of sustainable transport policies, including in particular, investments related to the implementation of sustainable aviation fuel.

The first element of the research was a literature review of sustainable aviation fuel issues and legislation related to the implementation of sustainable fuel deployment policies.

The research approach is typical of the secondary data verification process, as indicated (Yin, 2018).

Ultimately, the analysis should include air carriers with a share of more than 95% of the Polish market. However, due to limited access to data, the focus was on the implementation of statutory requirements by the largest air carriers with 86% share of the Polish market (CAA in Poland, 2024). At the same time, these air carriers, due to the specifics of the market, provide services on the global aviation market.

This research presents only a part of the overall project related to the implementation of various sustainable development instruments by air carriers.

In analysing the research problem, source data was analysed – materials published by the air carriers Ryanair, Wizz, Polish Airlines, Lufthansa and KLM, and then verified from a formal and legal point of view – regulations and regulatory documents published by global institutions related to air transport and institutions in the European Union. The dynamic growth of the market, the potential demand for SAF, and, at the same time, the lack of SAF production make the Polish market an interesting case study. According to (CAA in Poland, 2024) the Polish aviation market, it has largely recovered from the COVID-19 outbreak. In the first half of 2023, 23.2 million passengers were handled at Polish airports, which is 4 per cent more than in the first half of 2019 and 40 per cent more than in the corresponding period of 2022. 172,800 aircraft operations were handled – 8 per cent less than in 2019 but 19 per cent more than in the first half of 2022. Another reason is that carriers are seeing a greater problem with SAF availability in Eastern Europe, as Wizz Air, for example, pointed out directly in its annual sustainability report (Wizz Air, 2024a).

The results of the presented research are a consequence of the analysis of strategic documents published by the largest air carriers in Poland and, at the same time, selected European carriers.

Case study

The subject of the research was air carriers operating in Poland, serving European markets and, in some cases, domestic markets.

Table 1. Air traffic in Poland in 2021-2023

Air carriers	2021		2022		2023	
	Air traffic	Share [%]	Air traffic	Share [%]	Air traffic	Share [%]
Ryanair	5,689,777	34.07	12,759,812	38.93	15,118,018	36.57
Wizz	3,309,516	19.82	7,614,657	23.23	10,516,530	25.44
Polish Airlines	4,395,576	26.32	5,814,425	17.74	7,277,503	17.61
Lufthansa	753,364	4.51	1,518,248	4.63	1,817,616	4.40
KLM	415,429	2.49	637,521	1.95	793,255	1.92
Total: Polish market	16,699,056	100.00	32,772,379	100.00	41,336,353	100.00
Total: air carries	14,563,662	87.21	28,344,663	86.49	35,522,922	85.94

Source: (CAA in Poland, 2024).

The largest air carrier active in the Polish market is Ryanair, which had the largest market share of 36% in 2023. It was followed by Wizz with a 25% market share and Polish Airlines (LOT) with a 17% market share. The share of subsequent air carriers is small, below 10%.

In the ranking of European air carriers, in the classification of daily flights performed, it is Ryanair with an average of approximately 2.8 thousand flights per day, easy Jet with 1.5 thousand flights per day, Turkish Airlines with 1.4 thousand and Lufthansa with 1.1 thousand flights per day (Eurocontrol, 2023).

In the ranking of the 15 Best European Airlines – Top Carrier Ratings 2023 by AirAdvisor, the top rankings include Lufthansa, KLM and Polish Airlines (AirAdvisor, 2024). This selection is, therefore, a good one, as it shows the specificity and diversity of the airline operators. In addition, this selection shows the diversity of approaches by air carriers representing different business models.

Results of the research

The considerations above are related to the need for alternative fuel solutions. Nevertheless, the number of commercial flights using SAF increased to 450 000 in 2021, the use of SAF by more than 50 airlines (Ernst & Young, 2023). According to IATA estimates, in 2022, global SAF production was between 240,000 and 380,000 tonnes (300 million to 400 million litres), covering between 0.1% and 0.15% of total jet fuel demand (IATA, 2023b). The sale of this volume of fuel resulted in additional costs to the industry of between US$322 million and US$510 million (Research and Markets, 2020). Research and Markets (2020) assumes that biofuels will have the largest market share, remaining a viable SAF option. This approach follows the Energy Transitions Commission (ETC), which has carved out four SAF options: electric batteries, green hydrogen, hydrogen-powered electro fuels or e-fuels and biofuels. According to the assumptions of the documents analysed, there will need to be a rapid increase in supply in this market (see Table 1). In 2025, the share of SAF in aviation fuel is postulated to be 2%, requiring a 14- to 20-fold growth in supply. If we additionally take into account the forecast growth of the aviation market, these values will be even higher. An additional criterion appearing in the Fit for 55 documents is the share of e-fuels in total SAF from 2030.

Table 2. Sustainable aviation fuel requirements by document

Document	Data	Standard
fit for 55 (EASA, 2024)	2025 – 2% SAF in fuel 2030 – 5% SAF in fuel (incl. 0,7% synthetic/e-fuels) 2035 – 20% (5%) 2040 – 32% (8%) 2045 – 38% (11%) 2050 – 63% (28%)	Using SAF in air travel, including: Advanced biofuels, produced from feedstock listed in Annex IX, Part A of the Renewable Energy Directive, Fuels produced form feedstock listed in Part B, Synthetic Aviation fuels (Power-to-Liquid or e-fuels), Ensure electricity supply for stationary commercial aircraft at all gates by 2025 and additionally at all outfield positions by 2030.
Sustainability Criteria for CORSIA Eligible Fuels (ICAO, 2021)	2021-2023 – voluntary 2024-2026 – first phase 2027-2035 – second phase	(Principle 1) CORSIA SAF should generate lower carbon emissions on a life cycle basis. (Principle 2) CORSIA SAF should not be made from biomass obtained from land/aquatic systems with high biogenic carbon stock.
Fly net zero (IATA, 2021)	2025 – 381 mega tonnes (Mt) of CO_2 abatement; incl. 2% share in it 2030 – 979 Mt, 5% 2035 – 1,703 Mt, 17,5% 2040 – 3,824 Mt, 40% 2045 – 6,153 Mt, 55% 2050 – 8,164 Mt, 65%	In Fly net zero strategy SAF is responsible for lowering CO_2 emissions in 65%.

Source: authors' work based on (EASA, 2024; IACO, 2021; IATA, 2021).

On the other hand, it is worth looking at the declarations of carriers that state the SAF values they intend to incorporate into their operations. These declarations can be found in sustainability reports. The following table (Table 3) shows the declarations of selected traditional carriers. The criterion for the selection of carriers was market share, as determined by data from the Civil Aviation Authority (CAA in Poland, 2024). According to the data, in both 2022 and 2023, Ryanair (36.57% in 2023), Wizz Air (25.44%), LOT Polish Airlines (17.61%), Lufthansa (4.40%) and KLM Royal Dutch Airlines (1.92%) carried the most traffic.

Another issue to which we draw attention is the availability of SAF fuel in Europe. According to Report, the SAF market is experiencing strong growth driven by several key factors. Heightened global awareness of climate change and the need to reduce greenhouse gas emissions is forcing pressure on producers to increase the availability of air carriers to strive for utilisation (Research and Markets, 2020). Hence, a process of increased activity in research and development is taking place at many refineries to increase SAF yields coupled with advances in feedstock technology, resulting in a

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significant contribution to air transport growth. Therefore, market stakeholders realise that cooperation between air carriers and producers of sustainable aviation fuels for sustainable air travel is necessary. Also, governments and international aviation organisations are implementing supportive policies and regulations to encourage the use of SAF. For example, Polish enterprises Orlen is working on introducing sustainable aviation fuel to the market (Orlen, 2022). Despite the fact that PLL LOT aircraft currently use fossil fuels, LOT is planning to move to SAF (Polish Aviation Group, 2024). Aircraft owned by the Polish Airlines are relatively new, the fleet consisting of approx. 30% of machines are under 5 years old, which means that fuel efficiency is high.

Table 3. SAF declarations by airline

	Ryanair	Wizz Air	LOT	LUFTHANSA	KLM
Flights with SAF	12.5% by 2030	10% by 2030	-	6% by 2030 (incl. 1,2% e-fuels)	10% by 2030
GHG reduce by SAF	34% by 2050	25% (per passanger/km) by 2030	-	30,6% by 2030 (in general)	30% by 2023 (in general) 8% – SAF
Memorandum	Neste OMV Repsol Shell	Mabanaft/P2X Europe OMV Cepsa Neste	SkyNRG PKN ORLEN	Shell Global VARO Energy OMV	e-SAF Supply Group Total Energies OMV

Source: authors' work based on (KLM, 2019, 2020, 2024b; Lufthansa, 2022; Lufthansa Group, 2020b; Ryanair, 2022; Rynek Lotniczy, 2023; Wizz Air, 2024b).

In 2019, Lufthansa and Raffinerie Heide signed a joint declaration of intent on the future production and acceptance of electricity-based kerosene. The aim of the so-called Power-to-Liquid process is to produce synthetic crude oil from regeneratively generated electricity, water and CO_2, which can be processed into kerosene and used in any aircraft. Advantage: when the sustainable kerosene is burned, only as much CO_2 is released as was previously removed from the atmosphere during production.

In spring 2020, Representatives of the Lufthansa Group and Swiss Federal Institute of Technology Zurich (ETH Zurich), with its spin-offs Clime-works and Synhelion, signed a joint Letter of Intent for possible cooperation (Lufthansa Group, 2020a). This should result in the acceleration of SAF's market launch. The researchers and engineers at ETH Zurich have developed innovative processes that make it possible to extract CO_2 from the atmosphere and, together with water and with the help of concentrated sunlight, convert it into a synthesis gas that can be used to produce jet fuel. Such fuel releases only as much CO_2 as was previously extracted from the atmosphere. The signatories commonly prepare promising technologies for later industrial production (Lufthansa Group, 2020b).

KLM uses sustainable jet fuel – an alternative to fossil fuels – on many of its flights. KLM was the first airline to operate a commercial flight using eco-friendly aviation fuel in 2011. What's more, KLM made a 10-year commitment to develop and purchase 75,000 tonnes of sustainable jet fuel per year (KLM, 2020, 2024a).

Preparations are currently underway to build Europe's first ecological jet fuel factory. SkyNRG is building the factory in Groningen. The factory will be entirely dedicated to the production of sustainable jet fuel made from raw materials, mainly waste streams from the region. Construction was completed in 2022. The factory will be the first and largest of its kind in the world. Another interesting fact is that KLM is the first and only airline in the world to commit to using sustainable jet fuel on this scale.

KLM's ambition is to use at least 5% sustainable jet fuel by 2030. This is more than a hundred times more than KLM currently uses. This process will require new production facilities and more parties to stimulate the purchase of sustainable aviation fuel (KLM, 2020).

Some European countries have introduced, and others are considering policies to encourage the use of SAF in the future, from January 2020. Norway has introduced SAF blending rebates of 0.5% from 2022, with the ambition to increase this over time. Sweden is following a similar path, gradually increasing rebates to 27% by 2030 (EASA, 2022). France has set out its pathways for SAF in 2019. (SAF consumption targets of 2% by 2025, 5% by 2030 and 50% in 2050) and has started to regulate fuel suppliers with a target for advanced biofuels and fuels made from waste oils and fats (1% of jet fuel demand in 2022)(Republique Francaise, 2019). The Netherlands is considering a 14% SAF share by 2030 and a complete replacement of fossil fuels by 2050 (EASA, 2022).

European airlines have also announced corporate targets. For example, International Airlines Group (IAG) and Ryanair have committed to using 10% and 12.5% SAF, respectively, by 2030 (IAG, 2024). British Airways owner sets the goal to run 10% on flights on biofuels by 2030 (Surgenor, 2024), Ryanair donates $1.8m to sustainable aviation research as it commits to 12% SAF (EASA, 2022).

For its part, Wizz Air recognises the key role of SAF in the decarbonisation of aviation and that, in the context of the regulations indicated, the need for SAF sources will grow. As such, the company has indicated in its 2023 report that it will invest £5,000,000 to support the development of Firefly's SAF process. This declaration is linked to Wizz Air's first capital investment in SAF research and development. The main motivation for the agreement is to supply SAF to UK operations from 2028 – up to 525,000 tonnes over 15 years. The indicated volume of supply will potentially reduce around 1.5 million tonnes of lifecycle greenhouse gases compared to fossil aviation fuel (Wizz Air, 2023).

While these actions provide an incentive for the production and use of SAF, it is unlikely that these actions alone will enable the development of SAF at a competitive price and encourage its use across the EU in sufficient quantities to achieve significant emissions reductions from the aviation sector. Furthermore, stakeholders have repeatedly called for a harmonised and long-term policy as the most important measure to mitigate barriers to SAF production and use.

It is apparent that for most major airlines, the plans are more ambitious than those of the regulatory environment. This puts additional pressure on the SAF supply market and generates additional risks for smaller carriers that do not have such bargaining power. At the same time, major airlines are actively involved in creating demand for SAF, including by signing a Memorandum of Understanding for supply and supporting research and development. However, it is apparent that the same actors are active on the supply side of a number of airlines. This carries the risk of making a significant part of the SAF market dependent on the efficiency of only a few players.

Discussion and limitation

Sustainable aviation fuels appear to be the solution to the carbonisation of aviation. However, as they note (Rojas-Michaga et al., 2023)economic, and environmental performance of a Power-to-Liquid (PtL, the main problem associated with the low supply of SAF is the trouble associated with the availability of large quantities of good quality raw materials. The availability of SAF may also be affected by climate change – for example, reduced harvests due to droughts, especially in southern Europe. This threat is pointed out by Wizz Air, among others, in its sustainability report. Moreover, the carrier declares that SAF shortage risk presents an opportunity in the context of investing in the certification and future production of alternative fuels. According to Wizz Air's Annual Sustainability Report 2023, such commitment leads to access to higher SAF volumes at a cost lower than market price (Wizz Air, 2024a). The airline sees a solution in supplier diversification, but supply-side shortages could be a barrier to this.

Another challenge is connected with difficulties associated with the high price of sustainable jet fuel (Santos & Delina, 2021)and the current reduction methods of carbon offsets and increasing aircraft efficiency will not be enough to significantly lower emissions by 2050. Considering the prior growth of the aviation industry and to meet the Paris Agreement's 2-degree Celsius target, aircraft emissions must be reduced rather than simply offset. This Perspective discusses the role of sustainable aviation fuel (SAF and other factors affecting availability. For example, Ryanair is expecting 34% of the 2050 net zero target to be accomplished with the use of SAF. At the same time, he declares for this to happen, then accessibility barriers must be removed. One of the ways Ryanair uses is by signing memoranda with suppliers (Ryanair Group, 2021). Other described companies also do this, which, on the one hand, is a market advantage for them, but on the other hand, it can lead to the unavailability of SAF for smaller airlines that are less advanced in their sustainability transformation process. Additionally, carriers are funding SAF research and setting more ambitious targets for participation (Ryanair, 2022; Wizz Air, 2024b). One of the goals in this area is to reduce prices and the risk of unavailability. Another approach to market development is to combine SAF refuelling with the offsetting of residual emissions resulting from travel. An example of this is Lufthansa, which has introduced a Green Fares service since February 2023, in which it promises to reduce 20% through individual (additional) flight-related CO_2 emissions by using sustainable aviation fuels and the remaining 80% through offsets related to high-quality climate protection projects within Europe (Lufthansa Group, 2024). The concept used by KLM is to pay with 'miles' and cash for additional SAF, which has increased average customer spending on SAF. The goSAF corporate program, which takes into account cargo transport, is also used. Moreover, the Engineering & Maintenance team of KLM performed the world's first test run of an engine using 100% SAF (Air France & KLM, 2022).

A different issue is the refuelling management process driven by a number of factors, like the operational capabilities of the fuel agent, the availability of fuel, and the price. Such drivers influence cost and revenue policy and consequently affect the profitability of airline connections. According to (European Commission, 2021), one of the factors that distorts natural competition is the refuelling of more aviation fuel than needed, resulting in increased negative environmental impacts related to CO_2 emissions into the atmosphere. This phenomenon is known as tinkering. It offers an economic benefit when there is a considerable fuel price difference between the departure and arrival airports (Eurocontrol, 2019). However, another reason may be the inability to refuel at the destination airport (due to the risk of delays, social disruption or fuel shortages, among others). The phenomenon includes full refuelling (i.e., refuelling for the entire return flight) and partial refuelling (refuelling with less fuel than is needed for the return flight)(Tabernier et al., 2021)"ISSN":"2226-4310","abstract":"The majority of emissions from aviation come from the combustion of the fuel required to operate each flight. Keeping the fuel consumption required for a safe flight to the absolute minimum is therefore the simplest and most effective way to ensure that emissions from that flight are kept to a minimum. In practice, however, the fuel load is determined by each aircraft operator on the basis of a number of criteria maximizing first cost efficiency, rather than fuel savings. In this context, tankering is the practice of carrying more fuel than is necessary for the safe execution of the flight to avoid or minimize refueling at the destination airport. It offers an economic advantage when there is a significant difference in fuel prices between the departure and arrival airports, but considerably increases the amount of emissions produced, because the more fuel an aircraft carries, the heavier it is, and carrying this extra weight increases its fuel consumption. This paper presents the steps followed by EUROCONTROL in conducting a first study to estimate the number of times this practice would offer an economic benefit and the amount of extra CO2 emissions that would result. This study, limited to flights up to 1500 and 2500 NM, corresponding mainly to short and medium-haul flights, estimates that, in 2018, 21% of ECAC (In this paper, ECAC refers to the geographical region defined by the 44 member states that signed the European Civil Aviation Conference. In the context of a higher SAF price, this phenomenon may generate additional negative behaviour in the airlines. This problem has been recognised in European Union regulations and addressed in part of the Fit for 55 package – ReFuelEU Aviation. On the other hand, A positive example in terms of fuel supply can be found at Schiphol Airport. With KLM enabled during 2023, the refuelling of an additional quantity of SAF was financed by an additional payment of 1% to tickets for all flights from this airport, which was exploited to purchase and blend more SAF. During 2023, KLM voluntarily blended an additional 1.2% SAF, which was one of the top levels in the industry (KLM, 2024b).

(Ben Daley, 2010) points to the benefits of implementing SAF, including elements of economic, social, and environmental sustainability in terms of the costs and benefits for the aviation industry. Factors contributing to the persistence of the high price of SAF, according to (Wei et al., 2019), can be addressed with state aid or technological advances. At large airports with a high number of movements, operators managing aviation and fuel infrastructure use a special pipeline system. Such a system reduces the cost of fuel delivery, but previously, operators had high investment costs. For example, at Chicago's O'Hara Airport, such an aircraft fuel delivery system allows SAF to be blended with traditional JET A fossil fuel. An analysis (Wei et al., 2019) indicated that fuel use incentives by air carriers and the price of the feedstock are key variables affecting the cost of SAF production. Among the most important cost drivers they identified: type and quantity of waste, availability of this waste from the airport/refinery, SAF production costs, life cycle greenhouse gas (GHS) emissions, SAF delivery and logistics costs. Santos and Delina (2021) believe that an increase in the supply of SAF could come through government subsidies, but on the other hand, the air transport sector has received a lot of financial support from the COVID-19 crisis in the last 3-4 years. Tax credits could be an avenue to promote SAF.

The study was organised to analyse foundational data. In the next steps, it is worthwhile to conduct interviews with carriers, airports, and organisations that make recommendations on the use of SAF.

Conclusions and future research

The aim of this article was to analyse the impact of sustainable aviation fuels on the development of the aviation market. The research indicated that the requirements presented by IATA, the EU, and CORSIA may be barriers to growth for air carriers. This is mainly due to the rapid increase in the required share of SAF. The problem is the very low supply of the product on the market and, therefore, the lack of information on whether the solution is scalable to the extent indicated in the documents. RP1 was thus confirmed. According to RP2, aviation fuel producers are implementing joint activities to contribute to the availability of SAF. In this context, there is also an apparent disconnect between the carriers, which can be described as ‘large’ – both in terms of the number of transport operations and rolling stock. They are more aware of the situation, as evidenced by, for example, signing memorandums of understanding with suppliers and participating in R&D studies. The literature review also confirmed RP3, i.e. currently, there is no single leading technology in the production of sustainable aviation fuels. The market situation (low supply, lack of leading technology, lack of documented economies of scale and regulatory requirements) motivates airlines to cooperate in SAF research.

Concluding, sustainable jet fuels appear to be one of the more attractive avenues for decarbonising aviation. Unfortunately, currently, there is no economic rationale for purchasing sustainable fuel since the price of SAF is three times higher than traditional JET fuel. The costs of SAF are three to four times higher than those of kerosene, and regulations for airlines around SAF are still in progress. Therefore, air carriers are not opting for the widespread purchase of expensive fuel.

On the other hand, formal and legal conditions will make it necessary to refuel SAF in the near future. Managers realise that with higher aviation fuel prices, the passenger will consequently pay a higher price for the air transport service. This situation will lead to a decrease in demand for air travel. Moves to secure SAF availability among larger carriers are evident. However, it seems that due to the lack of supply, there is a risk that smaller airlines that do not take steps in this regard (for example, by signing a memorandum or co-financing SAF research) will be excluded from supply chains particularly if the technology does not evolve to achieve economies of scale.

Another factor that seems problematic is the issue of growth dynamics in the aviation sector. Overlaying it on the assumptions presented in terms of growth in SAF use at this point appears to be a significant difficulty from a market perspective. Moreover, other products used in SAF production are also limited in nature, like the amount of cooking oil or source material.

It also seems important to take into account other market dependencies, such as the fact that energy grain production limits food production potential. This, in turn, could prove problematic in the context of a growing population and the need for food security. In this context, the idea of synthetic fuels (e-fuels) seems attractive.

Another difficulty is the issue of estimating GHG emission reductions. As indicated in the literature analysis, estimates range up to 94%. Thus, difficulties may arise in estimating emission reductions by carriers. At the declarative level, there is a risk that all use the highest value, and it will be hard to assess the real decrease in GHG emissions.

In summary, the problem of SAF production and availability is complex. It applies not only to transportation but also to the area of food production and land use. This causes the solution to be complicated and difficult to evaluate in one dimension. Our analysis, on the one hand, fills a gap in the literature regarding the possibilities of using SAF in the context of aviation organisations’ regulations and requirements, and on the other hand, points out to air transport stakeholders selected problems regarding the use of SAF. In this context, there may be a need for governmental or organisational support in scaling SAF production. It is important to note that the implementation of SAF will oblige airlines, manufacturers, fuel producers and even governments to make strategic decisions at multiple levels. This should certainly be a source of in-depth research. An interesting point for further research is the balancing of SAF supply and demand, as it seems that the demand side's declarations exceed the supply side's capabilities.

To this end, we recommend further research, especially on the feasibility of implementing SAF and other activities with a sustainable plan. Another area is the study of the consequences of SAF production on society and the environment. An interesting aspect is the use of land and its relationship to food production. The correlation between the demand for SAF and the growth of the aviation market is another interesting area.

In addition, it is necessary to point out the applied nature of our research. This research may be a way to implement SAF deployment strategies by air carriers, while for air operators, such research highlights potential directions for the development of aviation infrastructure.

The contribution of the authors

Conceptualization, D.T. and J.Cz.; literature review, D.T., J.Cz. and A.M.; methodology, D.T. and J.Cz.; writing, D.T., J.Cz. and A.M.; conclusions and discussion, D.T., J.Cz. and A.M.

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References

Ahmad, S., & Xu, B. (2021). A cognitive mapping approach to analyse stakeholders' perspectives on sustainable aviation fuels. Transportation Research Part D: Transport and Environment, 100, 103076. https://doi.org/10.1016/J.TRD.2021.103076

Air France & KLM. (2022). *Introducing goSAF.* https://www.afklcargo.com/US/en/common/news/afklmp_cargo_introduces_gosaf.jsp

AirAdvisor. (2024). *Official Web Site.* https://airadvisor.com/en/blog/best-european-airlines

Andruleit, H., Meßner, J., Pein, M., Rebscher, D., Schauer, M., Schmidt, S., & von Goerne, G. (2018). Status, Daten und Entwicklungen der globalen Energieversorgung. Z Energiewirtsch, 42, 179-191. https://doi.org/10.1007/s12398-018-0231-5

Barke, A., Bley, T., Thies, C., Weckenborg, C., & Spengler, T. S. (2022). Are Sustainable Aviation Fuels a Viable Option for Decarbonizing Air Transport in Europe? An Environmental and Economic Sustainability Assessment. Applied Sciences, 12(2), 597. https://doi.org/10.3390/app12020597

Bhatt, A. H., Zhang, Y., Milbrandt, A., Newes, E., Moriarty, K., Klein, B., & Tao, L. (2023). Evaluation of performance variables to accelerate the deployment of sustainable aviation fuels at a regional scale. Energy Conversion and Management, 275, 116441. https://doi.org/10.1016/J.ENCONMAN.2022.116441

Daley, B. (2010). *Air Transport and the Environment.* London: Routledge.

Davis, R., Tao, L., Tan, E., Beckham, G., Humbird, D., Thompson, D., Roni, M., Grundl, N., & Biddy, M. (2018). *Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels and Coproduct.* Technical Report. https://www.nrel.gov/docs/fy19osti/71949.pdf

EASA & EEA. (2019). *European Aviation Environmental. Report 2019.* https://doi.org/10.2822/309946

EASA. (2022). *SAF policy actions.* https://www.easa.europa.eu/eco/eaer/topics/sustainable-aviation-fuels/saf-policy-actions

EASA. (2024). *ReFuelEU Aviation*. www.easa.europa.eu/en/light/topics/fit-55-and-refueleu-aviation

EEA. (2022). *Transport and Environment Report 2022.* https://www.eea.europa.eu/publications/transport-and-environment-report-2022

Ernst & Young. (2023). *Sustainable aviation fuel (SAF) on the rise.* https://www.ey.com/content/dam/ey-unified-site/ey-com/en-us/industries/aerospace-defense/documents/ey_saf_whitepaper_final.pdf

Eurocontrol. (2019). *European Network Operations Plan 2019-2024.* https://www.eurocontrol.int/publication/european-network-operations-plan-2019-2024

Eurocontrol. (2023). *EUROCONTROL Forecast Update 2023-2029.* https://www.eurocontrol.int/publication/eurocontrol-forecast-update-2023-2029

European Commission. (2019). *European Green Deal.* https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6691

European Commission. (2020). *Reducing emissions from aviation.* https://climate.ec.europa.eu/eu-action/transport/reducing-emissions-aviation_en

European Commission. (2021). *EMAS – Environment – European Commission*. https://ec.europa.eu/environment/emas/index_en.htm

Farooq, D., Thompson, I., & Ng, K. S. (2020). Exploring the feasibility of producing sustainable aviation fuel in the UK using hydrothermal liquefaction technology: A comprehensive techno-economic and environmental assessment. Cleaner Engineering and Technology, 1, 100010. https://doi.org/10.1016/j.clet.2020.100010

IAG. (2024). *IAG Reaches One-Third of 2030 SAF Target with Major E-SAF Deal with Twele.* https://www.iairgroup.com/media/vt2m0ejr/iag-reaches-one-third-of-2030-saf-target-with-major-e-saf-deal-with-twelve.pdf

IATA. (2015). *Sustainable Aviation Fuel Roadmap.* https://www.iata.org/contentassets/d13875e9ed784f-75bac90f000760e998/safr-1-2015.pdf

IATA. (2021). *Our Commitment to Fly Net Zero by 2050.* https://www.iata.org/en/programs/environment/fly-netzero/

IATA. (2023a). *Global Outlook for Air Transport. A local sweet spot.* https://www.iata.org/en/iata-repository/publications/economic-reports/global-outlook-for-air-transport---december-2023---report/

IATA. (2023b). *SAF Deployment.* https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/saf-policy-2023.pdf

IATA. (2024a). *Developing Sustainable Aviation Fuel (SAF).* https://www.iata.org/en/programs/environment/sustainable-aviation-fuels/

IATA. (2024b). *Global Outlook for Air Transport Deep Change. Deep Change.* https://www.iata.org/en/iata-repository/publications/economic-reports/global-outlook-for-air-transport-june-2024-report/

IATA. (2024c). *Environmental Protection.* www.icao.int/ESAF/env-protection/Pages/home.aspx

ICAO. (2021). *Corsia Sustainability Criteria for Corsia Eligible Fuels.* https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2005%20-%20Sustainability%20Criteria%20-%20November%202021.pdf

ICAO. (2023). *Effect of Novel Coronvirus (COVID-19) on Civil Aviation: Economic Impact Analysis.* https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf

KLM. (2019). *AFKL Sustainability Report 2018.* https://news.klm.com/afkl-sustainability-report-2018/

KLM. (2020). *KLM, SkyNRG and SHV Energy announce project first European plant for sustainable aviation fuel*. https://news.klm.com/klm-skynrg-and-shv-energy-announce-project-first-european-plant-for-sustainable-aviation-fuel/

KLM. (2022, December 5). *Air France-KLM and Total Energies sign memorandum of understanding to supply sustainable aviation fuel for 10 years.* https://www.airfranceklm.com/en/newsroom/air-france-klm-and-total-energies-sign-memorandum-understanding-supply-sustainable-aviation

KLM. (2024). *Sustainable Aviation Fuel (SAF).* https://www.klm.pl/en/information/sustainability/sustainable-aviation-fuel

Kolosz, B. W., Luo, Y., Xu, B., Maroto-Valer, M. M., & Andresen, J. M. (2020). Life cycle environmental analysis of ‘drop in’ alternative aviation fuels: a review. Sustainable Energy & Fuels, 4(7), 3229-3263. https://doi.org/10.1039/C9SE00788A

Larsson, J., Elofsson, A., Sterner, T., & Åkerman, J. (2019). International and national climate policies for aviation: a review. Climate Policy, 19(6), 787-799. https://doi.org/10.1080/14693062.2018.1562871

Lee, D. S., Fahey, D. W., Forster, P. M., Newton, P. J., Wit, R. C. N., Lim, L. L., Owen, B., & Sausen, R. (2009). Aviation and global climate change in the 21st century. Atmospheric Environment, 43(22-23), 3520-3537. https://doi.org/10.1016/j.atmosenv.2009.04.024

Lufthansa Group. (2020a, May 15). *Flying with sunlight.* https://newsroom.lufthansagroup.com/en/flying-with-sunlight/

Lufthansa Group. (2020b). *Sustainable Aviation Fuel.* https://www.lufthansagroup.com/

Lufthansa Group. (2022, September 13). *Lufthansa Group and OMV further strengthen partnership on Sustainable Aviation Fuel.* https://newsroom.lufthansagroup.com/en/lufthansa-group-and-omv-further-strengthen-partnership-on-sustainable-aviation-fuel/

Lufthansa Group. (2024). *Sustainable Aviation Fuel.* https://www.lufthansagroup.com/en/responsibility/climate-environment/sustainable-aviation-fuel.html

Mensen, H. (2013). *Handbuch der Luftfahrt.* Berlin: Springer Vieweg. https://doi.org/10.1007/978-3-642-3440 2-2

Myhre, G., Shine, K. P., Rädel, G., Gauss, M., Isaksen, I. S. A., Tang, Q., Prather, M. J., Williams, J. E., van Velthoven, P., Dessens, O., Koffi, B., Szopa, S., Hoor, P., Grewe, V., Borken-Kleefeld, J., Berntsen, T. K., & Fuglestvedt, J. S. (2011). Radiative forcing due to changes in ozone and methane caused by the transport sector. Atmospheric Environment, 45(2), 387-394. https://doi.org/10.1016/j.atmosenv.2010.10.001

Ng, K. S., & Sadhukhan, J. (2011). Process integration and economic analysis of bio-oil platform for the production of methanol and combined heat and power. Biomass and Bioenergy, 35(3), 1153-1169. https://doi.org/10.1016/j.biombioe.2010.12.003

Ng, K. S., Farooq, D., & Yang, A. (2021). Global biorenewable development strategies for sustainable aviation fuel production. Renewable and Sustainable Energy Reviews, 150, 111502. https://doi.org/10.1016/j.rser.2021.111502

Orlen. (2022, July 7). *Ekologiczne paliwo ORLENU zasili samoloty LOT-u.* https://www.orlen.pl/pl/o-firmie/media/komunikaty-prasowe/2022/lipiec/Ekologiczne-paliwo-ORLENU-zasili-samoloty-LOT-u (in Polish).

Perkins, G., Batalha, N., Kumar, A., Bhaskar, T., & Konarova, M. (2019). Recent advances in liquefaction technologies for production of liquid hydrocarbon fuels from biomass and carbonaceous wastes. Renewable and Sustainable Energy Reviews, 115, 109400. https://doi.org/10.1016/j.rser.2019.109400

PGL. (2024). *Polskie Linie Lotnicze LOT zaprezentowały strategię na lata 2024-2028.* https://pgl.pl/centrum-prasowe/polskie-linie-lotnicze-lot-zaprezentowaly-strategie-na-lata-2024-2028/ (in Polish).

Republique Francaise. (2019). *Feuille de route française pour le déploiement des biocarburants aéronautiques durables.* https://www.ecologie.gouv.fr/sites/default/files/documents/Feuille%20de%20route%20fran%C3%A7aise%20pour%20le%20d%C3%A9ploiement%20des%20biocarburants%20a%C3%A9ronautiques%20durables.pdf

Research and Markets. 2020. Global Sustainable Aviation Fuel Market. https://www.researchandmarkets.com/report%0As/5178303/sustainable-aviation-fuel-market-by-type?utm_source=BW

Rojas-Michaga, M. F., Michailos, S., Cardozo, E., Akram, M., Hughes, K. J., Ingham, D., & Pourkashanian, M. (2023). Sustainable aviation fuel (SAF) production through power-to-liquid (PtL): A combined techno-economic and life cycle assessment. Energy Conversion and Management, 292, 117427. https://doi.org/10.1016/J.ENCONMAN.2023.117427

Ryanair Group. (2021). *Aviation with Purpose. 2021 Sustainability Report.* https://corporate.ryanair.com/wp-content/uploads/2021/12/2021-Sustainability-Report_Spreads.pdf

Rynek Lotniczy. (2023). *PLL LOT: Nowa flota do 2030 r. Znamy potrzeby przewoźnika.* https://www.rynek-lotniczy.pl/wiadomosci/pll-lot-100-nowych-samolotow-do-2030-r-14863.html (in Polish).

Santos, K., & Delina, L. (2021). Soaring sustainably: Promoting the uptake of sustainable aviation fuels during and post-pandemic. Energy Research & Social Science, 77, 102074. https://doi.org/10.1016/J.ERSS.2021.102074

Staples, M. D., Malina, R., Suresh, P., Hileman, J. I., & Barrett, S. R. H. (2018). Aviation CO2 emissions reductions from the use of alternative jet fuels. Energy Policy, 114, 342-354. https://doi.org/10.1016/j.enpol.2017.12.007

Surgenor, Ch. (2024). *British Airways in multi-million-pound energy transition to reduce Heathrow ground emissions.* https://www.greenairnews.com/?p=5512

Tabernier, L., Fernández, E. C., Tautz, A., Deransy, R., & Martin, P. (2021). Fuel Tankering: Economic Benefits and Environmental Impact for Flights Up to 1500 NM (Full Tankering) and 2500 NM (Partial Tankering). Aerospace, 8(2), 37. https://doi.org/10.3390/aerospace8020037

Teoh, L. E., & Khoo, H. L. (2016). Green air transport system: An overview of issues, strategies and challenges. KSCE Journal of Civil Engineering, 20(3), 1040-1052. https://doi.org/10.1007/S12205-016-1670-3

Tzanetis, K. F., Posada, J. A., & Ramirez, A. (2017). Analysis of biomass hydrothermal liquefaction and biocrude-oil upgrading for renewable jet fuel production: The impact of reaction conditions on production costs and GHG emissions performance. Renewable Energy, 113, 1388-1398. https://doi.org/10.1016/j.renene.2017.06.104

Urząd Lotnictwa Celnego. (2024, July 21). *Statystyki wg portów lotniczych.* https://www.ulc.gov.pl/pl/statystyki-analizy/statystyki-i-analizy-rynku-transportu-lotniczego/3724-statystyki-wg-portow-lotniczych (in Polish).

Wei, H., Liu, W., Chen, X., Yang, Q., Li, J., & Chen, H. (2019). Renewable bio-jet fuel production for aviation: A review. Fuel, 254, 115599. https://doi.org/10.1016/J.FUEL.2019.06.007

Wizz Air. (2023). *WIZZ AIR Invests £5M in Sustainable Aviation Fuel Producer Firefly.* https://wizzair.com/en-gb/information-and-services/about-us/news/2023/04/24/wizz-air-invests-5m-in-sustainable-aviation-fuel-producer-firefly

Wizz Air. (2024a). *Wizz Air. Holdings PLC. Annual Reports and Accounts.* https://wizzair.com/cms/api/docs/default-source/downloadable-documents/corporate-website-transfer-documents/annual-reports/wizz_air-annual-report-and-accounts-f24_web.pdf

Wizz Air. (2024b). WIZZ *AIR sets 2030 sustainability targets, including powering 10% of flights with SAF.* https://wizzair.com/en-gb/information-and-services/about-us/news/2024/04/11/wizz-air-sets-2030-sustainability-targets-including-powering-10-of-flights-with-saf

Yin, R. K. (2018). *Case Study Research: Design and Methods (6th ed.).* Thousand Oaks: SAGE Publications.

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JAK ZRÓWNOWAŻONE PALIWA LOTNICZE KSZTAŁTUJĄ ROZWÓJ RYNKU LOTNICZEGO?

STRESZCZENIE: Według prognoz, rynek lotniczy będzie charakteryzował się dynamicznym wzrostem. Jednocześnie postulowana jest redukcja emisji gazów cieplarnianych z transportu. Jednym z proponowanych rozwiązań są zrównoważone paliwa lotnicze (SAF). Celem niniejszego artykułu jest analiza wpływu zrównoważonych paliw lotniczych na rozwój rynku lotniczego. Rozważone zostaną kryteria ekonomiczne i środowiskowe. W artykule zastosowano podejście oparte na analizie danych podstawowych, w tym artykułów naukowych, raportów branżowych i raportów zrównoważonego rozwoju wybranych przewoźników. Biorąc pod uwagę dynamikę rynku, wydaje się, że w tym momencie trudno jest zapewnić odpowiednie ilości SAF. Większe firmy lotnicze starają się zabezpieczyć dostawy, między innymi podpisując memoranda i współfinansując działania innowacyjne w celu rozwoju dostaw. Główną wartością artykułu jest przegląd kwestii zrównoważonych paliw lotniczych.

SŁOWA KLUCZOWE: lotnictwo, SAF, zrównoważone paliwa lotnicze, emisje, GHG

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