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Journal of Intercultural
Management

Vol. **15** | No. **3** | **2023**

pp. **4–25**

DOI **10.2478/joim-2023-0009**

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Challenges for the Aviation Market Related to Decarbonization and Sustainability in the Context of LOT Polish Airlines Operations

Received: 23-10-2023; Accepted: 14-11-2023; Published: 27-12-2023

ABSTRACT

Objective: In this article, the authors described the regulation on decarbonization and sustainability in the aviation market. Formal implementations of decarbonization and sustainable development in aviation were indicated, taking into account mainly the guidelines of the European Union, IATA, and ICAO. These regulations are important from the point of view of the dynamics of air transport market growth, what is the basis of economic theory. In addition, it is part of the fight against climate change, to which Poland is obliged (inter alia by the Paris Agreement). The purpose of the study is the understanding of the perception of decarbonization and sustainable development revealed by the young customers and the evaluation of practices in this field of the LOT Polish Airlines PLL LOT company analyzed in this case study.

Methodology: The authors used a case study of LOT Polish Airlines and an empirical survey of 190 students to verify to what extent the issues under regulation are important according to young customers and how they evaluate the sustainable activities carried out by LOT.

Findings: Despite LOT's significant commitment to sustainability, in the perception of students, these activities are not sufficiently communicated.

Value Added: The main contribution of the proposed article is to support airlines by presenting key conclusions on decarbonization. The attitudes of young student respondents towards airline sustainability and the recognition of LOT's airline activity in this area were also verified.

Recommendations: Airlines, in parallel with their sustainability activities, should develop a pathway for passenger education and clear communication about pro-environmental changes.

Key words: aviation, decarbonization, individual voluntary carbon offset, LOT Polish Airlines, CORSIA, Fly Net Zero, ReFuelEU, air carrier market

JEL codes: R41

Introduction

In the last ten years, the aviation sector has made improvement in CO₂ emissions per RPKs by 21.5%, new more efficient aircraft types have been launched to the market, and over 365 thousand flights have been fueled with SAF – Sustainable Aviation Fuel (Aviation Benefits Beyond Borders, 2022). Despite the far-reaching progress, aviation is still on its way to net zero emissions. A number of documents at various levels define the way to sustainability in aviation. The Polish market is influenced by CORSIA (ICAO), ReFuelEU Aviation (EU), and Fly Net Zero (IATA). Development in the context of further growth of aviation market will require decarbonization measures. The scope of changes is defined in documents created by various institutions (e.g., IATA, ICAO, European Union). Their role in shaping the future of aviation is important, and they all emphasize decarbonization. The issue of decarbonization in the European Union transport is raised increasingly frequently. The Kyoto Protocol (1997) and the Paris Agreement (2015) set the layout for the broader dialogue on this problem.

The pressure to decarbonize aviation is due to the dynamic growth of this mode of transport, on the one hand, and its carbon intensity on the other. The ability to adapt to sustainability criteria will determine the competitiveness and viability of aviation companies in the near future and this concerns also the continuously growing aviation market in Poland. The issue of decarbonization is of special importance also to one of the main carriers on the domestic market, that is, LOT Polish Airlines (further LOT).

Our paper addresses the changes in airline operations associated with decarbonization. The example of LOT as a carrier of strategic importance for Poland was used for the analysis. The purpose of this study is to indicate the directions

of change in aviation on the basis of the introduced regulations and to identify the implications for the national air carrier. It aims also to create a greater understanding of the decarbonization process in the perception of young customers of the Polish air carrier.

Theoretical Background

Polish Aviation Market

There are many factors that influence the growth of demand and supply of air transport – including market factors (inflation, unemployment rate, raw material prices, GDP levels, development of competition, access to new markets, implementation of new technologies, management skills) and non-market (pandemics, natural disasters, accidents, national or institutional policies, technical progress, regulation international and domestic institution, environmental policy) (Cowie, 2010; Vasigh et al., 2008; Kaczmarek, 2011). All these factors contribute to changes in air transport.

The air market is evolving constantly. The most noticeable example is the effects of the pandemic. The SARS COV₂ has caused changes in the behavior of air transport passengers. Between 2020 and 2022, there was a large decrease in the number of passengers, especially those on business trips. In 2022, the market started to grow rapidly again (64.4% increase in traffic in comparison to 2021) (Air Passenger Market Analysis, 2022). Based on the forecasts from aviation equipment manufacturers, passenger traffic is assumed to grow by 3.6–3.8% by 2040 (Airbus, 2021; Boeing, 2021).

Furthermore, the Eurocontrol forecast assumes a market growth on the European continent of 1.5% (Eurocontrol, 2023). Similarly, in Poland, which is one of the European sub-markets, demand for aviation services is also assumed to grow by 4.9% per annum (Tłoczyński & Zamojska, 2023). Poland's share of EU traffic is increasing year by year (excl. COVID-19 restriction period) and reached 3.78% in 2021 (compared to 1.91% in 2012) (Eurostat, 2023).

In 2022, air carriers operating on the Polish market carried 36 MM passengers, more than double than in 2021, representing 83% of 2019 traffic (CAA in Poland, 2023). The structure of air carriers on the Polish market is comparable to other countries with similar development parameters (Spain, Italy, Croatia, etc.) (CAPA, 2023). Poland is dominated by low-cost traffic (LCC). It held a 61% share of passenger transport in 2022 (5 pp. more than in 2019). In contrast, legacy air carriers held a share of approximately 38% (8 pp. less than in 2019) (CAA in Poland, 2023). This traffic structure is an indicator of intra-regional competition. However, the national air carrier LOT holds a decisive share in traditional traffic with the result of 61% in 2022 (in comparison: Lufthansa – 11%, Enter Air – 6.5%, Air France – 2.1%, KLM – 4.6%, and British Airways – 1.9%) (CAA in Poland, 2023). The dominance of national carriers on domestic markets is natural. LOT Polish Airlines has the largest share at its home airport – Warsaw and, additionally, offers connections from regional airports (Cracow, Gdansk, Katowice, Wroclaw, Poznan) (LOT Polish Airlines, 2023).

By 2030, it is planned that LOT will have enlarged its fleet to over 100 aircraft (Rynek Lotniczy, 2023). The investment is linked to the realization of the CPK (Central Airport for Poland) plans and the aircraft replacement process. Undoubtedly, the modernization and the purchase of a new aircraft is linked to the assumed increase in demand for air services. On the other hand, the changes will have a negative impact on the environment. Therefore, in the face of environmental challenges, LOT Polish Airlines is forced to take decarbonization measures immediately.

Regulations on Decarbonization Connected with Aviation

Due to the potential risks associated with the rapid growth of the aviation market, it is widely indicated that air transport should be decarbonized. Moreover, aircrafts emit gases and molecules directly into the upper troposphere and lower stratosphere. These gases and molecules change the concentration of greenhouse gases (GHG) in the atmosphere (including CO₂, ozone, and methane), cause

the formation of condensation trails, and may increase cirrus cloudiness (Penner et al., 1999). “The chemical composition of exhaust gases from aircraft turbine engines, as a result of further photochemical reactions taking place in the atmosphere, causes other negative phenomena like acid rain and photochemical smog” (Pawlak & Kuźniar, 2017). All of these aspects contribute to climate change.

Aviation needs to adapt climate change mitigation solutions. Many actors are trying to influence the growth of sustainable aviation, including European Union, the International Air Transport Association (IATA), or the International Civil Aviation Organization (ICAO). All these entities provide recommendations for decarbonization shown in the table below.

Table 1. Requirements of documents

FIELD/ DOCUMENT	SAF	NEW TECHNOLOGY	OPERATIONAL EFFICIENCY	OFFSET
ReFuelEU (European Union)	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%)			
CORSIA (ICAO)	2021–2023 – voluntary 2024–2026 – first phase 2027–2035 – second phase			
Fly Net Zero (IATA)	2025 – 381 megatons (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%	2040 – 3,824 megatons (Mt) of CO ₂ abatement, incl. 7,5% share of non-drop-in fuel technology 2045 – 6,153 Mt, 10% 2050 – 8,164 Mt, 13%	2025 – 381 megatons (Mt) of CO ₂ abatement; incl. 1% business as usual improvements 2030 – 979 Mt, 2% 2035 – 1,703 Mt, 3% 2040 – 3,824 Mt, 3% 2045 – 6,153 Mt, 3% 2050 – 8,164 Mt, 3%	2050 – reducing transport emissions by 90% by 2050, compared to 1990 levels

Source: ReFuelEU, CORSIA & Fly Net Zero.

ReFuelEU is part of the Fit for 55 package, which in turn is the result of the work on the European Green Deal (European Green Deal, 2023). The concept is based on incorporating increasingly more sustainable aviation fuel (SAF) into the fuel tanked. SAF is a solution not interfering with the aircraft structure. ICAO defines SAF as renewable or waste-derived fuel that meets several sustainability categories (e.g., the reduction in net life cycle GHG emission by at least 10% in comparison with conventional fuels). From January 2022, seven different SAF production pathways have been certified for blending with conventional kerosene at a volume ratio of up to 50% (Teoh et al., 2022).

The document also assumes the use of e-fuels (synthetic fuels), which are a substitute for fossil fuels. This types of fuel are hydrocarbon fuels synthesized from hydrogen (H_2) and CO_2 , where H_2 may be produced in the process of water/steam electrolysis and CO_2 is captured from the combustion of fossil, biogenic sources, or directly from the atmosphere. The benefits in terms of climate change mitigation are unclear: e-fuels can either have higher or lower climate change impacts (compared to fossil fuels), depending on factors like: the electricity mix, the origin of CO_2 , the technology for H_2 production, and the electrolyzer efficiency (Ballal et al., 2023).

ReFuelEU also prohibits the practice of “tankering”, i.e., buying more fuel than necessary for a flight. This practice is used, among others, to reduce costs (refueling at airports where fuel is cheaper or avoiding refueling with SAF) but results in increased combustion and GHG emission. According to Tabernier et al. (2021), keeping the fuel consumption necessary for a safe flight at a minimum level is the simplest and most effective way to lower emissions from that flight, because tankering is responsible for 901,000 tons of CO_2 emission per year. The Fit for 55 package also includes changes to the EU ETS by phasing out free allowances for the aviation sector by 2026. The industry will take more financial responsibility for its carbon footprint, which is a solid cost signal leading to emission reductions. This solution was established at the end of 2022 and, according to it, the EU ETS will apply to intra-European flights (including flights departing from the UK and Switzerland), while CORSIA will apply to routes to and from third countries participating in CORSIA between 2022 and 2027 (Proposal for a Directive of the European Parliament

and of the Council amending Directive 2003/87/EC as regards aviation's contribution to the Union's economy-wide emission reduction target and appropriately implementing a global market-based measure).

CORSIA is a solution proposed by ICAO and adapted by the European Union. CORSIA is a baseline system under which CO₂ credits can be freely traded on the so-called credit markets. The baseline above which emissions must be compensated or reduced is defined as the average of the total CO₂ emissions from all international flights covered by the scheme in 2019 and 2020. This will meet the Carbon Neutral Growth 2020 strategy target. In its essence, the scheme resembles the EU ETS. Airlines have the choice between purchasing credits for emissions in excess of their individual CO₂ limit or reducing emissions. This decision will depend on the abatement costs for an additional unit of CO₂. In this way, CO₂ can be reduced in a cost-effective way while meeting a given environmental target (Scheelhaase & Maertens, 2020).

In 2021, the International Air Transport Association (IATA) launched Fly Net Zero regulations. The main idea of the commitment is to achieve net zero carbon emission by 2050 (IATA, 2021). The strategy is based on four pillars: (1) SAF, (2) new aircraft technologies, (3) improvement of infrastructure and operational efficiency, and (4) offset. The approach is more comprehensive – addressing not only the mentioned earlier SAF but also other questions. Technologies improving the efficiency of a new aircraft by an average of 1–2% per year are unfortunately counterbalanced by an average annual growth in travel of 4–5% (Kramer et al., 2022). According to the IATA approach, new technologies include, among others, aerodynamic and alternative propulsion solutions (i.e., electric or hydrogen). The main problem with hydrogen fuel nowadays is enlarging the size of traditional tanks, because of its larger volume. It is proposed to achieve 30% reduction in fuel burn by the year 2035 due to the evolution of technology. The same year electric/hydrogen aircraft should be available for regional markets (50–100 seats, 30–90 min flights). Five years later, in 2040, there will be new aircraft solutions available, such as blend-wing bodies (full-scale working prototypes) and electric/hydrogen for short-haul markets (100–150 seats, 45–120 min flights). According to the Waypoint 2050 report, by 2050, regional flights should be operated by electric, hybrid,

and hydrogen fleets (Aviation Benefits Beyond Borders, 2022). New body solutions are primarily associated with proposals such as canard wing, blended wing, strut, or truss-braced wing. Efficiency can be described as aircraft operations (airline and aircraft operator). It may be measured using weight reduction, aerodynamic improvements of in-service, or systems improving efficiency during operations. In 2045, necessary infrastructure for new energy requirements (like low carbon electricity or hydrogen) will be available. On the other hand, enhancements in air traffic management and the extent of airport operations refer to structural changes in air traffic management (ATM operations), energy savings at the airport, restrictions on the use of auxiliary power units, single-engine taxiing, and reduced taxiing times (IATA, 2021).

In addition, Fly net zero takes into account passenger liability proposing individual voluntary carbon offset (IVCO) as a possibility. These solutions transfer the “polluter pays” principle to the level of the individual (Berger et al., 2022; Gössling et al., 2009; Ritchie et al., 2021; Müller, 2008). IATA defines individual voluntary carbon offset as a method for individuals (e.g., airline passengers) or organizations to “neutralize” carbon emissions connected with flight by investing in carbon reduction projects (IATA, Carbon Offset, 2023). IVCO programs, in general, are based on a unified pricing system connected with the average emission of flight (Choi et al., 2018). Dubois et al. (2019) indicated that there is a need for stronger policy interventions at the passengers’ level (e.g., higher taxes or reduced availability of air travel), but it will be acceptable only if the rules would apply to everyone. The proposed legislation mainly affects airlines, but even now passengers can take part in voluntary activities such as individual carbon offset or International Air Passenger Adaptation Levy (IAPAL).

Methodology

The research conducted is exploratory in nature (Stebbins, 2001; Vanhamme, 2010). Based on the literature, four areas of particular relevance to sustainable airline transformation were identified, among them: technological

development – the need for changes in the fleet, usage of sustainable aviation fuel, individual voluntary carbon offset offer, and increasing operational efficiency. These areas formed the basis for the construction of the research tool (student survey questionnaire) and the structure of the case-study analysis.

The first tool used in our study was the case study method (Yin, 2018) based on the analysis of the largest air carrier operating in Poland – LOT. The choice of such a company is not accidental. The main rationales for the choice of the sector and carrier include:

- Representativeness of the air carrier on the scale of the CEE region,
- The share of air transport in environmental pollution is 13% in gas emissions and 5% in global CO₂ emissions (European Environment Agency, 2022).

LOT Polish Airlines is a public air carrier, its shareholders are the State Treasury (69%) and the Polish Aviation Group (31%). The Polish air carrier is one of the 12 oldest airlines in the world, with origins dating back to 1929. The public capital structure entails many advantages as well as risks for the economic functioning of the company. The pros include the possibility of receiving state guarantees for the purchase of rolling stock and the implementation of relevant policies, e.g., pro-environmental. The cons include the dependence on politics and the lack of flexibility in decision making, which is a consequence of the period of time needed to take decisions (LOT Polish Airlines, 2023).

The micro- and macroeconomic environment of the company's operation points to several levels of competition and cooperation. In terms of competition, we observe intra-industry (LOT Polish Airlines versus Ryanair, Wizz, Lufthansa, Enter Air) and international (LOT competes with global carriers – the carriage of passengers by selected European carriers on the Polish market is presented in Table 2) rivalry. On the other hand, LOT struggles with rail, bus, and private car carriers. The competitiveness of air transport and thus of the air carrier increases with distance. It is assumed that the distance in which air transport is more competitive with other alternative means of transport is around 500–600 km (Tłoczyński, 2017a).

Table 2. Air carriers operating on the Polish market (2019–2022)

Air carrier	2019	2020	2021	2022	Dynamic (2019=100)
Ryanair	11 970 956	3 911 458	5 689 777	13 313 781	111.21%
LOT Polish Airlines	11 792 713	3 585 503	4 395 576	8 469 123	71.81%
Wizz	9 487 041	3 354 764	3 309 516	7 616 727	80.28%
Lufthansa	2 345 158	562 147	753 364	1 518 248	64.74%
Enter Air	917 004	273 228	800 316	900 510	98.20%
KLM	665 646	263 958	415 429	637 521	95.77%
Total market	43 840 172	13 375 725	16 699 056	35 983 471	82.08%

Source: Civil Aviation Authority in Poland.

The Polish air market is rapidly recovering from the Covid-19 pandemic (air traffic in 2022 reached 82% over that in 2019). The participation of LOT in the market share has been stabilized for many years. Further growth in the number of passengers carried is to be expected. Such indications result from, among others:

- Construction of the Central Airport in Poland,
- Prospects for the development of passenger air traffic,
- Increasing mobility of the Polish society,
- Prospects for GDP growth in Poland (Tłoczyński & Zamojska, 2023).

In the context of dynamic development, this paper focuses on the implementation of decarbonization processes. The paper takes into account documents regulating the implementation of pro-environmental policies by the European Union and global institutions, as well as available documents published by LOT and governmental institutions.

When assessing the risk of implementing the decarbonization process, an analytical method was used, taking into account the ESM method. EMS is a set of guidelines necessary to analyze the management of an organization, based on the identification, assessment, monitoring, and reduction of negative factors of the company's activities on the environment (ICAO, 2018).

It is considered a more rigorous standard than ISO 14001, while at the same time, providing legal security using compliance with environmental regulations introduced by public institutions (Mańkowska et al., 2023) which, in the case of LOT, is advisable.

To date, Polish legislation has not forced air carriers to implement pro-environmental procedures, despite the fact that Poland has an Environmental Protection Law (Parliament in Poland, 2001). In business practice, LOT conducts pro-environmental activities on many levels. Examples include cooperation with the Orlen Group to use SAF, or the offset policy.

For the purposes of the article, students were also surveyed. Using the knowledge gathered during the desk study of LOT activities, we prepared a questionnaire. It tested whether the students were familiar with concepts related to sustainable aviation (e.g., SAF, IVCO), whether they had experience with LOT, and how they rated the various elements of LOT's sustainability policy, especially those concerning decarbonization. A total of 190 students took part in the survey conducted from 07–16.10.2023, of whom 116 were studying economics. The majority of respondents were male (54%). 92% of those surveyed were aged 18–25, the remainder were older. A slightly higher proportion of respondents were Master's students (52%). One person was a doctoral student. 51% of respondents (97 people) had experience with LOT. Most of them (63%) had flown with LOT between 2 and 5 times, 27% had flown only once. The remainder had more extensive experience involving 6 flights and more.

Research

Starting with the case study, it can be observed that LOT Polish Airlines has a long tradition of activities connected with sustainability. In 2009, the air carrier became involved in environmental activities by providing passengers with the possibility to use a CO₂ emissions calculator on its website. This allows each traveler to see how much carbon dioxide, per passenger, will be emitted into the atmosphere on their flight, and what the cost would be to neutralize

the global warming impact. The booking passenger can make a voluntary donation to neutralize the negative impact of CO₂ on the environment. In addition, LOT is the first Star Alliance member to join the Aviation Global Deal – AGD (the group of airlines actively supporting climate protection measures). The main objective of this group is to bring about a global solution for an emissions trading scheme in the aviation sector. The AGD includes, among others, Air France/KLM, British Airways, Cathay Pacific, Finnair, as well as the world's largest airport operator, BAA, and the international NGO The Climate Group (Tłoczyński, 2017b). Since October 2019, LOT has been supporting the Forest Carbon Farms project, which aims to increase the amount of carbon dioxide captured and stored by Polish forests. Over a period of 30 years, each hectare of forest covered by the program will absorb additional 37 tons of CO₂, i.e., a total of 1 MM tons more than what these areas would have absorbed without the measures implemented with LOT's support. The project is being implemented as an initiative of Destination ECO (LOT Destineco, 2023). As part of its operational activities, LOT is successively reducing CO₂ emissions by optimizing flight routes and operations procedures, precise selection of climb and landing speeds, precise calculation of the aircraft's center of gravity, regular airframe and engine cleaning and reducing the weight of the aircraft. Whenever possible, the carrier uses an external power supply instead of fuel at airports. LOT also invests in technical solutions like flight planning data analyzing, which allows making connections more efficiently and economically. The airline is constantly modernizing its fleet and implementing environmentally friendly technologies. These activities are also carried out off-board. Moreover, LOT is active in reducing plastic items, including straws, as well as plastic-coated film and paper. In September 2018, the company was awarded the Green Office certificate, which confirmed proper environmental management in the office building. LOT attaches great importance to proper waste management, water, energy- and paper-saving solutions, and pays close attention to their environmental policies when selecting suppliers (LOT Destineco, 2023; Destineco App, 2023). Furthermore, LOT has its own environmental policy. It is based on 10 points among them: compliance with regulations, cooperation with IATA, rational waste management, raising

environmental awareness among employees and co-workers, promoting environmental performance among customers and incorporating environmental performance criteria into purchasing processes. In summary: as of 2023, LOT is involved in a number of sustainable activities, which are mainly communicated on the carrier's website and in the trade media. The range of activities is wide and reflects in particular the assumptions of IATA, which takes the broadest approach to decarbonization and sustainability. As a next step, it was verified whether the activities undertaken are recognized by potential student customers/clients.

The results of the student survey indicate that practically all respondents (98%) have encountered the expressions 'greenhouse gas emissions' (98%) and 'carbon footprint' (96%). At the same time, 66% of surveyed students had heard of 'decarbonization' related to these concepts. Significantly fewer respondents were aware of the terms 'SAF' (37%) and 'voluntary carbon offset' (24%).

The students surveyed rated (on a scale from 1 to 5, where 1 means bad, 2 – rather bad, 3 – neither good nor bad, 4 – fairly good, 5 – good) the validity of the airline's sustainability proposals. When considering the median across all students, a value of '4' was assigned to the travel carbon calculator, commitment to species conservation and biodiversity maintenance, commitment to reforestation, actions that reduce energy consumption or support investment in renewable energy, replacement of the fleet with a lower-emission fleet, elimination of plastic from the airline's offerings, changing the equipment and materials used to greener ones, and use of sustainable jet fuel. The only lower median score (3) was for voluntary carbon offsets. The same pattern was also observed when respondents were divided into those with and without experience with LOT.

The students surveyed were also asked whether they were familiar with the sustainability elements of LOT's offerings and activities. Of those who reported traveling by LOT Polish Airlines (n=97), 61% said they were aware of the airline's fleet upgrades (including the purchase of the Boeing 787 Dreamliner, Boeing 737 MAX), while 57% said LOT was reducing the proportion of plastic in its operations, including by switching from plastic to wooden cutlery. The fewest respondents were aware of LOT Destineco's program (15%)

and the airline's involvement in measures to protect the species of Manchurian cranes at the Zoo (Gdansk, Warsaw) (19%). Also in the group that had never travelled by LOT ($n=93$), the most widely known issues were fleet replacement (among 43% of respondents in this group) and plastic cancellation (49%). And similarly, the least familiar were the LOT Destineco program (11% of indications), crane protection (24%), and the Star Alliance program (24%).

A moderately strong correlation was detected between the experience of using LOT services and knowledge of the Star Alliance program (0.33). A correlation was also detected between the use of LOT services and knowledge of fleet modernization (0.29), balanced meals on board (0.24), and use of reusable plates (0.18). All of these relationships were statistically significant with $p < .05$.

In summary, the students surveyed had a general understanding of decarbonization and sustainability issues in aviation. It is natural that among those who traveled by LOT, the proportion of respondents recognizing the elements of sustainability proposed by LOT was higher. However, among those who had never flown with the surveyed carrier, knowledge of its activities was also significant.

Discussion and Recommendations for Air Carriers

As a first step, consideration should be given to educating passengers about their own options for reducing emissions resulting from the flight – through the use of individual voluntary carbon offsets. It has been shown that respondents are very familiar with the terms 'greenhouse gas emissions' and 'carbon footprint', which means they are aware of the problem. At the same time, the terms 'SAF' and 'carbon offset' were found to be much less common. This indicates that, despite being aware of the problem, the students surveyed are not familiar with solutions that can influence GHG reduction.

Considering that, the first solution, which should be more intensively promoted, is individual voluntary carbon offset (IVCO). Researchers point that the greatest amount of toxic compounds is introduced in the higher layers

of the atmosphere (8–12 km above sea level), i.e., at altitudes of long-haul flights (Pawlak & Kuźniar, 2017). It follows that IVCO should be promoted especially for flights of this nature. Berger et al. (2022) indicated that the cost of the offset does not have a meaningful effect on the decision to compensate. According to their research, neither booking classes nor flight length category are predictors of IVCO. Cost of the offset and cost of the ticket have no significant influence on the decision to compensate one's flight-related emissions. Interestingly, the route is not indicative: climate vulnerability of the destination (measured by climate risk index) does not predict offset behavior. On the other hand, research showed that passengers' subsidiary spending and buying vegetarian meal is associated with a higher likelihood of IVCO. In Schwirplies' and Zeigler's (2016) research conducted among more than 2000 participants from Germany and the USA, results in both countries supporting the hypotheses about significant positive influence of environmental awareness, warm glow motives, and the desire to set a good example on offset behavior. At the same time, some passengers' motives differ considerably, like: a green identity enhances the willingness to pay higher prices for climate-friendly products among German clients, whilst weakly decreases the willingness to buy carbon offset in the USA. Ritchie, Kemperman and Dolnicar (2021) discovered that local projects and those perceived to be effective at reducing a higher percentage of emissions have a greater impact. The offer of offsets' choice and of various providers does not influence willingness to pay. This suggests that the most effective way of promoting offset (even for international flights) may be developing local projects and communicating actual results. LOT is active with IVCO and offers its passengers the opportunity to buy offsets regardless of the length of the route. An additional advantage is the financing of local project in Poland. It offers potential passengers from the Polish market a chance to verify and assess the legitimacy of the project being financed. Additionally, challenges to offsets are connected with public critique. For example, forest carbon credits have been kept outside of some carbon markets (like the European Union's ETS) because of their unclear results in CO₂ mitigation. Reducing carbon emissions by increasing energy efficiency has become more popular for offsetting,

although it is also controversial. Often, carbon reduction projects would have taken place anyway, which can have adverse effects if decision makers do not implement policies to use them as an additional tool (Wozny et al., 2022). Assuming, LOT, like any other carrier, should incorporate the researches' observations into its offset strategy. LOT's undoubted advantage is the implementation of a local program, which should be promoted irrespective of the passengers' destination. At the same time, students' low knowledge of IVCO suggests that these programs should be promoted more intensively. Preferences and communication should differ depending on the country of origin of the passenger due to the cultural differences displayed; therefore, consideration should be given to which target groups to effectively address the offset message.

Another solution to reduce a passenger's own emissions is to pay a surcharge for sustainable aviation fuel. The majority of students surveyed (54%) would be willing to pay around 10% extra to the current ticket price if PLL LOT used SAF. 38% of respondents would not opt for a surcharge under the assumption of using SAF. The remainder would be willing to pay more than 10% more for a ticket. In terms of refueling, it should be avoided. It is also important to monitor the SAF and e-fuels market. LOT (as well as other carriers) has already taken some steps to secure the supply of sustainable aviation fuels by signing a memorandum with Orlen (Obserwator Logistyczny, 2022).

Subsequently, there is a need to more widely communicate the activities already implemented. An example is the low awareness of the LOT Destineco program among the students. This is all the more important as LOT's involvement in activities of a sustainable nature may, according to 43% of respondents, constitute a competitive advantage in the long term.

The highest CO₂ and HC emissions occur during the aircraft's taxiing operations on the apron and taxiway. This is due to the low engine load and incomplete combustion occurring in the combustion chamber. In contrast, the highest NOx emissions occur during the take-off and climb phases. This is related to the fact that the engine is operating at its design parameters and the combustion reaction in the combustion chamber occurs in the most near-complete

manner (Pawlak & Kuźniar, 2017). For LOT and other carriers, it is important to operate direct flights that generate less pollution.

According to WayPoint 2050, since the last decade, airlines have spent over a trillion dollars on more efficient aircrafts, whilst the whole aerospace sector has paid over \$150 billion on efficiency research and development (Aviation Benefits Beyond Borders, 2022). Newer generation engines have lower CO₂ and HC emissions than older engines. This is due to the refinement of the combustion chamber design, optimization of the combustion process and the use of modern analytical and engineering methods (e.g., Computational Fluid Dynamic) and new construction materials such as composites (Pawlak & Kuźniar, 2017).

It is beginning to be a good practice among airlines to create and introduce public sustainability reports. An example is Ryanair, creating its documents using various standards such as Sustainability Accounting Standards Board, Taskforce On Climate-Related Financial Disclosures, and Global Reporting Initiative (GRI). For LOT, this could be a good example of using international standards for reporting. In addition, some airlines (Wizz, Ryanair, Lufthansa) undergo an assessment by an independent body like CDP Project (CDP Project, 2023). Although LOT started its work towards sustainability, some areas require additional intervention.

The authors did not encounter any major problems during their activities. However, in a further approach, it could be interesting to obtain a panel of respondents reflecting the structure of LOT's passengers in order to verify how the sustainability measures are perceived by different passenger groups. Passenger awareness surveys for sustainable aviation and decarbonization also seem interesting.

The next stage of research should be interviews with representatives of air carriers operating on the selected market. Such a study would show potential directions for the implementation of a pro-environmental policy.

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