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The Impact of Climate Change on Air Transport

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Abstract:

Purpose: *The object of the research is the changing climate and its impact on air transport in Poland. The primary objective of the study was to present the most crucial elements of the air transport sector, vulnerable to the more and more frequent climate changes, and vulnerability indicators which allow to evaluate the impact of the change of climatic elements on the operation conditions of air transport.*
Design/Methodology/Approach: *The research process was conducted in two major stages. The first step was to select and indicate elements vulnerable to climatic factors having a key impact on the decisions regarding the essential characteristics of the transport sector while presenting the vulnerability indicators. This was performed with the application of a diagnostic survey using the questionnaire tool. The survey was conducted among the passengers of Warsaw airports in the year 2017.*
Findings: *The current warming of the climatic system entails measurable consequences which soon will have very costly and inevitable consequences both for air transport and economy in Europe and elsewhere, if no fast and firm corrective and remedial actions are taken.*
Practical Implications: *Climate change presents a considerable global threat. The overwhelming majority of recent scientific research and climate change reports confirm that current global warming is the result of human activities. Climate has already started to change, and it is evident that the rate of change is increasing. It has begun to affect air transport, i.e., one of the transport branches most vulnerable to climatic changes. Its sensitivity to climatic conditions should be viewed in relation to three basic elements: infrastructure, means of transport, and social comfort. Appropriate operation of the transport sector, in turn, may be guaranteed only if climatic factors are considered.*
Originality/Value: *Indication of the most crucial elements of the air transport sector, vulnerable to the more and more frequent climate changes, and vulnerability indicators which allow to evaluate the impact of the change of climatic elements on the conditions of operation of air transport.*

Keywords: *Air transport, infrastructure, climate, vulnerability indicators, climatic factors*.

JEL Code: *N7, N70, Q54, R41, R42.*

Paper type: *Research article.*

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1. Introduction

There are no panacea or instant solution in the fight for our transport systems to be more immune. It is a task composed of many details. Richard Brown (https://klimada.mos.gov.pl/wp-content/uploads/2014/12/Transport-infografika-MŚ.pdf).

Climate change and its consequences, i.e., temperature rise or extreme phenomena surge, have become more and more profound over the last several decades. In fact, climate change is any modification of the average weather conditions in each region. These changes include, amongst other things, the frequency of storms, temperature fluctuations, wind force, and precipitation. The above phenomena caused by climate change pose a very serious risk for the functioning of air transport (Chakuu, Kozłowski and Nędza, 2012).

In the context of this transport branch, temporary changes of weather conditions, which will become more and more frequent according to forecasts, are also crucial. The underlying threats are strong wind, icing, and fog, which periodically may put on hold all air transport opportunities, above all in case of regional and less well-fitted airports ("Strategic Adaptation Plan for the sector and areas vulnerable to climate change until 2020 with a 2030 projection, 2013).

2. Climate in Poland – News and Forecast

Geographic location in addition to the diverse physiography of the territory of Poland in the transitional area between the Western Europe and the continental zone of the Eastern Europe contribute to the highly varied and variable nature of the Polish climate. It is related to air circulation and directions of winds developing in the northern hemisphere of the temperate zone due to planetary circulation throughout the year, and because of monsoon circulation resultant from thermal and barometric gradients between the Atlantic Ocean and its adjacent seas and the continent expanding towards the east (Leszczyński and Domański, 1992). In the winter half-year, when the Atlantic Ocean becomes the source of heat for the western part of the continent, the temperature of the area of Poland increases westwards by 0.3°C per 1 degree of longitude. In the summer half-year, where the situation reverses and the continent becomes warmer than the ocean, the temperatures over Poland increase eastwards, but only by 0.1°C per 1 degree of longitude (Kożuchowski, 2011).

Oftentimes, the weather type changes overnight, or by the hour. The average value of annual air temperature fluctuates between 5°C and 9°C. The warmest area is the south-western part of Poland, whereas the coldest is the north-eastern area of the country and mountainous regions. The average annual temperature amplitudes range from 19°C on the coast to 23°C in the east of the country. What is typical of such changing climate is the number of frost days with a maximum temperature below

0°C occurring between November and March (with the highest number of frost days in January), increasing from the west (less than 20 days per year in the lower Oder River and along the coast) to the north-east (to more than 50 days in the Suwałki Lakeland), and in the mountains to 192 days on the Śnieżka mountain and 146 on the Kasprowy Wierch mountain. The lowest temperatures recorded in Poland were in Siedlce –41°C (1940) and in the Żywiec Basin –40,6°C (1929). The number of days with ground frost (minimum temperatures below 0°C) which may occur between early autumn (fall) and late spring ranges from 80 (at the seaside) to over 120 in the north-eastern regions and exceeds 200 in the mountain.

In Poland, there are six seasons of the year, with early spring (prevernal season) typically extending from mid-March to the beginning of April (about 20 to 25 days). It features changing weather conditions, frequent precipitation (rain, snow or sleet), major air pressure fluctuations and strong wind. The temperatures range from 0°C to 5°C. Spring lasts between 50 and 60 days (April, May). It is characterized by temperatures ranging from 5°C to 15°C, strong sun radiation, less cloud cover, and little precipitation. Additionally, it features chilly days in May due to an influx of cool air masses from the Arctic which, given the very low amounts of water vapour and strong overnight radiation, may produce ground frost. Summer in Poland lasts approximately 100 days and comprises the months of June, July, and August. There are plenty of storms or rains. The average daily temperature does not drop below 15°C. Autumn (fall) lasts between 50 and 60 days (September, October). It is associated with little cloud cover and large amount of sunlight referred to as the "Indian summer". In autumn, air temperatures gradually go down, with the largest temperature reduction noted at clear nights, when the Earth is radiating heat collected in summertime. The temperatures in that period range from 5°C to 15°C. Around 1 November, temperatures usually drop below 5°C and early winter (pre-winter) lasting over 25 days begins. Temperatures range from 0°C to 5°C, the days are grey, cloudy, and full of precipitation. Winter begins in early December. It lasts between 90 and 100 days. The average temperature during the day very often drops below 0°C.

The duration of the above presented seasons differs in various parts of the country: summer lasts from 60 to 70 days in the northern part of Poland, up to 100 days in the south-east, central Poland, western and south-western parts; winter lasts from 10 to 40 days at the seaside and in the west, between 3 and 4 months in the north-east, whereas in the Tatra Mountains it may last even 6 months (Kostrowicki, 1961).

Precipitation depends to a large extent on the lay of the land. Both precipitation scarcity and excess may have disastrous effects. Poland is located within the temperate humid zone of European precipitation. Average total precipitation is nearly 600mm, but it can range from 500mm in the central Poland to nearly 800 mm at the coast, and over 1000 mm in the Tatra mountains. The highest precipitation is recorded in summer, where it is 2- or 3-times (or even 4-times in case of the Karpaty mountains) higher than the winter-time volumes. Heavy rainfall (precipitation intensity > 2mm/min) occur from April to September, with the top frequency in July, and are often associated with storms and storms with hail. Snowfall occurs in the winter season, from November (or September in the mountains) to April, and account for 15% to 20% of the total annual precipitation. The number of days with snow cover ranges from 30 to 120. Most snow days are observed in the mountains (over 50) and in the eastern part of Poland (50-80). In the western part, there are 30 to 40 days with snow. Snow cover lasts longest in the north-east (from 90 to 100 days), and in the mountains (over 200 days; Kasprowy Wierch – 231). The thickness of snow cover rarely exceeds about a dozen centimeters. The exception here is the mountains – 1 m (the Tatra mountains – over 2 meters) (Leszczyński and Domański,1992; Woś, 2010).

Since the 19th century, the Polish climate has been characterized by a systematic air temperature rise. Since 1989, the rise has been much significant. What is more, the structure of precipitation, above all in the warmer part of the year, has also altered. At present, precipitation is more rapid, short-term, destructive, and more and more often results in flooding. Slowly, low rainfall (below 1mm/day) is starting to disappear. Simulated temperature shows a clear upward trend throughout the country – more warming is expected by the end of the century. Temperature rises feature regional and seasonal variations. Over the last thirty years of the 21st century, the largest temperature rises (above 4.5°C) with respect to minimum temperatures are recorded in winter in the north-eastern region, and with respect to high temperatures – in summer, in the south-eastern Poland. Temperature rise is further associated with changes in the course of all other climatic factors based on this variable. The thermal extension of the vegetation period is particularly evident, with a drop in the number of days with minimum temperature below 0°C and an increase in the number of days with maximum temperature over 25°C, with spatial diversification of the said characteristics.

Less apparent are the trends regarding precipitation. Simulations demonstrate that by the end of the century precipitation in winter will be suspended, and summer precipitation will decrease. Precipitation characteristics indicate that zero-precipitation periods will extend, the total maximum precipitation will increase, and the snow cover period will shorten (Strategic Adaptation Plan for the sector and areas vulnerable to climate change until 2020 with a 2030 projection, 2013).

3. Materials and Methods

The object of the research was changing climate and its impact on air transport in Poland. The primary objective of the study was to present the most crucial elements of the air transport sector, vulnerable to the more and more frequent climate changes, and vulnerability indicators which allow to evaluate the impact of the change of climatic elements on the conditions of operation of air transport. The presented research goal led to the following research problem: What is the effect of climate change on the functioning of air transport? The source of data have been European

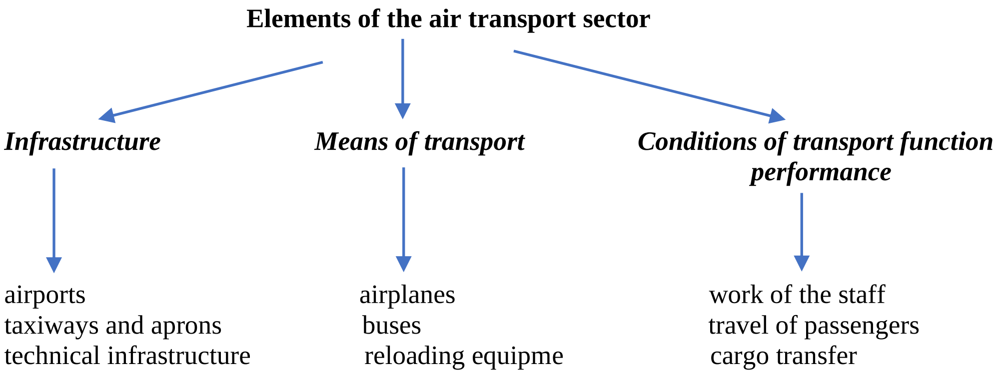
Parliament documents, legal acts, books and online publications relating to the operation of the air transport sector, climate change and its impact on air transport.

To improve our understanding of the problem of the impact of climate change on the operation of air transport and in order to attain the research goal, the research process was conducted in two major stages. The first step was to select and indicate elements vulnerable to climatic factors having a key impact on the decisions regarding the essential characteristics of the transport sector while presenting the vulnerability indicators. This was performed with the application of a diagnostic survey using the questionnaire tool. The survey was conducted among the passengers of Warsaw airports in the year 2017. Here, it should be emphasised that the applied methodology is directly related to a part of research conducted as part of the KLIMADA project carried out between 2011 and 2013 at the request of the Minister of Environment and the Strategic Adaptation Plan up to 2020 with a 2030 perspective (SPA 2020).

4. Results

Figure 1 shows the elements of air transport vulnerable to climate change analysed in terms of:
- transport infrastructure;
- means of transport;
- conditions of transport function performance.

Figure 1. *Elements of the air transport sector*



Source: *Own study compiled based on (Nurzyńska, 2016).*

Among the elements presented in Figure 1, the most vulnerable to the direct impact of climatic factors and contact with atmospheric factors is infrastructure. Table 1 shows the negative effects of climate change, projected until the end of 21st century, on air transport infrastructure.

Table 1. *Negative effects of projected climate change on air transport infrastructure*

Item	Climatic factors	Air transport infrastructure
1.	Frost	0
2.	Snow	1
3.	Rain	2
4.	Wind	2
5.	Heat	2
6.	Fog	0

Note: **0 – neutral, 1 – impeding, 2 – limiting, 3 – precluding*
Source: *The development and implementation of the Strategic Adaptation Plan for the sector and areas vulnerable to climate change, Stage III – Adaptation of the vulnerable sectors and areas of Poland to climate change by the year 2070 – Project, 2013.*

The lifetime of infrastructural facilities is between 50 and 150 years. Therefore, all activities undertaken today ought to account for potential future climate change to occur in 20 or 70 years. The analysis of the expected climate change demonstrates that it will have a negative impact on transport in a long-term. Thus, it is worth bearing in mind that in the years to come, until 2070, there will be an abundance of extreme occurrences impeding the operations of the air transport sector.

In Table 2, you will see the most important climatic factors distorting smooth functioning of air transport. Given the assessments provided by the survey respondents, selected distortions were attributed an extent (degree) of their burdensome nature. The surveyed airport passengers were to indicate climatic factors which had an unfavourable impact on air transport functioning and next, to evaluate the extent of nuisance on a scale of 1 to 3, where:
1 – minor offset,
2 – major offset,
3 – unable to operate.

Table 2. *Effect of climatic factors on air transport*

Item	Climatic factor	Air transport disturbances	Degree of nuisance
1.	**Fierce gusts of wind**	cancelled descent approach or redirection to another airport	1
		need to stop radars, disturbed radar forces operations or need to install protective equipment (protective shield)	3
		need to put aside and inactivate passenger boarding bridges	1
2.	**Strong wind perpendicular to the runway centre line**	delayed performance of airport operations, suspended landing operations	2
3.	**Wind shear under 1500 feet**	suspended landing operation (a wind shear detection radar may be installed at the airport)	1
4.	**Whirlwinds**	damage to ground air traffic control equipment	1

		delayed or suspended air traffic	2
5.	**Heavy snowfall; Massive snowfall;**	chance of ILS (instrument landing system for decreased horizontal and vertical visibility) deactivation	1
		over-snowed airfield, extension of time taken to restore normal airport operations	1
		need to keep equipment for airport, runway and taxiway maintenance in winter	1
		impeded access to route, radiolocation and radio-communication facilities precluding overhauls or repairs	2-3
6.	**Heavy rainfall; Downpours; Flood;**	flooding of airport surface, obstructed water drainage	1
		damage to a bus which run into a puddle at the airport	1
		local flooding of ground and infrastructure facilities, ground support equipment failure and damage	1
7.	**Lightning; Storms; Widespread storm activity**	need to change aircraft routes, air traffic delays	2
		damage to ground air traffic control equipment (repairs or upgrades are required)	1
		Aircraft equipment failure or malfunction	1
8.	**Extreme hot weather or over long periods; Extreme ground inversion**	possible overheating of ground air traffic control equipment	1
		air conditioning equipment failure	2
		ground inversion has an impact on aircraft performance (take-off at a short runway)	1
9.	**Frost; Severe frost or over long periods;**	damage to power lines supplying ground air traffic control equipment	1
		need to use electric power generators	1
		freezing of pneumatic systems in buses, tool-in-use systems, valves and pumps in subsidiary vehicles	1
		fuel supply disturbance	2-3
10.	**Fog**	periodic reduction of traffic capacity and potential delays in air operations	1
		take-off impediments	1
		precise descent approach impediments	1
		cancelled descent approach or redirection to another airport	1
11.	**Low cloud base**	cancelled descent approach or redirection to another airport	1
12.	**Prolonged icing and turbulence**	need to change aircraft routes; air traffic delays	1
13.	**Volcanic dust**	air traffic limitations, delays	1
		prolonged dust suspension in the air may completely stop air operations	2-3

Source: *Rymsza, 2010.*

While analysing the data included in Table 2, given the specific features of air transport, it ought to be highlighted that air transport is more vulnerable to momentary weather conditions than climate change. Air transport dependence on climatic conditions is most vital at aircraft take-off and landing. The underlying risk for aircraft in the airfield is strong wind, gusts and icing. The remaining phenomena, such us downpours or heavy snowfall, may delay operations or have a negative impact on their regularity. Nowadays, however, they do not constitute a direct threat because air transport is prepared to operate under the said conditions. Poor visibility as a result of fog or volcanic dust emission may lead to a complete stop of air transport functions performance. Nonetheless, let us not forget the short-term nature of such phenomena, which, finally, contributes to nothing more but delays.

In contrast, higher air temperatures will have a dramatic impact on air density and will necessitate an increase in aircraft speed, especially during ascending and increased fuel consumption, and during take-off – thinner air will require either much longer runways or load reduction (The development and implementation of the Strategic Adaptation Plan for the sector and areas vulnerable to climate change, Stage III – Adaptation of the vulnerable sectors and areas of Poland to climate change by the year 2070 – Project, 2013).

5. Costly Climate Change

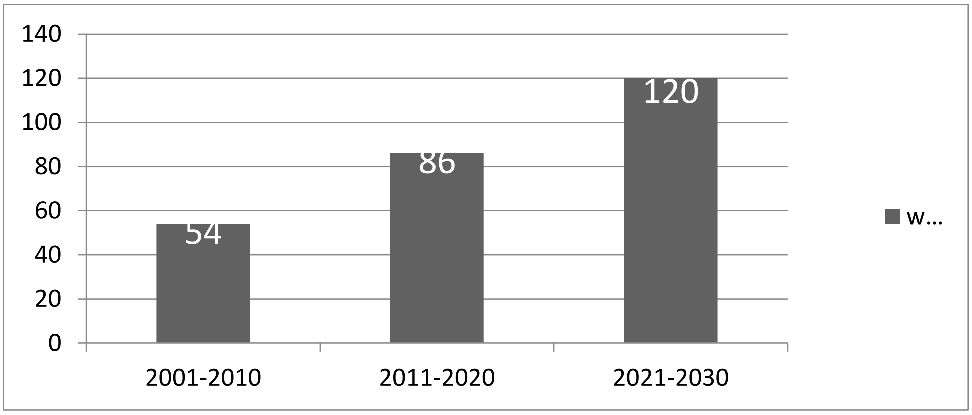
The analysis of the literature on the effect of climate change on the functioning of air transport reveals that the most substantial risk will be both high weather changeability and more frequent and intensive extreme hydrological and meteorological phenomena. Losses relating to climate change are reported not only by carriers but also by countries. A good example here is the United States of America, where the annual damage due to the above specified circumstances has been calculated. The estimates assumed that the cost of one uninterrupted flight is USD 150,000, and one cancelled flight – USD 40,000. Therefore, the total yearly loss calculated for 16 American air carriers was USD 47 million for interrupted flights and USD 222 million for cancelled flights (Kundzewicz and Kowalczyk, 2008).

What is more, American scientists warn against a massive impact of climate change on air transport en route Europe – USA, the consequences of which may be not only extension of flight duration but also an increase in the price of tickets. All the above is due to the change in the speed of the jet stream – air currents above the Atlantic Ocean flowing from the west to the east. As a result, aircraft flying from Europe to the USA will have to face a strong frontal wind, and on their way back – fierce wind blowing in their rear ends. It will translate into flight time extension and fuel consumption increase, which as an effect will cause a rise in the prices of plane tickets.

According to Professor Williams of the University of Reading, every transatlantic plane will spend 2,000 hours in the air more per annum. This will translate into an increase of fuel prices by 22 million dollars per year, longer flight times, and delays at airports. A shorter flight one way will not compensate for the losses generated on its return. It is estimated that the London – New York route will have a half more flights lasting over 7 hours, and that the return flights will twice as often be under 5 hours and 20 minutes long (https://nt.interia.pl/technauka/news-zmiany-klimatu-opoznia-loty-transatlantyckie,nId,2143428).

Official financial losses resultant from climate change are published by the European Environment Agency (EEA) every four years. The latest publication demonstrates that over the period 1980 - 2013, the losses relating to extreme weather phenomena cost Europe 400 billion Euros. Poland incurred approximately 14 billion Euros losses over the 33 year-period.

Figure 2. *Losses due to extreme climatic phenomena over the period 2001-2030.*



Source: *Own study compiled on the basis of: https://businessinsider.com.pl/wiadomosci/zmiany-klimatu-koszt-dla-europy-i-polski/h452ktl] (accessed on 10/01/2020).*

Having regard to information to date, in the year 2013 the Polish government developed an adaptive plan for the sectors and areas vulnerable to climate change until 2020, with a 2030 projection, which shows that in the first decade of the 21st century the losses incurred as a result of extreme weather phenomena in Poland amounted to ca. PLN 54 billion. If Poland fails to take appropriate action, the consequences of the changes will cost us another PLN 86 billion by the year 2020, and as much as PLN 120 billion by the year 2030 (https://businessinsider.com.pl/wiadomosci/zmiany-klimatu-koszt-dla-europy-i-polski/h452ktl)- Figure 2.

6. Conclusions

Climate change and transport - a lot is needed but little is done. This one sentence of the European Environment Agency (EEA, 2008) impressively concludes the issue of the impact of the transport sector on climate and of climate on transport branches, including air transport which is struggling with the climate changes presented in the above publication and posing a major global threat. Scientific research and reports concerning climate change reveal that current global warming is an effect of human activity, e.g. use of fossil fuels, agricultural practices, or land use change (https://www.europarl.europa.eu/RegData/etudes/note/join/2009/405382/IPOL-JOIN_NT(2009)405382_PL.pdf).

We know that climate is not constant. However, in the past, natural changes occurred a lot slower – on the geological time scale even several thousand, hundred, or million years. Today, we are witnessing climate change because it is happening during one's lifetime (Kundzewicz, 2013). The current warming of the climatic system entails measurable consequences which soon will have very costly and inevitable consequences both for air transport and economy in Europe and elsewhere, if no fast and firm corrective and remedial actions are taken. Climate changes are already underway and picking up. But it is never too late to combat them (Popkiewicz, Kardaś and Malinowski, 2018).

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