TRANSPORT PROBLEMS 2020 Volume 15 Issue 4 Part 2
PROBLEMY TRANSPORTU DOI: 10.21307/tp-2020-067

Keywords: air transport; airport; environment; solar panels

Dariusz TŁOCZYŃSKI*
University of Gdansk, Faculty of Economics
Armii Krajowej 119/121, 81-824 Sopot, Poland
Małgorzata WACH-KLOSKOWSKA
WSB University in Gdansk, Faculty of Finance and Management
Grunwaldzka Av. 238, 80-266 Gdańsk, Poland
Rodrigo MARTIN-ROJAS
University of Granada, Faculty of Business and Economics
Campus de Cartuja s/n, 18071, Granada, Spain
**Corresponding author*. E-mail: dariusz.tloczynski@ug.edu.pl

AN ASSESSMENT OF AIRPORT SUSTAINABILITY MEASURES: A CASE STUDY OF POLISH AIRPORTS

Summary. Air transport, like every economic branch, strives for development. Air traffic is growing dynamically, which means that the natural environment is increasingly being polluted each year. Therefore, entities operating in the air transport sector should care for the environment. One of these entities - airports - introduces many restrictions for aircraft with high CO_2 (carbon dioxide) emissions. At the same time, they introduce many ecological activities. Every year, also at the largest Polish airports, managers carry out activities aimed at caring for the environment. The main goal of the article is to evaluate the implementation of ongoing projects related to environmental protection at selected Polish airports. For this purpose, a survey was conducted at Polish airports in March 2020. The main research thesis is that as a result of the development of air traffic, airports will start investing more in innovative solutions related to environmental protection, including solar panels. This issue is extremely important from the point of view of economic, environmental, and corporate social responsibility. The main problems of the environmental policy are areas related to waste, water, and energy management. Some airports take up challenges related to the implementation of innovative solutions, including sustainable energy management. Tasks related to reducing energy consumption and increasing the use of green energy at airports will be of key importance.

1. INTRODUCTION

In the last 5 years of the twentieth century, air traffic was at the level of 4 billion passengers transported, so the offer of carriers is constantly enriched with new connections, with new types of aircraft. On the contrary, as a result of technical and technological progress and increasing responsibility for the natural environment, all entities operating in the air transport environment strive to implement environmental protection policy. Although air transport is synonymous with innovation and progress, many people view aviation as a polluting and hazardous factor to the environment. Air transport contributes to approximately 2% of global carbon emissions [1]. IATA predicts that the number of passengers will double to 8.2 billion per year by 2037 [2]. Boeing forecasts a demand for 42,700 new aircraft over the next 20 years [3]. Airbus predictions are very similar [4]. Therefore, environmental issues will become more and more important, and environmental regulation is necessary to increase the efficiency of green technology innovation.

In 2020, there were 15 airports in Poland: 1 central, serving as a hub - Warsaw Chopin Airport - and 14 regional airports. A characteristic feature of regional airports is a strong correlation with the economy of the region. Therefore, based on air traffic, there is a division into large airports: Kraków, Gdańsk, Katowice, Wrocław, Warsaw, Modlin, Poznań, and Wrocław, and small ones with a low share in the Polish aviation market: Rzeszów, Szczecin, Bydgoszcz, Olsztyn, Lublin, Łódź, and Zielona Góra (see: air traffic in Polish airports Table 1). As a result of the increased mobility [5] of the Polish society[1], and thus also the development of accessibility [6] and connectivity [7], carriers carry more and more passengers each year. In 2010-2019, there was an increase in passenger transport by carriers[2] by 152%, and air traffic at airports[3] increased by 139%. The development of traffic forces activities related to the construction and expansion of aviation infrastructure, the communication system, and non-market challenges, such as COVID 19. The government's strategy provides for the construction of Solidarity Transport Hub Poland [8]. As a result of the analysis of transport data, the authors of the article state that it is a dynamically developing market, which forces operators and airports to undertake the necessary actions related to, among others, environmental protection.

Referring to the analysis of the literature and market analyses, the authors diagnosed several research problems relating to the environmental policy of Polish airports: 1) an indication of activities undertaken by the managers of aviation infrastructure and 2) identification of the reasons for the use of sustainable energy sources, e.g., photovoltaic panels.

Based on the public's desire to implement a policy of sustainable transport development, Polish airports are also implementing many investment projects related to the implementation of environmental policy. Based on such premises, the main goal of the article emerges - assessment of the implementation of the projects related to environmental protection at selected Polish airports. It should be also hypothesized that as a result of the development of air traffic, airports will start investing more in innovative solutions related to environmental protection - solar panels.

This also led us to promote green technological innovation in air industry, so that the environmental protection might well be achieved. In this sense, the European Commission describes green technological innovation as a generic term covering technology, craftsmanship, and products that produce little or no pollution [9]. These products have limited ecological impact and follow the principles of a Green Economy by saving resources and energy and eliminating or decreasing their associated pollution and damage to the environment [10].

As a result of analysis of the literature sources on the subject and research at Polish airports, some important tools have been identified, which in the near future will significantly contribute to the improvement of airport ecological policy. Up to this point, the literature on the subject did not indicate innovative instruments for creating environmental policy in relation to that managing aviation infrastructure. Undoubtedly, case studies can be a valuable source of information for owners and operators of air transport infrastructure.

2. LITERATURE OVERVIEW

Air travel is still gaining popularity around the world. However, it also leads to excessive consumption of resources and the deterioration of the ecological environment owing to the negative externalities of the exhaust fumes [11]. It seems that the biggest challenge for the aviation industry in terms of ecology is the pressure to reduce carbon dioxide emissions. By 2050, the European Union requires the aviation industry to reduce CO_2 emissions by 75%, nitrogen oxides by 90%, and noise by

[1] The mobility of the Polish society in 2004 was 0.23, to increase in 2010 to 0.48, and in 2019 to 1.24, which means that one Polish resident made at least one air trip during 2019.

[2] In 2019, the largest shares in the passenger transport market had: Ryanair (27.28%), Polish Airlines LOT (26.92%), Wizz Air (21.64%), Lufthansa (5.35%), easyJet (2.38%) and Norwegian Air Shuttle (2.04%)

[3] In 2019, the largest share in passenger service at airports was held by: Warsaw Chopin Airport (38.48%), Kraków Airport (17.16%), Gdańsk Airport (10.65%), Katowice Airport (9.89%), and Wroclaw Airport (7.14%).

65%. In 2020, a new system for compensation and reducing emissions in international aviation, agreed by 70 countries, will enter into force.

Engine manufacturers, e.g. Rolls-Royce, focus on the production of aircraft engines that are more fuel efficient by up to 25% [12]. Several airlines are investigating the possibility of using biofuels, but biofuel is currently more expensive than fossil fuels, and some biofuels in storage may degrade over time, which creates additional problems [13]. Similarly, airports are introducing more and more technological solutions in the field of minimizing ecological threats in their areas. The International Civil Aviation Organization (ICAO) has been dealing with the negative effect of air transport on the environment for many years. The latest set of trends discussing issues of noise, local air quality (LAQ), and exhaust emissions was the subject of analysis in 2019, at the 40th session of ICAO [14].

ICAO also supports airports in implementing the so-called green programs covering the problems of smart terminals, the use of renewable energy, green mobility, resilience to climate change and biodiversity protection, and community involvement in sustainable development, to exchange and harmonize best practices among airports. ICAO documents mention Green programs, referred to as Eco Airport Toolkit e-collection. They aim to provide practical and ready-to-use information to support the development of green aviation infrastructure projects [15].

At European level, the European Union Aviation Safety Agency (EASA) deals with (among others) activities in the field of environmental protection. In the issued environmental report, the European Union postulates the use of investments based on innovative technology; this is associated with an increase in noise levels and CO_2 emissions. In 2015-2018, the number of European airports participating in the Airport Carbon Accreditation has increased from 92 to 133, and airports reaching CO_2 neutral status rose from 20 to 37. Thus, in the light of the authors of the Report, stakeholder involvement is crucial to identify sustainable mitigation measures, in the Collaborative Environmental Management process [16]. In Poland, the Environmental Protection Act applies, which sets out the principles of environmental protection and the conditions for the use of its resources, taking into account the requirements of sustainable development. All investments made by airports are subject to the same regulation as any other economic activity.

When conducting literature studies in relation to the main research problems, the authors grouped the issues according to the results of the survey. Basic issues related to sustainable energy management were analyzed by M. Radovanovic, S. Popov, and S. Dodic [17] or Md Hasanuzzaman and N. Abd Rahim [18]. They indicated how to manage the future energy system, and the economic and environmental effect of energy consumption and storage. Regarding sustainable water management, such studies were carried out by M. Scholz [19] and others. They pointed to the challenges related to around flooding, water supply, water quality, and the possibility of using new technologies in ecological policy. On the contrary, the issue of sustainable waste management was the subject of research by S. El Haggar [20] or A. Kumar and S.R. Samadder [21]. However, the analyzed studies refer to general issues, often related to the implementation of new technologies, as well as challenges for the modern world. With regard to airports, the issue of sustainable management is the subject of research in the macro-environmental aspect by M. Chaouk, R. Pagliari, and R. Moxon [22]. The energy management analysis was carried out by M.P. Uysal and M.Z. Sogut [23].

The research works [24,25] focused mainly on problems related to noise, air quality, bird migration, and inconvenience of roads and highways the around airports. These problems are widely known, but current research into environmental issues for airports is also carried out by researchers dealing with environmental issues at airports. They present the issue of using new energy sources as a case study in their paper. Similarly researchers [26–28] indicate the latest projects related to environmental protection. These include water quality, eco design of airport, waste management at airports, a focus on the production of renewable energy at the airport, car parking with special zone for electric car, and installation of solar panel systems. In turn, S. Sreenath [29] and her research team evaluated the use of solar PV in relation to issues (assess the glare occurrence). Other researchers [30] also have similar concerns about glare, but they point to photovoltaic deployment at most airports around the world, primarily on the American continent [31]. Rhodes and Wield [32] first proposed green innovation and described it as technological innovation for the purpose of environmental protection.

In the light of the analysis of the literature on the subject, there are also opportunities for the use of renewable energy sources in front of Polish airports, which will result in the improvement of the natural environment. In fact, if they do it, we could assert that green technological innovation sources help to decrease the associated air pollution and damaging to the environment from air transport [33].

3. METHODOLOGY

When analyzing environmental issues in the literature, it should be noted that the availability of research issues is low in relation to economic problems of new applications in environmental policy. Obviously, there are research works in the field of using new environmental solutions, but from a technical and technological point of view. Therefore, research is a challenge to the gap in the academic literature. Research conducted for the purposes of studies was of an exploratory nature [34,35]; they are the initial stage of the scientific process, so there is no need to establish research hypotheses. Thus, the purpose of such research is to enrich knowledge and expand existing knowledge to include observations, analyses, and preliminary scientific research [36]. To this end, the case study [37] was presented - selected regional airports in Poland as companies ready for new challenges related to environmental protection. This does not mean that Polish airports have not implemented programs related to environmental protection to this airport. Over the dozen or so decades, many activities were carried out in concern for the natural environment. Therefore, the case study fits perfectly into the literature niche. The choice of research subject - Polish airports - results from the following premises: volume of air traffic, representativeness of these ports in the region of Central and Eastern Europe, air transport is widely recognized as a harmful ecological branch of transport, and Poland is a country with a high degree of environmental pollution. Small regional airports with low air traffic were excluded from the analysis, and selected airports were subject to comparative analysis based on the following criteria: the type of actions implemented so far, planned investment process in environmental protection, and possibilities of using photovoltaic batteries.

To verify some activities at airports, primary research was carried out using a questionnaire. The main method was a survey addressed to the departments responsible for implementing the environmental policy of the analyzed airports. The questionnaire was sent in March 2020 to the central airport in Warsaw and to the main regional airports (Kraków, Gdańsk, Katowice, Wrocław, and Poznań). In 2019, the indicated ports had 88.5% market share. The main criterion for selecting ports was their financial capacity to carry out activities related to environmental protection and the implementation of innovative solutions. Such a selection proves the representativeness of the conducted research. The questionnaire was sent to people dealing with environmental issues at airports. In the questionnaire, closed and open-ended questions were formulated so that the respondents could indicate specific actions taken at each airport. The main purpose of the e-mail questionnaire was to indicate environmental investments carried out at airports and an opinion on the possibility of using photovoltaic panels in the airport area. The main problem was the indication of quantitative data. The main reason for the limitations in this respect is the protection of data against competition, which is unfortunately specific to the Polish market and at the same time hinders the conduct of scientific research. Responses to open-ended questions on pro-ecological activities were sorted, and then weights were given on a scale of 1-3 (1-the lowest, 2-average, and 3-the highest). In the absence (Warsaw and Krakow) of a return to the questionnaire, secondary data were used.

4. RESULTS

4.1. Identification of ecological threat factors at airports

Environmental pollution around airports can be caused by various factors. The most common sources of pollution include [38] take-off and landing operations; operations carried out with the participation of vehicles used by passengers (commuting / departing to / from the airport), as well as

by airport employees; activities related to the cleaning and maintenance of aircraft and ground handling vehicles; de-icing aircraft, runways, taxiways, and aprons by using de-icing agents; activities related to loading and storage of aviation fuel; maintenance of facilities constituting the airport infrastructure; and construction works related to the construction of airport facilities.

To minimize the risk of the indicated pollution, airports are adapting their activities in accordance with the recommendations of national, European, and global aviation organizations (see Tab. 1). Among others, cities prefer taking passengers to the airport using a greener means of transport - rail. Infrastructure managers have the appropriate equipment to keep all elements of the aviation infrastructure ready. On the contrary, de-icing operations are carried out in designated places.

Table 1

Measures to prevent the most common sources of pollution at Polish Airports

Airport (Distance to city [km])	Air traffic/ Aircraft movement in 2019 (2010)	Capability for removal of disabled aircraft	De-icing facilities	Fueling facilities/ Capacity	Types of clearing equipment
Warszawa (7.4)	18,844,591 (8,666,552) / 180,562 (116,691)	- low chassis trailer with a tug, - aeroplane tow bars, - equipment for removal of disabled aircraft: category I, max B737 or A320 (max gross weight 55 t): - aeronautical lifting cushions (4 kits), - harness system for aircraft lifting, - ground mats for construction of emergency roads	Elephant - 12, Kiitokori - 5	3 Cisterns of 4200 - 62000 liters capacity	snow removal set (plough, runway sweeper, and blower) - 11, runway snow plough - 14, rotary plough - 4, spreader – 3
Kraków (16.7)	8,402,859 (2,839,124) / 58,771 (29,706)	tug, tow bars, air cushions (up to 219 539 kg MTOW)	Kittokori - 2, ELEPHANT MY - 4, Mallaghan TA8200 - 3, Vestergård -2 Beta deicing vehicles	JET A-1: 5 x 27000 L, 3 x 33000 L, 1 x 38000 L, 1 x 18000 L, 2 x 35000 L, AVGAS 100LL: 1 x 8000 L	runway sweeper - 13, rotary blower - 4, airport sprayers - 2, spreader - 1, tractor sprayers - 2, tractors with blade ploughs - 3, tractors with front-end loaders – 3
Gdańsk (16.4)	5,361,134 / (2,208,819) / 41,088 (25,006)	up to MTOW 5700 kg	Kiitokori EFI 2000 – 2, Haenlein Eisbar II – 1, Vestergaard Elephant – 1, Elephant Sigma - 2	JET A-1 (6 tank trucks - 4 x 28300 L, 2 x 18000 L), AVGAS 100LL (1 tank truck - 5500 L)	snow removal set - 9, runway snow plough - 3, rotary plough - 3, spreader vehicle - 2
Katowice (33.0)	4,843,650 (2,366,410) / 32,959 (20,446)	aerodrome operator has signed a contract for removal of disabled aircraft with external operator, up to 100 000 kg MTOW	5 vehicles	tank trucks: Jet A-1: 1 x 18000 L, 4 x 35000 L, 3 x 40000 L, 4 x 60000 L, AVGAS 100LL: 1 x 8500 L	runway snow plough 6 m - 7, runway snow plough 9 m - 5, road snow plough 2.55 m - 3, runway sweeper: - OLH 4500 “Madro” - 5, - OLH 3850 “Hydrog” - 2, - OVERAASEN RS400 - 5, rotor snow blower - 3, spreader - 1, de-icing sprayer 6000 l

					and 12000 l - 2, excavator - 1, multifunction vehicle (sweeper, plough, sprayer) -1
Wrocław (10.7)	3,496,898 (1,598,533) / 27,716 (17,975)	equipment for removal of disabled aircraft up to MTOW 5700 kg: crane - 1 (up to 2HR), pneumatic lifts - 6+2, tractors - 2	Kiitokori EFI 2000 LHC – 3, Clariant Safewing MP II Flight type II	fuel station capacity: AVGAS 100LL - 50000 L, JET A-1 - 50000 L; Tank trucks: 3 x 42000 L	snow removal kit (plough, runway sweeper, blower) - 5, compact cleaner - 1, snow blower - 1, runway snow plough - 2, rotary plough - 2, spreader - 2, sprayer - 2, aerodrome sprayer - 1
Poznań (6.2)	2,372,184 (1,383,656) / 18,998 (16,738)	the aerodrome manager has an agreement signed with an external body on the removal of disabled aircraft, maximum up to MTOW 100 000 kg	de-icing devices - 3	JET A-1 (1 x 39000 L, 2 x 38000 L, 2 x 33000 L); fuel dispenser - AVGAS 100LL	runway snow plough - 5, road snow plough - 5, heavy snowblower - 2, runway sweeper - 5, spreader - 2, sprayer – 2

Source: [39]

It should be noted, however, that the degree of this pollution may depend on the effectiveness of the operation of airport equipment and any ground services responsible for the safe operation of aircraft, passengers, and cargo at the airport as well as the operation of aircraft engines in operating carriers.

The relation between air traffic and potential threats (de-icing, fueling facilities) and actions taken by airports (types of clearing equipment, rescue equipment, or capability for removal of disabled aircraft) should be indicated. The selected operational threats (directly dependent on air traffic) and selected devices indicated in Table 1 are aimed at preventing environmental pollution. The certification of airports and the related categorization of airports (depending, among others, on air traffic) forces airports to have an appropriate number of security features. This is a prerequisite for the conduct of operational activities at airports.

4.2. Assessment of the implementation of the environmental policy by Polish airports

In addition to the aforementioned activities, environmental management in Polish airports often focuses on the following environmental aspects:

- protection against aviation and traffic noise,
- rainwater management,
- waste management,
- reducing fugitive emissions to air, and
- energy saving and environmentally friendly technologies.

These activities focus on running systems for continuous monitoring of air noise, allowing for the assessment of long-term noise levels and registration of air operations carried out at the airport in accordance with the flight plan. In cooperation with air traffic control entities, procedures for performing take-off and landing operations are modified to reduce the effect of aviation noise on the environment and, if possible, reduce aviation fuel consumption and exhaust emissions. Activities also include restrictions on operational activities, spatial planning and land management around the airport, organizational activities, and environmental education activities.

The airport's operational services carry out ongoing inspections and maintenance of water facilities. Selective waste collection is carried out at the airports, the environmentally safe management of which is entrusted to specialized external companies. Modern heating devices and means of transport, as well as creating the right amount of airport parking lots, contribute to better management of air emissions.

The airport manager can conduct educational activities and a number of activities to improve the operation of aircraft at the airport, which are environmentally friendly. One such activity is the electrification of the ground handling equipment used. Fixed electrical ground power (FEGP) has been introduced at Polish airports. An additional element is the provision of a GPU (Ground Power Unit) at parking spaces. The use of power generators minimizes the use of APU (Auxiliary Power Unit). It should also be mentioned that the structure of carriers operating at a given airport is also important. LCC operators, due to the characteristics of their business plan, themselves strive to introduce savings by limiting the operation of aircraft on the ground to a minimum. In January 2020, at the Gdańsk Airport, a handling agent performed the country's first fully ecological aircraft service. It performed full eco-service of aircraft rotation only using electrical equipment.

Airport authorities are striving to reduce energy consumption and CO_2 emissions at airports. Airports should aim to gradually achieve CO_2 neutrality despite further economic growth. To achieve this, they should consistently work on implementing ecological programs, which may include improving energy efficiency, using CO_2-free energy sources, switching to electromobility, using geothermal energy for heating and cooling or building a photovoltaic system, increasing the use of public transport, extending the line railways in agglomeration, greater financial burden on louder planes - a new model for charging excessive noise, changing lighting systems to LED systems, etc.
A positive example of green innovation pro-ecological activities among Polish airports is also Warsaw Chopin Airport, which uses renewable energy sources. The solar power plant is composed of photovoltaic panels and was founded in 2016. The free space was allocated for the construction of solar panels, which supply a significant part of the airport. The power plant provides approximately 30% of energy and is mainly used to power ventilation systems, air conditioning, and dryers in toilets. The port authorities in Warsaw are striving to implement the idea of sustainable environmental policy so that in the future more than half of Warsaw Chopin Airport will be powered by ecological energy. Airport activities in relation to environmental policy management are presented in Table 2.

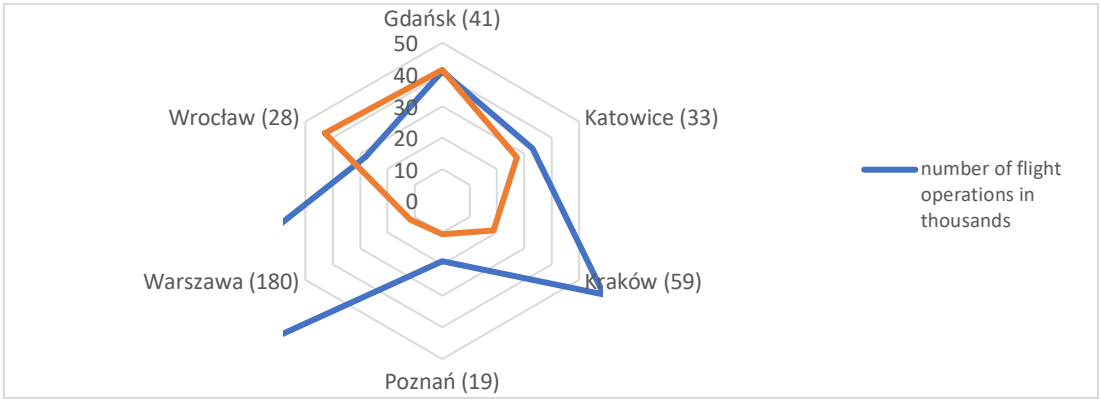
In the light of the primary research carried out in selected ports and supplementing these data with secondary information, a comparison was made of the environmental activities carried out. Respondents indicated the intentions of the airport authorities in the near future. Of course, these activities will change in the near future.

When analyzing existing activities, attention should be paid to the effectiveness of the enterprises carried out. To this end, the indicated projects were divided into three groups and assigned weighting: the lowest, the average, and the highest, and then they were referred to the aircraft traffic at the airport. Movement aircraft was analyzed because the greatest threat to the environment occurs at the conjunction between the aircraft and the plane, but the maximum number of points was awarded to those activities that are very innovative and affect other environmental factors (Figure 1).

The largest number of environmental projects in relation to the number of movements was carried out at in Wroclaw and Gdańsk. However, in Gdańsk, the number of activities is adequate to air traffic. Of course, the number of air operations at these airports was smaller than in Warsaw. At Warsaw Chopin Airport, the number of pro-ecological activities taking into account the weighting criterion in relation to air traffic was similar to that in Poznań (approximately 11). Taking into account the number of operations performed in Warsaw (180,000), the number and importance of undertaken environmental measures should be much higher. This is evidenced by the distance in the figure between the curve of the number of operations (blue) and the coefficient marked in orange. A much lower disproportion between activities and air traffic (movements) occurs in Krakow. However, also, in Poznań and in Katowice, aircraft movements are greater than the ratio of the number of weighted operations to the number of flight operations. Of course, such research is also fraught with some errors, including lack of full answers. It was not possible in the present study to financially quantify the environmental measures of the Polish Airports as the data are not available in the public domain. If financial data were used, this would be a much more complete picture of environmental operators' activities in relation to air traffic.

The vast majority of these environmental projects have been implemented over the past ten years. During this period, air traffic at the analyzed ports increased by an average of 64%. A larger number of start-off and landing operations contribute to an increase in environmental risk. Therefore, as a

result of the development of air traffic and the increase of awareness in relation to ecology, Polish ports have implemented a number of protective measures. At present and in the near future, one should expect continuation of conducting a conscious, socially responsible policy of sustainable development in the scope adequate to the conducted transport and non-transport activities [40]. Certainly, in relation to the latest and planned EU regulations, the concept of implementing renewable energy sources will have a broader application. Photovoltaic panels can be one example of scientific polemics.



Airport (xxx) – number of flight operations in thousands

Fig. 1. The relation between environmental activities taking into account their importance in relation to movements aircraft in the analyzed airports. Source: own research

Based on the data from Table 2, all specified airports in Poland take up pro-ecological activities. The main areas of these activities include the following:

- water resource management (rainwater retention, water treatment, reducing water consumption, and wastewater quality testing),
- waste segregation (sorting municipal waste, reducing waste generation, and waste monitoring analysis), and
- noise monitoring (separation of noise hazard zones).

In the first two areas, activities undertaken by the analyzed ports are implemented to a different extent. The airports of Gdańsk, Kraków, Warsaw, and Wroclaw started cooperation with the Polish Air Navigation Services Agency (PANSA) in the field of noise monitoring in the airport and airport areas. Unfortunately, only airports in Gdańsk, Katowice, and Warsaw implement projects related to sustainable energy management (this activity was of the highest importance for the authors of the study). At Gdańsk Airport, investments were made in the field of energy-efficient lighting fittings in buildings and outside, recovery of thermal energy from the Terminal, and energy-efficient runway lighting system in LED technology. In 2018, an audit was carried out in the port of Gdańsk to obtain more energy from renewable sources by 2025. The Port Authority of Gdansk is considering building a system of photovoltaic panels.

The airport in Katowice replaced the heating boilers with gas, whereas the airport in Warsaw built a modern system of photovoltaic panels, which enables obtaining electricity from solar energy. It should be emphasized that expansion of a solar power plant composed of photovoltaic panels is planned in the Warsaw port, and the installation of photovoltaic panels is planned in the port in Katowice. Over the next 5 years, all surveyed ports plan to implement innovative pro-ecological projects, including electric car charging stations (Katowice), construction of a fully ecological airport city in Gdańsk, installation of solar panels, and replacement of light sources with LED (Poznań). An implementation of the Environmental Management System based on the ISO 14001 has been introduced at Warsaw Airport. Airport in Warsaw complies with the legal requirements and other environmental regulations applicable to its business operations. Striving to increase environmental awareness, the airports in Kraków and Poznań conduct educational activities for employees and airport users. The main topic of the training is the reduction of plastic waste and selective waste collection at the airport.

Table 2

Analysis of pro-ecological activities at airports in Poland

Air-port	Actions taken and assigned weights (1 - the lowest, 2 - average, 3 – the highest)	Future actions
Gdańsk GDN	• energy-efficient lighting fittings in buildings and outside (2) • recovery of thermal energy from the T2 Terminal (3) • water-saving taps with photocells in toilets (1) • municipal waste sorting (1) • rainwater retention system with rainwater treatment facilities (1) • the use of biodegradable agents for de-icing surfaces and aircraft in the winter season (2) • continuous noise monitoring system (2) • optimization of inbound and outbound routes as well as verification and optimization of take-off and landing procedures in cooperation with PANSA (3) • energy-efficient runway lighting system in LED technology (2) • a toilet flushing system and recovered rainwater were used in the DHL building (1) • monitoring of birds and other animals' activity in the area of the airport (1) • 12 electric car charging stations (2)	• planned investments to minimize environmental impact (e.g., emissions of exhaust gases and noise), due to the situation related to COVID-19, have been suspended • construction of a fully ecological airport city
Katowice KTW	• replacement of boilers for gas (3) • construction of retention tanks (2) • protection of habitat species (2) • the use of gray water (1) • waste segregation (1)	• installation of solar panels • new charging places for electric vehicles
Kraków KRK	• continuous monitoring of air noise, implementation of anti-noise procedures in cooperation with external bodies (2) • monitoring the amount of gas or flue gas dust released into the air (2) • systematic replacement of equipment, devices and machinery park that meets the highest available environmental standards, the use of 6 hybrid cars on the tarmac (2) • quantitative and qualitative monitoring of generated waste, reduction of waste generation at source, equipping waste production facilities with appropriate environmental protection devices, waste segregation (1) • qualitative and quantitative monitoring of water abstraction for domestic purposes and introduction of treated rainwater from paved surfaces of the airport to natural receivers (1) • rational management of green areas (1) • installing a system for automatic recognition, tracking and analyzing the movement of birds at the airport, the use of "falconry" services (1) • conducting systematic ecological education of employees (1)	• construction of an alternative drainage system and / or construction of a sewage treatment plant
Poznań POZ	• rainwater retention at the airport (1) • education addressed to airport users in the scope of reduction of plastic waste and selective waste collection at the airport (1)	• replacement of light sources with LED, use of motion detectors when lighting corridors, toilets
Warszawa WAW	• implementation of the Environmental Management System based on the ISO 14001 standard (3) • aircraft noise monitoring system (2) • implementation of economic mechanisms mobilizing carriers to use a modern and quiet air fleet (2) • cooperation with the Polish Air Navigation Services Agency in the scope of optimizing the rules of air traffic organization so that in terms of acoustics it would be the least burdensome for the environment (3) • own rainwater and snowmelt treatment plant discharged from the airport and additionally a network of separators that ensure surface water protection (1) • retention tank system with a total capacity of approx. 40,000 m3, ensuring, among others protection of areas below the airport against flooding during periods of intense precipitation (1) • aircraft de-icing stations are equipped with installations enabling separation of sewage generated during de-icing and their proper management (2) • a modern system of photovoltaic panels, enabling the acquisition of electricity from solar energy (3)	• expansion of a solar power plant composed of photovoltaic panels

	• piezometer system, by means of which the state of the soil and water environment is controlled (2) • rational management of hazardous and non-hazardous waste that are managed in accordance with such priorities as recycling, recovery and disposal (1) • municipal waste management is adapted to applicable legal requirements, taking into account the principle of selective and non-selective collection of this waste (1)	
Wrocław WRO	• continuous air noise monitoring system (2) • construction of noise barriers at the terminal (2) • implementing silent take-off and landing procedures (2) • conducting constant quality tests of sewage, groundwater, rainwater and snowmelt from the airport area (1) • decommissioning the biological and mechanical sewage treatment plant at the airport and connecting some of the facilities to the existing municipal sanitary sewage system, contributing to the improvement of surface water status around the airport (1) • a person is employed (so-called falconer) who is responsible for scaring away birds and monitoring and repelling wild animals (1) • functioning of an automatic bird repelling system that uses solar energy to power its power (1) • use of water in a closed cycle (1) • waste segregation (1)	• rainwater retention • modification of waste segregation methods (reduction of plastics) • more effective media management • reducing noise emissions to the environment (organizational / procedural)

Source: own research; [41]

As a result of the analysis of the activities of individual airports, it should be noted that there is a large disproportion in the undertaken and future activities.

5. DISCUSSION

5.1. Possible directions of environmental policy development at Polish airports

Defining the most important directions for the development of environmental policy is a polemical issue. It depends on many factors. The authors are aware of the many challenges faced by the managers of Polish airports in relation to the issue of environmental protection. Air transport has never been and will never be green transport, but the main challenges for the environmental policy implemented by Polish airports should be indicated:

1. Area related to the use of sustainable energy sources.
2. Area related to the use of water.
3. The area related to noise reduction issues.

It cannot be unequivocally assessed which area of development is important for Polish airports. This is a moot point. These elements of development need to be looked at from the formal and legal point of view, as well as methods of obtaining capital and subsidies from various forms of external aid, including the European Fund, Polish-government environmental funds, or access to local sources of public aid.

On the other hand, the indisputable question is the cost and revenue calculation, including the answer to the question which ports are predisposed to major challenges in the field of environmental infrastructure development. The conducted research shows that the issue of using sustainable energy sources is important for building the image of the company - airports as entities implementing Corporate Social Responsibility projects. Therefore, in the opinion of the authors of the research and airport representatives, the issue of using renewable energy for the needs of airport infrastructure should be discussed. The authors are aware that this is a very broad issue, but in their research, they focus only on investments in solar panels.

The use of renewable energy sources can provide airports with many financial and social benefits, often difficult to measure. This is demonstrated by B. Kilkis and S. Kilkis when presenting the concept of a zero-energy airport. The airport acquires energy from diversified sources, including ground heat pump and solar panels, as well as biogas and waste heat [42]. However, the polemical issue is the concept of using energy from photovoltaic panels, owing to the threat to flight safety (the possibility of dazzling pilots, and electromagnetic interference). Nevertheless, the authors of the report

Developing a Business Case for Renewable Energy at Airports [43] indicate that renewable energy projects are most often financed under various subsidies or private inquiries. One of the concepts is the possibility for the port to sell surplus energy produced, which affects airport revenues. Owing to different grant levels, however, it is difficult to clearly assess the business level of implemented environmental investments.

In Poland, the law on renewable energy sources is constantly adapted to technological trends. Pursuant to the Energy Law, a license for electricity generation is required for installations above 500kW. Only in Warsaw, Gdańsk, and Katowice airports are willing to build and use photovoltaic energy. Of course, the cost of construction itself is difficult to determine, owing to the specificity and location of ports and the prices at which energy operators sell electricity. It should be estimated, however, that the costs of such an investment carried out on the ground construction fluctuate between PLN 2.5 and 3.0 million / MWp (Wp unit used in photovoltaics - the maximum energy that solar panels can generate under conditions providing 25° C, about $3m^2$ of 4 panels creates power 1 kWp). Profit from such surface of photovoltaic batteries can range from 0.95 - 1.2 MWh. At the same time, port operating hours will also have an impact on the efficiency of panel use. Most airports operate 24 hours. However, demand varies from time of day. Considering the largest peek in servicing aircraft and passengers, the question arises whether such an investment will be economically justified. Figure 2 presents the distribution of air traffic at selected airports.

Based on the data in Fig. 2, there is a great variation in air traffic throughout the day at regional airports. The biggest peek is in the morning. Although in the spring and summer, it corresponds to the sunny season, in the winter, it is night time. The situation is different at Warsaw Chopin Airport, where the port already generates a part of the demand for electricity from solar panels. Such an investment is possible because the distribution of air traffic in Warsaw is not as diverse as at regional airports depending on the time of day. In turn, the sunny day starts at 4.00 a.m. in the summer and ends around 9.00 p.m., whereas in the winter, the sunrise begins around 7.00 a.m. and the sunset starts at 4.00 p.m. In addition to sunrise and sunset times, the occurrence of cloud cover should be taken into account. For regional airports, where the peak time is the early morning hours, and therefore the time to prepare the infrastructure for air operations is shifted a minimum of two hours earlier, the question arises about the payback period from photovoltaic panels investments. An additional cost when using energy is also the cost of service, washing, and periodic inspections.

In addition, the authors point to legal regulations regarding installations above 50kWp, then the owners of solar panels pay the surplus to the energy operator at prices set by the Energy Regulatory Office. This situation occurs when the energy produced is not consumed on a regular basis. In the case of simultaneous production and consumption of energy, ports can save both the component of purchase of active energy and the surplus of this energy. In the event of surplus energy, it goes to the power grid and may return to port, but on a different commercial basis. This means that the size of PV installation should be defined for airport's own electricity use.

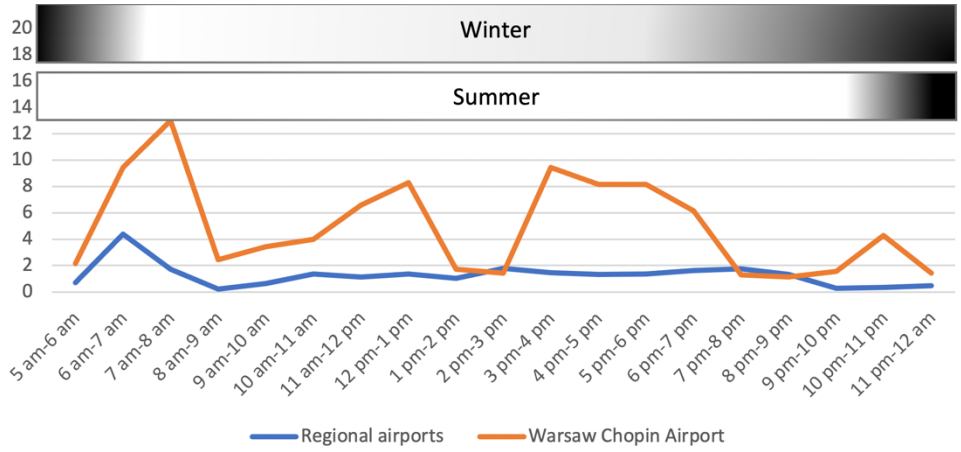


Fig. 2. Average hourly number of air operations performed at the analyzed airports. Source [44]
The average number of operations was calculated for the period July 11-17, 2020

To sum up, making a decision to buy or lease solar panels is a very individual business. The decision is accompanied by many economic (earned profit, capital availability, earned income, and rising energy costs) and non-economic (changes in law, EU, and national policy) factors, as well as by the opportunities arising from the development of air traffic and climate change. The disadvantage is probable purchase of batteries for accumulating electricity. Special support programs for institutions implementing environmental policy may be a factor supporting this type of investment. Both, government authorities, shareholders and managers themselves see the need for changes in the policy of using renewable sources.

6. CONCLUSIONS

The environmental effects of the operation of the airport are mainly visible in the effect on the level of air, soil, and water pollution and noise. The development of air traffic, and thus the development of airports, presents the owners and management of airports with the problem of creating an airport development strategy and operating in accordance with the principles of sustainable development.

According to the principles of eco-development, interference in the environment should positively affect well-being, as well as bring benefits to the environment by saving its natural resources.

However, based on the research, it should be noted that all airports implement green innovative projects, but the scale of these activities is varying. Planned projects for subsequent periods should be the result of air traffic. Certainly, government and EU authorities should consider more public aid for environmental activities. This issue could allow use to reveal the effect of different sources of environmental regulations on different technological innovations and provide references and suggestions for Poland to use combined environmental policy tools and to explore different types of green technology innovations.

The management boards of Polish airports set themselves the goal of operating them in the most efficient way from the point of view of energy, resources, and environmental protection. The directions of ecological development concern the implementation of various activities leading to the status of green airports. As part of the strategies implemented, among others activities aimed at reducing noise in the long term, there are implemented programs to protect the airport environment against noise, e.g., areas of limited use. Moreover, climate protection programs are an essential element of the "Green Airport" strategy. One of their assumptions is the systematic reduction of energy consumption by airports, and therefore the obligation to reduce the emission of gases that have an impact on the climate, by using renewable energy sources (e.g., photovoltaic panels), and thus reducing CO_2 emissions. In terms of atmospheric air quality, airports should monitor, test, and document the effect of substances deteriorating air quality in the vicinity of the port. All activities, data, and results relating to environmental and climate protection should be published. It is also necessary to point out the implemented policy of sustainable water management and sustainable management of waste generated in airports. A systemic approach to environmental management allows for coordination and facilitation of activities in the aforementioned areas: noise mitigation, air protection, water and sewage management, protection of the soil and water environment, and waste management. A key research issue was to explore the differences and common practices in applied environmental strategies and systems. Although most airports recognize the need for an environmental management strategy, few regional airports have set specific targets for their environmental performance. It seems that airports serving more than five million passengers a year (Gdańsk, Kraków, Warsaw) have a more detailed environmental strategy. Similar conclusions were reached by D. Dimitriou, A. Voskak, and M. Sartzetaki [45]. On the contrary, the remaining analyzed airports (Katowice, Poznań, and Wrocław) do not currently have a clearly defined operating strategy, so their activities are carried out blindfold. This may result from the fact that the concentration of activities consists in implementing only the necessary environmental instruments imposed by law. Only Katowice Airport from this group shows the direction of environmental investments when deciding to install solar panels.

To sum up, growth of airports is encouraged by its economic and social benefits; such growth should be a green growth in which increase of capacity does not happen at the cost of more environmental burdens of the soil and water environment, as well as waste management.

This is obviously a difficult topic for discussion, but in the near future, further in-depth analysis in this area should be undertaken.

References

1. *Working Towards Ambitious Targets.* Available at: https://www.iata.org/en/programs/environment/climate-change./
2. *IATA Forecast Predicts 8.2 bilion Air Travelers in 2037*. Available at: www.iata.org/en/pressroom/pr/2018-10-24-02./
3. *Comercial Market Outlook 2020-2039.* 2019. Available at: https://www.boeing.com/commercial/market/commercial-market-outlook/.
4. *Global Market Forecast. Cities, Airports & Aircraft 2019-2038. 2019.* Available at: http://gmf.airbus.com/assets/pdf/Airbus_Global_Market_Forecast_2019-2038.pdf?v=1.0.1.
5. Tłoczyński, D. & Hoszman, A. & Zagrajek, P. *Transport lotniczy w rozwoju globalnej mobilności*. Gdańsk: Wydawnictwo Uniwersytetu Gdańskiego. 2020. [In Poland: Tłoczyński, D. & Hoszman, A. & Zagrajek, P. *Air Transport in Development Global Mobility.* Gdańsk: University of Gdańsk].
6. Reynolds-Feighan, A. & McLay, P. Accessibility and Atractiveness of European Airport: A Simple Small Community Perspective. *J Air Transp Manag*. 2006. Vol. 12. No. 6. P. 313-23.
7. Malighetti, P. & Paleari, S. & Redondi, R. Connectivity of the European Airport Network: "Self-Help Hubbing" and Business Implications. *J Air Transp Manag.* 2008. Vol. 14. No. 2. P. 53-65.
8. S*olidarity Transport Hub Investment Programme. Stage I. 2020-2023*. Available at: https://www.cpk.pl/en/news/the-government-adopted-the-multiannual-programme.
9. *European Aviation Environmental. Report 2019*. Available at: https://ec.europa.eu/transport/sites/transport/files/2019-aviation-environmental-report.pdf.
10. *Reducing Emissions from Aviation*. Available at: https://www.ec.europa.eu/clima/policies/transport/aviation_en.
11. Rennings, K. Redefining innovation – eco-innovation research and the contribution from ecological economics. *Ecol Econ*. 2000. Vol. 32. No. 2. P. 319-332.
12. *Rolls-Royce Aims for 25% Fuel Cut with New Engine after Ł24m Government Investment* Available at: https://www.imeche.org/news/news-article/rolls-royce-aims-for-25-fuel-cut-with-new-engine-after-24m-government-investment.
13. Urbanek, J. *Czy branża lotnicza będzie kiedykolwiek bardziej eko?* Available at: https://www.rynek-lotniczy.pl/wiadomosci/czy-branza-lotnicza-bedzie-kiedykolwiek-bardziej-eko-5995.html [In Poland: *Will the aviation industry ever be more eco*?).
14. *2019 Environmental Report. Aviation and Environment.* Available at: https://www.icao.int/ environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB (1).pdf.
15. *ICAO.* Available at: https://www.icao.int/environmental-protection/pages/Airports.aspx.
16. *European Aviation Environmental. Report 2019.* Available at: https://ec.europa.eu/transport/sites/transport/files/2019-aviation-environmental-report.pdf.
17. Radovanovic (Golusin) M. & Popov, S. & Dodic, S. *Sustainable Energy Management*. Cambridge: Academic Press. 2013.
18. Hasanuzzaman, M. & Abd Rahim, N. *Energy for Sustainable Development*. Cambridge: Academic Press. 2019.
19. Scholz, M. *Sustainable Water Treatment*. Amsterdam: Elsevier. 2018.
20. El Haggar S. *Sustainable Industrial Design and Waste Management*. Cambridge: Academic Press. 2007
21. Kumar, A. & Samadder, S.R. A review on technological options of waste to energy for effective management of municipal solid waste. *Waste Manag*. 2017. Vol. 69. No. November. P. 407-422.

22. Chaouk, M. & Pagliari, R. & Moxon, R. The Impact of National Macro-environment Exogenous Variables on Airport Efficienty. *J Air Transp Manag*. 2020. Vol. 82. No. January. P. 1-11.
23. Uysal, M. & Sogut, M.Z. An Integrated Research for Architecture-Based Energy Management in Sustainable Airports. *Energy.* 2017. Vol. 140. No. 2. P. 1387-1397.
24. Young, S.B. & Wells A. *Airport Planning & Management*. New York: McGraw Hill. 2011.
25. Neufville, R. & de Odoni, A. *Airports Systems*. New York: McGraw Hill. 2003.
26. Harley, G. & Timmis, A. & Budd, L. Factors Affecting Environmental Practice Adoption at Small European Airports: An Investigation. *Transp Res Part D Transp Environ*. 2020. Vol. 88. No. November.
27. Budd, T. & Budd, L. & Ison S. Environmentally Sustainable Practices at UK Airports. *Transport*. 2015. P. 116-23.
28. Glenn, B. & Panarat, S. & Wild, G. An Assessment of Airport Sustainability, Part 2 – Energy Management at Copenhagen Airport. *Resources.* 2018. Vol. 7. No. 2(32).
29. Sreenath, S. & Sudhakar, K. & Yusop, A.F. & Cuce, E. & Soloimin E. Analysis of solar PV glare in airport environment: Potential solutions. *Results Eng*. 2020. No. 5.
30. Anurag, A. & Zhang, J. & Gwamuri, J. & Pearce, J.M. General design procedures for airport-based solar photovoltaic systems. *Energies*. Available at: https://www.mdpi.com/1996-1073/10/8/1194.
31. Kandt, A. & Romero, R. *Implementing Solar Technologies at Airports*. Available at: https://www.nrel.gov/publications.
32. Rhodes, E. & Wield, D. *Implementing New Technologies: Innovation and the Management of Technology*. Hoboken, New Jersey: Wiley Blackwell; 1994.
33. Liao, Z. Temporal cognition, environmental innovation, and the competitive advantage of enterprises. *J Clean Prod*. 2016. Vol. 135. P. 1045-1053.
34. Stebbins, R.A. Exploratory research in the social sciences Sage. *Qual Res methods Ser.* Available at: http://www.sciepub.com/reference/174737.
35. Bansal, H. & Eiselt, H.A. Exploratory research of tourist motivations and planning. *Tour Manag.* 2004. Vol. 25. No. 3. P. 387-396.
36. Williamson, K. & Johanson, G. *Research Methods*. Hull: Chandos Publishing; 2017.
37. Yin, R.K. *Case Study Research: Design and Methods*. 6th ed. Thousand Oaks, USA: SAGE Publications. 2018.
38. Luter, L. Environmental impact of airport operations, maintenance, and expansion, CRS. In: *Report for Congress.* 2007th. West Randolph. 2007.
39. *AIP Polska*. Available at: https://www.ais.pansa.pl/aip/.
40. *Civil Aviation Authority in Polan*d. Available at: https://ulc.gov.pl/en./
41. *The Sustainability Report of Kraków Airport*. Available at: http://krakowairport.pl/-multimedia/balice_raport_zrownowazonego_rozwoju_2018_flipbook_EN/.
42. Kilkis, B. & Kilkis, S. New exergy metrics for energy, environment, and economy nexus and optimum design model for nearly-zero exergy airport (nZEXAP) systems. *Energy*. 2017. Vol. 140. No. December. P. 1329-1349.
43. Barrett, S.B. & DeVita, P.M. & Kenfield, J. & Jacobsen, B.T. & Bannard, D.Y. Developing a Business Case for Renewable Energy at Airports. Developing a Business Case for Renewable Energy at Airports. *Transportation Research Board*; 2016. No 151.
44. *Flightradar24*. Available at: https://www.flightradar24.com/.
45. Dimitriou, D. & Voskaki, A. & Sartzetaki, M. Airports Environmental Management: Results from the Evaluation of European Airports Environmental Plans. *Int J Inf Syst Supply Chain Manag*. 2014. Vol. No. 7(1). P. 1-14.

Received 29.06.2019; accepted in revised form 09.12.2020