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INDUSTRIAL SNOW AND SELECTED ECONOMIC IMPACTS ON THE OPERATION OF KOSICE AIRPORT

Summary. The aim of the paper is to describe industrial snow as a meteorological phenomenon of anthropological origin and the physical principle of its formation in the context of Kosice Airport, with international traffic. The research also focused on selected economic impacts on the operation of Kosice Airport, which is located next to the large industrial complex U.S. Steel Kosice. There are only a few international airports in the world that are affected by industrial snow, which is why we also focus on the economic impact of maintaining the operational areas of the airport to the required extent according to standards. A solution to the problem is also proposed based on the scientific works of experts who focused their scientific activities on the issue of industrial snow production. In addition to the differences in the formation of industrial and natural snow, the article mentions the differences in the structure and properties of crystalline elements and their distribution according to the external meteorological conditions under which they are formed. The paper identifies meteorological situations that are favorable for the formation of industrial snow and due to the mutual location of the airport and the industrial complex, the airport is affected by industrial snow. This article describes the selected economic impacts of industrial snowfall on air traffic at Kosice Airport from 2017–2022. These were expressed after providing data from the airfield maintenance department of the Kosice Airport. At the same time, airport maintenance workers shared their unique experiences with this special meteorological phenomenon. The outcome of this research brings the unique method of industrial snow day occurrence and helps to explain this rare weather phenomenon and its impact on transport and social aspects.

1. INTRODUCTION

Snow covering the surface is a complication for all kinds of transport, including air traffic. With industry development, a special meteorological phenomenon of anthropological origin, "industrial snow" occurs under specific meteorological conditions. The subject of the article is the assessment of the impact of industrial snow on the Kosice International Airport on its flight operations and the assessment of selected economic impacts of industrial snow on the operation of Kosice Airport. The aim of the article is to describe industrial snow and its economic impacts on the operation of Kosice International Airport. The article focuses on the description of the process of the formation of industrial

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snow, the type of ice crystals, the type of precipitation, and their impact on aviation traffic. For these purposes, two research questions were formulated.

Research Question 1: Is the main source of air pollution in the vicinity of the Kosice Airport an industrial complex whose composition of emissions creates the conditions for the formation of industrial snow at the investigated airport?

Research Question 2: What is the expected economic impact of industrial snow on the maintenance of airport areas at the selected airport?

The problems associated with this phenomenon are mainly the cleaning of movement surfaces, in which case the airport spends money on their removal, even though it did not snow in another part of the city. The results show that this entire situation is caused by the U.S. Steel Kosice industrial complex near the airport. The theoretical basis for researching the issue is based on a search for relevant scientific works. The analytical part uses objective data provided by the Slovak Hydrometeorological Institute, which operates a network of precipitation measuring stations. Days with the occurrence of industrial snow at the airport in Kosice were identified by the utilized comparative method and confirmed by satellite images from the Sentinel System.

This research contributes to the understanding of the impact of the unexpected influence of industry on the character of the weather on the microscale. Due to the composition of the exhalations, which arise from the production technologies used at these resorts, the weather is unintentionally affected, which leads to increased economic costs of dealing with the phenomenon of industrial snowfall at Kosice Airport.

This introductory section is followed by a review of the research on industrial snow in Section 2. The methodological approach used for the study is presented in Section 3. The results are presented in Section 4, and the findings and the study's recommendations are discussed in Section 5. The conclusions are presented in Section 6.

2. LITERATURE REVIEW

The issue of industrial snow has already been addressed by a number of scientists, who have focused on the physical essence of the formation of industrial snow, identified the atmospheric conditions suitable for its formation, and assessed the impact of the formed snow on microclimatic changes in the affected regions. Liechti [1] discussed the industrial parks located in Switzerland and their influence on the production of industrial snow. The author concluded that industrial snow is formed in areas where there are sources of heat and moisture, and the necessary condition is a low base of stratus clouds that is radiatively cooled.

The snow pollution caused by various chemical substances discharged from the chimneys of a company that processed iron was discussed previously [2]. This work shows that elements such as nickel, zinc, and lithium were found in the snow cover, impacting environmental pollution in Finland downstream of the Iron factory. The values of metals in snow cover, as well as hydrocarbons, phthalates, and phenols, exceeded the existing maximum allowable concentrations.

According to the National Weather Service, industrial snow at Amarillo, Texas, USA, was caused by the presence of cold, low clouds into which water vapor from nearby industrial areas ascended, causing accumulating snow. The authors refer to this phenomenon as similar to lake effect snow in the Midwestern United States [3]. The problem of the modification of local climate caused by urban areas, the so-called urban rainfall effect, has been discussed by Dr. Marshall as the relationship between urbanization and its influence on winter precipitation [4, 5].

In other work, Yamamoto investigated a phenomenon he called "Factory snow" [6]. He describes it as snow that falls from the smoke and steam released from the Asahikawa National Pulp Factory in winter, and this snow only covers the area near the factory. According to Yamamoto, the causes of this snow include emissions from factory chimneys or smog and pollution caused by factory fumes.

According to the authors, this type of snowfall occurs in fog or a low cloud layer in combination with a significant temperature inversion near the ground, less air movement, and temperatures below

freezing. This industrial snow is mostly missed by precipitation radars and is difficult to predict because it is extremely localized.

2.1. Industrial snow as a meteorological phenomenon

Industrial snow is a type of snowfall that occurs only in areas that are near industrial facilities that release warm water vapor into the air along with other particles, such as dust or sand, during their operation. Important conditions for the formation of industrial snow are the presence of an inversion layer at ground level, which causes an increase in temperature with height, the presence of a low layer of fog or stratus type of clouds, and an anticyclone, which is an area of high air pressure and temperatures close to or below the freezing point [3]. The Slovak Hydrometeorological Institute divides the types of weather situations into up to 25 categories according to their direction of flow (e.g., a southwestern cyclone, which runs from the southwest to the northeast) or describes a unique phenomenon, such as pressure saddles, that depends on the season (e.g., a western anticyclone of the summer type) [7]. Four types of anticyclonic situations are favorable for industrial snow formation.

1. Anticyclone over central Europe (denoted by *A*). Its edges extend to western and southeastern Europe. The high pressure often has a separate center at higher levels, which is maintained north of the 50th parallel. In some cases, this high pressure will merge with a band of high pressure off the Azores or a low-pressure wake from the lead cyclone from Iceland to the southeast of the Iberian Peninsula. The frontal zone from the moderate latitudes of the Atlantic Ocean passes north to Scandinavia, where it turns to the southeast. This is a frequent occurrence in winter and spring [7].

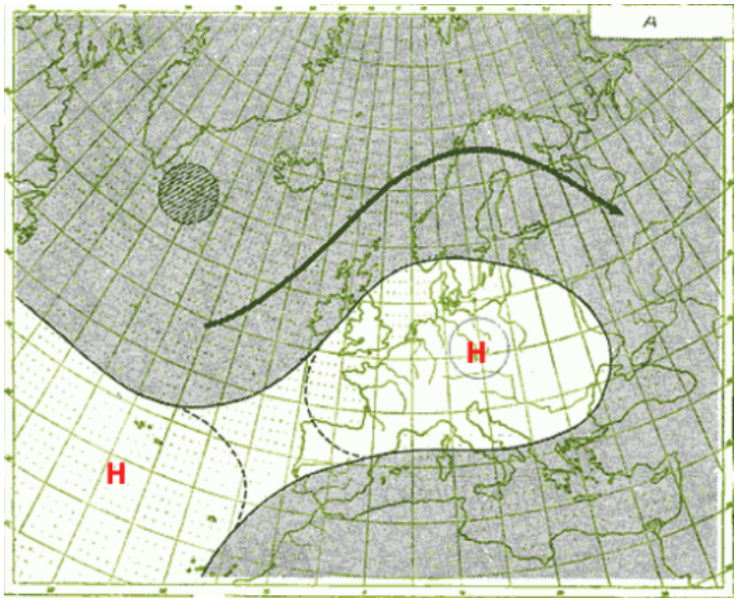

Fig. 1. Anticyclone over Central Europe [Source: https://www.shmu.sk/sk/?page=8]

2. Baroclinic anticyclone (denoted by *Ap*). This is a moving type of anticyclone formed by the closure of pressure areas in the southwest, west, and northwest, which separate from the stationary pressure areas over the Azores and Greenland. It is divided into four groups according to the path of its flow. The wandering anticyclone of the first group comes from Spain and lasts for one day. The second group, which goes from the 50th parallel from the south of Great Britain to Slovakia, occurs most often over the territory of the Slovak Republic. Such a pressure rise lasts approximately two days and occurs mainly during the transition between seasons [7].

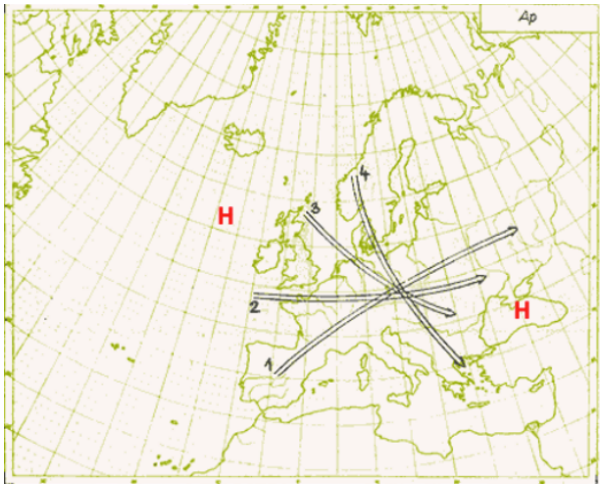

Fig. 2. Baroclinic Anticyclone [Source: https://www.shmu.sk/sk/?page=8]

3. Western anticyclonic situation (denoted by *Wa*). The controlling cyclone is located between Greenland, Iceland, and Norway, while its northern edge extends over our territory. A frontal zone moving from the temperate areas of the Atlantic Ocean passes through Scotland, southern Scandinavia, and the Baltic Sea and then moves northeast. Warm fronts from the ocean are directed towards the land and pass north of Slovakia, while only their edges affect the northern border areas. The situation is concluded by a cold front passing through our territory. Such an anticyclonic situation occurs mainly in the summer and autumn but also sometimes occurs in spring [7].

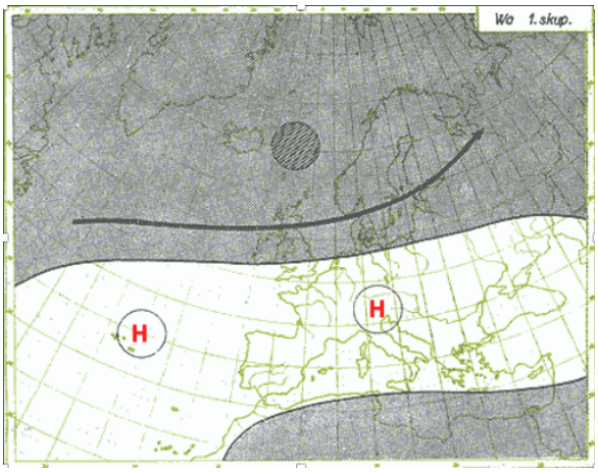

Fig. 3. Western anticyclonic situation [Source: https://www.shmu.sk/sk/?page=8]

4. Southwest anticyclonic situation (denoted by *SWa*). A characteristic of this situation is the presence of a cyclone over the Atlantic, from which an area of higher pressure extends to the east, reaching as far as Central Europe. The frontal zone develops between these two formations, and according to the size of the cyclone and the mutual temperature contrasts, it develops in two ways. In the first case, there is a stationary cyclone near Iceland, and the anticyclone affects the Carpathians and Ukraine. In the second case, due to the strong temperature contrast, the front moves towards the Baltic Sea, while the low pressure moves from Scotland to the north of Russia; meanwhile, the high pressure is either stationary and affects the area as in the previous case, or a wandering anticyclone is formed that passes through the territory of Slovakia. It tends to occur in the first half of winter [7].

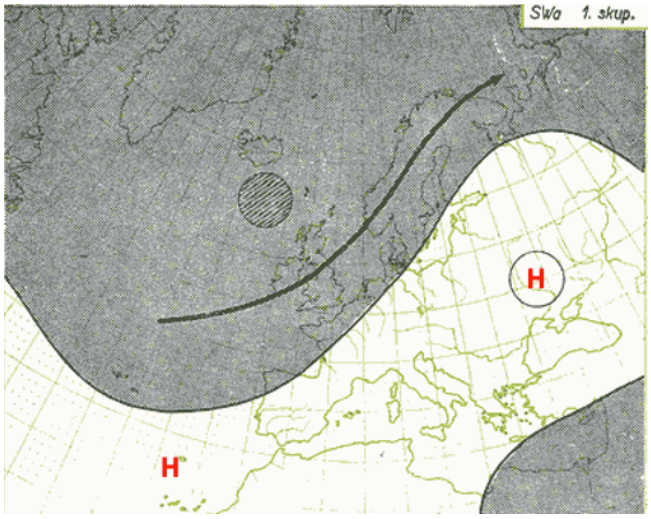

Fig. 4. Southwest anticyclonic situation [Source: https://www.shmu.sk/sk/?page=8]

Due to the release of water vapor into the inversion cloud layer, condensation or the direct deposition of vapor particles occurs when the inversion ceiling is reached, at which point further ascent is no longer possible. Along with water vapor, there are condensation nuclei in the emitted substances to which water or ice particles subsequently bind. Ice crystals in a saturated environment keep growing in the form of snowflakes, and after they reach a certain height above the clouds, they fall to the earth's surface. This is practically snow created by human activity. Because industrial snow appears under low cloud cover, this phenomenon is very difficult for meteorological services to predict, as it is a phenomenon of anthropological origin and its area of effect largely depends on a favorable synoptic situation. Another variable is the intensity of the release of water vapor into the air by the industrial complex. In addition, stratus clouds at low altitudes cannot be detected by radars [2, 3].

The flakes of industrial snow are smaller than natural snowflakes, reaching an average size of only 1-2 mm. A significant difference is greater adhesion compared to natural snowflakes. This feature makes it very difficult to maintain public spaces or movement areas of airports, as industrial snow adheres even to surfaces from which natural snow would immediately fall. Another important factor, especially when identifying whether it is industrial or natural snow, is the occurrence of high pressure in the given area. In this case, the snowfall was caused by industrial activity.

Other differences include the chemical composition. Since industrial snow is the result of air pollution by releasing water vapor and other small particles, it contains traces of various chemical elements. As an example, it is possible to cite a case in the Irkutsk region, where laboratory tests of snow identified the presence of substances such as zinc, cadmium, lead, tungsten, mercury, and antimony [2, 8]. The largest share among the emitted emissions of the U.S. Steel Kosice has carbon dioxide, sulfur dioxide, nitrogen oxide, and solids. These are discharged together with water vapor, while solid substances form condensation cores that aid the formation of industrial snow [9].

3. DATA AND METHODS

The first part of the analysis of the occurrence of industrial snow compares the measured data of the Velka Ida Precipitation Station and the Synoptic Station at Kosice Airport from 2017-2022 in December and January. The Slovak Hydrometeorological Institute provided data on daily precipitation, new snow cover, and total snow cover. This pair of stations was chosen because of their location concerning the airport, the Kosice Airport station is located directly at the airport, and with the help of the above-mentioned observations, it is possible to determine industrial snow at the airport with a south or southeast wind. The Velka Ida station is located in the village of the same name, and its measurements make it possible to confirm industrial snow with north and northwest winds. The air distance between

these stations is approximately 10 kilometers, and their mutual location precludes duplicate observations of industrial snowfall.

After identifying the days with the possible occurrence of industrial snow at the airport in Kosice based on a comparison of precipitation totals from selected meteorological stations, it was possible to proceed with their visual verification using images from satellites and records of weather situations. The outputs of the mission of the European Space Agency, which is named after Copernicus, were used to visualize the problem. For this mission, a pair of satellites orbiting Earth in the same orbit was created, namely Sentinel A, and B, which are shifted by 180° relative to each other. The first of the satellites was launched in 2015, and the second was launched in 2017. They are designed to monitor changes on the earth's surface for maritime surveillance, emergency management, land monitoring, and urbanism purposes. The images show an area with a width of 290 kilometers, and the area of the airport is recorded every two to four days [10]. The diagram can express the algorithm for the identification of the industrial snow event in Fig. 5.

The algorithm was developed by the authors of this article in the Department of Flight Preparation of the Faculty of Aeronautics of the Technical University of Kosice. Its unique structure makes the identification of days with the occurrence of industrial snow very effective in three massive databases of meteorological reports from the airport, Mala Ida station, and satellite images.

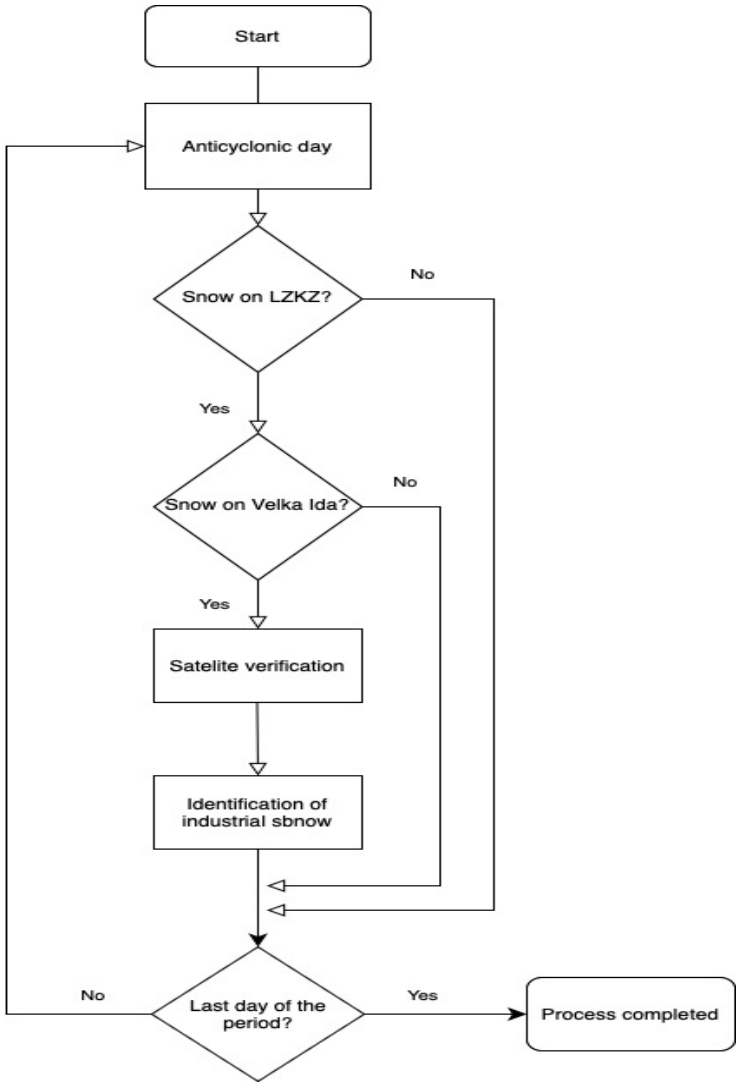

Fig. 5. Methodology algorithm

With the help of satellite images from the Sentinel-2 satellites, it was possible to examine in more detail the influence of high-pressure situations and wind direction on the occurrence of snowfall in the vicinity of the airport. Even though the first satellite was launched in 2015, the image database has only been available since 2016, which is why this period is chosen in this work [10]. Based on the date of the satellite images, it was possible to identify the type of weather situation, after data analysis from the database of the Slovak Hydrometeorological Institute.

The presence of elements such as snow, ice, sleet, slush, or blown snow in the movement areas of the airport represents a safety risk that can contribute to aviation incidents or accidents on the ground [11], flight delays, or airport closures. Snow cover is quite common in Slovakia in the winter months, and it is associated with the costs of removing snow from the airport's traffic areas. A unique characteristic of the Kosice Airport is the influence of the industrial complex in its vicinity and the occurrence of snowfall related to it, even when snowfall does not occur at other airports. This represents additional costs for the airport's winter maintenance compared to other airports. After identifying the average number of days with industrial snow, it was possible to calculate these extra costs, considering the snow removal technique.

4. RESULTS

This section identifies the source of air pollution that results in industrial snow formation and quantifies the days on which industrial snow occurs. The identification of the number of days with industrial snow leads to calculations of extra costs for keeping the movement areas of the Kosice Airport clean of snow and ice. This section also provides answers to the research questions.

4.1. Industrial Snow Days Identification

Through a detailed analysis of daily precipitation totals and the height of the new snow cover, the days on which industrial snow occurred at Kosice Airport were identified. These were the days when the synoptic conditions for the formation of industrial snow were met and no precipitation was recorded at the precipitation station in Mala Ida. The station in Mala Ida is not affected by the industrial complex, and its data allowed for better identification. For example, we can cite the cases from 3.1.2020 and 4.1.2020, when 3.2 mm of precipitation fell at Kosice Airport, representing 5 cm of snow. After the breakup of the low clouds, it was possible to identify the area affected by industrial snow through a satellite image.

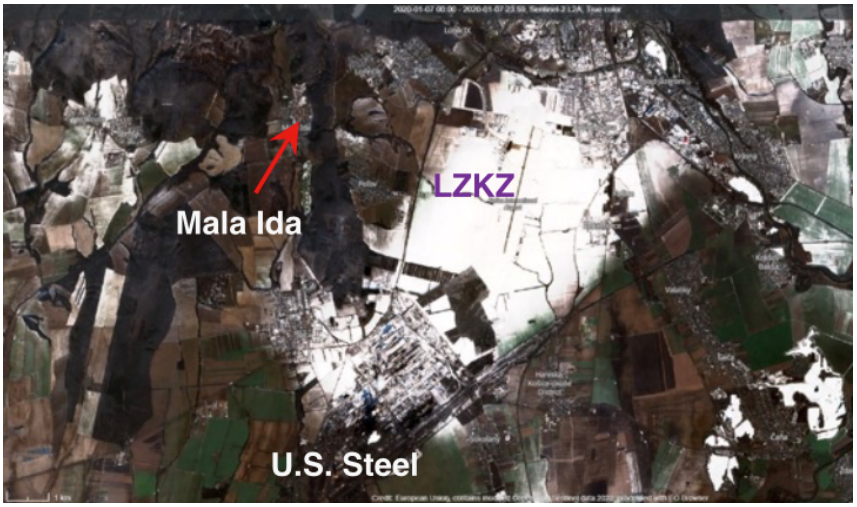

Fig. 6. The area affected by industrial snow in Kosice [Source: https://dataspace.copernicus.eu/browser/]

Figure 6 shows a distinct snow-covered area with a contrasting snow-free surface, with a significant transition. The industrial complex is located southeast of the airport. The runway is visible after the snow has been shoveled. With a south-easterly flow, the industrial snow was spread in the direction of the flow towards the northeast and covered the downstream area. However, the precipitation-measuring station in Mala Ida did not record any precipitation, as it is located outside the affected area.

Using a combination of numerical data from precipitation measuring stations and Sentinel satellites, it was possible to identify the industrial complex U.S. Steel as the source of industrial snow. At the same time, it is the answer to Research Question 1 (Is the main source of air pollution in the vicinity of the Kosice Airport an industrial complex whose composition of emissions creates the conditions for the formation of industrial snow at the investigated airport?) The answer is yes, the main source of air pollution in the vicinity of the Kosice Airport is the industrial complex whose composition of emissions creates the conditions for the formation of industrial snow at the investigated airport and expresses the number of days with the occurrence of industrial snow. The amount of precipitation falling from industrial snow in liquid equivalent is shown in Table 1.

Table 1

Industrial snow precipitation falling in liquid equivalent

Monthly precipitation totals from industrial snow at Kosice Airport [mm]						
Month	2017	2018	2019	2020	2021	2022
December	0.0	0.0	5.0	0.0	0.0	10.9
January	0.0	0.0	0.0	11.5	0.0	8.1

In climatology, the height of the snow cover is measured, as is the liquid equivalent obtained from the melted snow. Table 1 shows the total precipitation (in mm) of the water column for December and January from 2017-2022, identified as a result of industrial snow. It is the result of processing data on daily precipitation totals for the last five years. The impact of industrial snow was most shown on December 5, 2019, when up to 5 mm of precipitation was recorded at Kosice Airport, while it did not snow at all in Mala Ida. On this day, the center of the high pressure occurred over the territory of Slovakia [7]. An anticyclone was accompanied by a low inversion, which created ideal conditions for the formation of industrial snow. For the practical needs of winter maintenance of the airport, not only is the water value of the falling snow important, but so is the height of the new snow cover. This is shown in Table 2 as a monthly amount in December and January from 2017-2022.

Table 2

Height of new snow cover from industrial snow

A monthly amount of new snow cover from industrial snow in Kosice Airport [cm]						
Month	2017	2018	2019	2020	2021	2022
December	DIS	DIS	10	0	0	10
January	1	1	0	13	0	6

Note: DIS = discontinuous snow cover.

If Table 2 shows 0 cm for the month, it means that only natural snowfall occurred at Kosice Airport. One of the goals of this work was to determine the days when only industrial snowfall occurred at the airport and, in turn, identify its impact on the operation of the Kosice Airport.

The combination of natural and industrial snow is very difficult to identify and quantify. An equally important criterion for evaluating the economic impact of industrial snow on the operation of the airport in Kosice is the number of days with the occurrence of this phenomenon of anthropological origin, which is shown in Table 3.

Table 3

Number of days with industrial snowfall at Kosice Airport

Number of days with the occurrence of industrial snowfall at Kosice Airport						
Month	2017	2018	2019	2020	2021	2022
December	0	5	4	0	0	3
January	1	0	0	4	0	5

From 2017–2022, there were 22 days with industrial snowfall. According to Table 3, the frequency of these days is directly correlated with the number of days with the need for winter maintenance of the Kosice Airport to clean the runway and other traffic and service areas. The end of the first week of December 2019 and the second week of 2022 stand out from the more detailed data for December of the last five years. During this period, the investigated area was repeatedly under the effect of an anticyclone, which created suitable conditions for the formation of industrial snow. The differences in the measured data compared to the station in Mala Ida represented up to 6 centimeters of new snow cover [7].

Various equipment, such as snowplows, de-icers, snowblowers, and vehicles equipped with brushes, are used for the maintenance of snow-covered movement surfaces. The condition of the runway and other moving surfaces is checked by an inspection vehicle at the same time as a visual inspection of the condition. The results of this check are reported to the airport dispatching team, which decides on the need for intervention. After the air traffic control team gives permission to enter the runway, the winter maintenance vehicles exit, which prioritizes take-off and landing runways, then exits, taxiways, and, finally, stands.

4.2. Economic impacts

Several vehicles, such as Claas tractors, RS200 sweepers, snowblowers, Zetor tractors, and associated equipment, operate in the winter maintenance of Kosice Airport. One set of vehicles consists of a Claas tractor and an RS200 sweeper. Usually, two work sets are used at the same time, each with a working reach with an overlap of three meters. In case of a higher snow cover, a snow blower is also included in the set, which is otherwise only used to clean the edges of the moving surfaces. The consumption of specific machines is expressed in Table 4.

Table 4

Fuel consumption of various types of equipment used at Kosice Airport for cleaning

Type of technique	Fuel consumption
Claas tractor	14 liters per hour
Zetor tractor	9 liters per hour
Sweeper RS200	35 liters per hour
Snowblower	45 liters per hour

The technique uses diesel. Thanks to the information provided by the management of Kosice Airport, it was possible to determine how many liters of diesel are consumed by one run of winter maintenance vehicles. The composition of the vehicles during a standard intervention is as follows: two Claas tractors, two RS200 sweepers, and one snow blower. Together, they consume 143 liters of diesel per hour of work.

Table 5 provides the time required for one run for snow removal by winter maintenance vehicles. Table 5 shows us the time required to clean the movement surfaces.

Table 5

Time required to clean the movement surfaces

Movement surfaces	Time required for cleaning
Runway area and exits	60 minutes
Taxiways Alfa, Zulu, and stands 1, 2, 3, 4, 5, 6	40 minutes
Stands 7, 8, 9, 10	40 minutes
Taxiway Charlie	15 minutes
Stand 2	20 minutes

The equipment can work simultaneously, so the resulting time does not represent the total time needed to clean the moving surfaces but the time during which the machines will work and consume fuel. If there is ice on the moving surfaces, a Zetor tractor is sent into service along with a device for spraying the surfaces with a special liquid, the consumption of which is 3000 liters of liquid in 30 minutes. Its price is €1,800 per 1,000 kilograms and the specific density is 1,345 kg/m^3, which means that 4035 kilograms of liquid are consumed in 30 minutes of activity. These data are presented in Table 6.

Table 6

Time consumption, fuel, and spray consumption

Type of cleaning	Machine usage time	Fuel consumption	Consumption of spray liquid
Cleaning without spraying (2x Claas, 2x RS200, 1x Snowblower)	175 minutes	420 liters	0 liters
Spraying (1xZetor)	30 minutes	4.5 liters	3000 liters
Cleaning with spraying (2x Claas, 2x RS200, 1x Snow blower + 1x Zetor)	175 minutes cleaning, 30 minutes spraying	424.5 liters	3000 liters

This information makes it possible to calculate the price of one run of winter maintenance without spraying the surfaces with the liquid. Due to the variability of diesel prices in different years, the annual average price of diesel for 1 liter was used for the civil sector in the years 2017-2022 [12]. The resulting financial costs for fuel when removing snow or frost from airport areas in Kosice are interpreted in Table 7.

Note: CES = cleaning excluding spraying, “DS” = de-icing spray, “CIC” = cleaning including spraying.

If spraying for de-icing and anti-icing is required, the cost of spraying must also be added, which amounts to €7,263 for one cleaning cycle. The number of runs of the airport's winter maintenance equipment due to industrial snow depends on the number of days with the occurrence of this snow, which is expressed in Table 3.

Table 7

The price of fuel consumed for one operation of the winter maintenance at Kosice Airport

	Price in euros					
	2017	2018	2019	2020	2021	2022
Price of fuel	1.13€/l1	1.24€/l1	1.23€/l1	1.06€/l1	1.24€/l1	1.71€/l1
CES	474.60	520.80	516.60	445.20	520.80	718.20
DS	5.08	5.58	5.53	4.77	5.58	7.69
CIC	479.68	526.38	522.13	449.97	526.38	725.89

These facts answer Research Question 2 (What is the expected economic impact of industrial snow on the maintenance of airport areas at the selected airport?) The answer is as follows: assuming that only one run of the airport's winter maintenance was necessary on a given day, the total costs without spraying in five years amounted to approximately €12,671.40. With de-icing and anti-icing spraying, the costs of winter maintenance of the airport due to industrial snowfall rise to approximately €172,457.40 from 2017-2022, assuming one trip of the machine. Exact financial costs cannot be calculated without detailed reports of the work done, number of trips, time of use of machines, price of fuel, and other conditions that affect winter maintenance for each identified day of industrial snowfall.

Estimating the future costs of removing industrial snow from airport areas is problematic due to the irregular occurrence of days with favorable meteorological conditions for its formation. However, scientists are finding connections between global warming and disturbed weather patterns. Thus, it can be concluded that the costs associated with operation in the winter months generally increase [13]. Whether there is an increasing trend in the number of days with the occurrence of industrial snowfall is a topic for further scientific investigation.

5. DISCUSSION

Industrial snow creates increased costs for the maintenance of airport areas. However, other costs associated with removing snow from loading aircraft, which must undergo de-icing and anti-icing procedures before take-off, were not included. Another possible extra cost is the formation of frost on ultrasonic anemometers, which can cause a loss of data on wind parameters. Regarding how this feature affects the adjacent urban areas, this phenomenon takes on complex dimensions. This type of snow creates complications in transportation in affected villages and urban areas. The need to shovel snow from roads and sidewalks burdens the budget of individual municipalities. In addition to complications in traffic, there is a risk of pedestrians falling, with subsequent costs of medical healthcare and employees being out of work. Thus, this is a very complicated topic, and it is not clear who should bear the costs increased by cases of days with the occurrence of industrial snowfall.

The first option is the administration of legislation on compensation for the environmental burden of similar industrial centers. The problem is that industrial snowfall is not regular, and the affected area is usually downstream of the airflow. This would create a problem with the identification of costs for managing this externality and their subsequent compensation for the specific area.

With the current trend of building new industrial parks in Slovakia, possible environmental burdens on biospherically valuable areas, underground drinking water, arable land, and so on. should be assessed. A detailed study on the location of industrial parks was prepared by the Ministry of the Environment of the Slovak Republic [14]. It would also be appropriate to assess the fact of the future possible occurrence of industrial snow and its impact on the surroundings of future industrial parks. This preventive measure could prevent the occurrence of this externality. It is important to point out this issue, especially for possible future projects, as during the construction of a new airport or various industrial complexes, it is also necessary to consider this environmental load on the surroundings and assess the possible interactions between various projects and their economic impact on the maintenance of roads in an operable condition. This article presents a new perspective on the possible environmental, economic, and socio-economic impacts of building industrial parks in unsuitable areas.

The identification of days with industrial snow was the most significant problem during this scientific research. The researchers had to process three massive databases, such as the database of synoptic situations over the territory of Slovakia, a climate database measuring the amount and type of precipitation from two precipitation measuring stations, and an extensive dataset of satellite images of the Copernicus database. The algorithm used to gradually filter out days without a theoretical assumption for the formation of industrial snow, the absence of precipitation at the reference station, and the subsequent verification by satellite images (shown in Fig. 6) made it possible to make this part of the research much more efficient and applicable to other localities with industrial snow. This algorithm can be considered a novelty in the investigation of this phenomenon in the atmosphere of

anthropological origin. This study also contributes to the literature on the topic of industrial snow, which is unique and under-researched, especially in the context of air transport.

6. CONCLUSIONS

According to this study on industrial snow at Kosice Airport, the costs associated with eliminating the problem are not borne by the entity that creates the problem but by the entity affected by the problem. In the case of industrial snow, the origin of which is an industrial complex near the airport, the surroundings of the industrial area bear the consequences. The records of the Slovak Hydrometeorological Institute and satellite images show that industrial snowfall is a problem for the economic operation of Kosice Airport, which must deal with increased winter maintenance expenses.

With temperatures well below freezing in 2017, industrial snow formation was less likely to occur. Global warming, as an assumption concerning the occurrence of milder winters, which may be more favorable for the formation of this type of snow, may significantly restrict the operation of the airport during heavy industrial snowfall, which would have major economic impacts on the management of the airport.

Scientists and meteorologists warn that climate change is causing more extreme winter weather and that the impact of industrial snow and extreme weather will soon increase the cost of dealing with these weather events [14]. Therefore, environmental protection plays a significant role in aviation agencies' interests regarding climate change. Over the years, the national governments who cooperate under the Chicago Convention, also commonly referred to as “ICAO Member States,” have agreed to concentrate their aviation environmental collaboration on three core areas: climate change and aviation emissions, aircraft noise, and local air quality [15].

In addition to having direct environmental impacts on production and society, climate change can increase the operating costs of airports and air transport in general. Therefore, emphasis is placed on the creation of so-called “green airports,” which was the subject of an ICAO seminar in Athens on April 18-19, 2024. Recommendations on ways to reduce CO_2 emissions through recommendations for flight procedures during pitching or descending aircraft have been accepted [16], as International Civil Aviation Organization (ICAO) Secretary General Juan Carlos Salazar told global airline leaders at the IATA World Sustainability Symposium, recently held in Miami on 24-25 September 2024 [17].

However, industrial snow affects both the airport area and nearby urban areas in the airflow direction. Close urban areas and villages can also be identified in the satellite images of the Sentinel system. For the safety of residents and the flow of traffic, local governments must also deal with this negative externality. Industrial snow has a different chemical composition than natural snow, and therefore, it is possible to consider the environmental load, which was not considered during the creation of similar industrial complexes. The high chimneys in the industrial complex near the airport were supposed to ensure greater dispersion of dispersive substances. In the case of industrial snowfall, these chemical substances are concentrated in the area defined by industrial snowfall. Similarly, other areas with a concentration of industry can be affected.

The industrial complex such as U.S. Steel brings massive economic benefits for the Slovak national GNP and, due to its technological need for continuous operation, will produce industrial snow in the future as well. A possible solution is the introduction of new technologies in the production processes, which may reduce the costs of dealing with this phenomenon for Kosice Airport and surrounding areas while reducing other environmental impacts. Changing the legislation to impose the obligation to implement these precautions could limit the environmental and economic impacts of industrial snow, along with comprehensive efforts to limit human impacts on climate change, which support the frequency of these events.

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