Original article

An assessment of the aviation industry's impact on air pollution from its emissions: worldwide and the Ukraine

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ABSTRACT

CO₂ emissions are one of the main causes of the global problem of climate change, the solution to which requires the efforts of every country. One of the main polluters is the energy sector, which includes transport. Despite the seemingly small share of aviation in emissions, its role as a polluter and CO₂ emitter cannot be underestimated due to calculated specific rate and a number of factors that were researched. The purpose of this study was to analyze the aviation share in the polluters' structure and to study if Covid-19 restrictions influence on it, to investigate the share of CO₂ emissions from air transport in Ukraine and to assess its impact, to forecast CO₂ emissions in Ukraine by 2030 and to build scenarios of possible changes in the direction of decarbonization in the aviation industry. Analysis and synthesis, comparison, methods of pairwise regression and modelling scenarios were used for solving these tasks. The results show that the aviation industry could achieve the carbon reduction targets only by applying different types of carbon pricing with conducting the research and development in the sphere. The last significant improvement in aircraft design technologies and flight operations was achieved almost 60 years ago. Economic incentives at the international and local scales should be used to stimulate aviation manufacturers to invest significant money on R&D to find stable solutions to achieve decarbonization. Development of Ukrainian aviation industry should not stand aside from global trends and must meet modern challenges, including environmental issues. The created scenarios show solutions to achieve decarbonization goals that align with EU best practices.

KEY WORDS: aviation industry, transport, decarbonization, CO₂ emissions, air pollution

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1. Introduction

Since the second half of the 18th century, mankind has lived through industrial revolutions. In the 19th century, the development of Industry 3.0 caused a gradual increase in carbon dioxide (CO₂) emissions resulting from the combustion of a growing quantity of fossil fuels, particularly coal. However, it was not until the second half of the 20th century that CO₂ emissions increased sharply, followed by an increase in average global temperatures. The world carbon emissions from fossil fuel burning was at a level of 2,000 million tons in the period from 1880 to 1955 (75 years), for the next 63 years it increased 5 times and reached

almost 10,000 million tons. The development of the world's economies in the post-industrial period has led to an exponential increase in climate change and the negative consequences of global environmental problems for mankind.

The International Energy Agency (IEA, 2020) looks at CO₂ emissions from energy production alone – in 2018 it reported 33.5 billion tonnes of energy-related CO₂ and transport accounted for 8 billion/33.5 billion = 24% of energy-related emissions. According to Intergovernmental Panel on Climate Change (IPCC, 2014), the largest polluters in the transport sector are road transport (11.9%) and aviation (1.9%). Despite the seemingly small share of aviation, its role as a polluter and CO₂

emitter cannot be underestimated due to a number of factors that will be discussed in this article.

2. Methods

This article assesses the impact of the aviation industry on air pollution by its emissions and the research aims were: 1) to analyze the role of transport as one of main polluters in the context of the problem of global climate change; 2) to explore the influence of Covid-19 quarantine measures on the emissions levels and on postponing the solution to the global problem; 3) to allocate separately the share of air transport in general CO₂ emissions; 4) to study the achievements of the aviation industry in matters of decarbonization; 5) to analyze the world and Ukrainian experiences of climate change and emission reduction at the legislative level; 6) to provide scenarios for the decarbonization of the Ukrainian aviation industry, by considering certain sectoral and general strategies adopted at the state level, as well as its international commitments. The authors used a comparative method in their study of indicators for different years and different researchers, analysis and synthesis in the study of certain aspects of the problem and generalization of the results, and used pairwise regression and scenarios for modelling.

3. Materials

The issues of global warming and climate change caused by anthropogenic greenhouse gas emissions (GHG), as well as the harmful impact of air pollutants on human health, have been becoming increasingly important over the past few decades. CO₂ comprises 74% of GHG. Most CO₂ emissions (89%) as was shown by [GE & FRIEDRICH \(2020\)](#) are from the use of fossil fuels, especially for generation of electricity and heat, transportation, manufacturing and consumption. The future global warming effect will depend on the concentrations of GHG in the atmosphere and the natural climate variability ([PIŁATOWSKA & WŁODARCZYK, 2018](#)). The importance of climate change, which is largely due to rising CO₂ emissions, has been recognized not only internationally but globally, by all countries committing themselves to sustainable development.

The Paris Agreement, which should replace the Kyoto Protocol, is an agreement under the United Nations Framework Convention on Climate Change (UNFCCC) to regulate measures to reduce CO₂ emissions from 2020. The Paris Climate Agreement obliges all states, regardless of their level of economic development, to take responsibility for reducing harmful emissions into the atmosphere.

After signing, each country had to make nationally determined contributions to achieve two key goals: to reduce GHG to zero during the second half of the 21st century, and to prevent global average temperatures from rising by more than 2°C (possibly by 1.5°C) relative to pre-industrial indicators.

Moreover, the Chilean Presidency of the 25th session of the Conference of the Parties (COP 25) to the UNFCCC announced a renewed Climate Ambition Alliance, including 73 UNFCCC parties, 14 regions, 398 cities, 768 businesses and 16 investors working to achieve net-zero CO₂ emissions by 2050.

Ukraine ratified the Paris Agreement in 2016. Due to this on July 18th, 2018, the Government of Ukraine adopted the Low Emission Development Strategy of Ukraine until 2050 ([UKRAINE 2050, 2018](#)). This document provides for the reduction of emissions, an increase in the absorption of GHG, and the introduction of environmentally friendly production using "green" technologies in all sectors of the economy. Ukraine defines ambitious, but at the same time substantiated and fair targets with regard to the level of GHG emissions according to the Paris Agreement requirements ([UNFCCC, 2015](#)). It will not exceed 60% of 1990 GHG emissions level in 2030, in the implementation period 1 January 2021 – 31 December 2030. Ukraine will participate actively in the development of existing international market mechanisms and the implementation of new ones. The declared GHG emissions level does not account for the participation of Ukraine in international market mechanisms ([INDC OF UKRAINE, 2015](#)).

Currently we shouldn't ignore the impact of the Covid-19 crisis, which is likely to have led to the largest drop in energy-related CO₂ emissions since World War II. Emissions from transport account for the largest share of the global decrease. Those from surface transport, such as car journeys, fell by approximately half at the peak of the Covid-19 lockdowns, by December 2020, emissions from road transport and aviation were still below their 2019 levels, by approximately 10% and 40%, respectively, due to continuing restrictions as was shown by [FRIEDLINGSTEIN \(2020\)](#).

This drop not only occurred at a huge human cost but will also be temporary unless governments make sustained structural efforts to reduce CO₂ emissions in the long term. Therefore, despite the sharp decline in CO₂ emissions during the quarantine restrictions for the Covid-19 pandemic, we see a clear trend towards a return to previous years' emissions, and accordingly the task of complying with the Paris Agreement has not lost relevance.

IEA has called for governments to use the opportunity of the post-Covid-19 economic recovery spending to accelerate clean energy transitions. These near-term investments and spending decisions will have long-term impacts on emissions, and present an opportunity to secure a more sustainable energy future. The measures needed to achieve a sustainable recovery require sound policy frameworks, whether these be to support deployment of renewable energy, modernize and extend the electricity grid, reduce methane emissions or reform fossil fuel subsidies.

Therefore, the negative impact of CO₂ emissions on global climate change is one of humanity's global challenges and is being addressed at the level of international cooperation and dialogue by committing to consistently and irreversibly reducing emissions to zero by 2050. At the level of each country, it is possible to implement these commitments by working with carbon pricing, which is an instrument that captures the external costs of GHG emissions and ties them to their sources through a price, usually in the form of a price on the CO₂ emitted. Carbon pricing can take different forms and shapes ([CARBON PRICING DASHBOARD](#), n.d.), such as: an emissions trading system (ETS, which is used in Canada, Mexico, EU, Kazakhstan, Australia), a carbon tax (Argentina, South Africa, Canada, Spain, France, Ukraine), an offset mechanism (Taiwanese Environmental Protection Administration, as shown by [TSE-LUN CHENAB ET AL.](#), 2019), RBCF (The Green Corridor in Columbia as shown in [WORLD BANK GROUPE](#), 2017), internal carbon pricing (Yale's campus programme, as shown by [GILLINGHAM ET AL.](#), 2017).

Ukraine has already implemented a carbon tax and has ETS under consideration (the government has announced its intention to work towards its implementation). Thus, the rate of environmental tax for CO₂ emissions from stationary sources of pollution in 2019 had raised to 10 UAH per ton, from 0.41 UAH in 2018. That is, its size increased by 24.4 times. If the annual amount of CO₂ emissions of the business entity exceeds 500 tons per year, then in accordance with paragraph 250.2 of Art. 250 of the Tax Code of Ukraine, it is obliged to register as a taxpayer in the tax (reporting) period when the excess occurred. It must also make and submit the tax report, to charge and pay the ecological tax for the tax period in which there was such an excess.

[DRAFT LAW](#) #4101 from the 15th of September 2020 on Amendments to the Tax Code of Ukraine and Other Laws of Ukraine on Ensuring a Balance of Budget Revenues will provide a gradual increase in the rate of environmental tax for CO₂ emissions

from January 1, 2021 from UAH 10.00 per ton to UAH 30 per ton in 2024 (so, an annual increase of UAH 5 per ton).

Summarizing, whichever way countries choose to estimate carbon, it will increase the cost of the final product (the cost of paying the carbon tax or buying quotas or investing in low-carbon projects will initially be transferred to the finished product). Accordingly, the competition will increase not only between the producers of a particular product, but also between entire industries (eco-efficient and inefficient) and supply chains.

Historical data for GHG Emissions, provided by Climate Watch ([WORLD RESOURCE INSTITUTE'S CAIT CLIMATE DATA EXPLORER](#), 2014), shows that energy consumption is by far the biggest source of human caused GHG, responsible for 73% worldwide. The energy sector includes transportation, electricity and heat, buildings, manufacturing and construction and other fuel combustion industries.

[MENGPIN & JOHANNES](#) (2020) previously analyzed that within the energy sector transport emitted 7.9 GtCO₂e in 2016, or 15% of the total energy related emissions. [ENERGY TECHNOLOGY PERSPECTIVES](#) (2020) reported that transport plays a significant role, including rail, aviation, shipping, buses, trucks, cars, even 2/3 wheelers, which emit together almost the same volume of CO₂ as the steel, cement and chemical industries.

As was shown previously, the growth of competition between entire industries in the context of meeting the goals of sustainable development and considering environmental factors is still important and actual, but there is also intra-industry competition, for example, between different modes of transport that can be combined in different ways to build supply chains.

Since the entire transport sector accounts for 21% of total emissions ([RITCHIE](#), 2020), and road transport accounts for three-quarters of transport emissions, road transport thus accounts for 15% of total CO₂ emissions. From this research aviation accounts for only 11.6% of transport emissions (while it often gets the most attention in discussions on action against climate change). It emits just under one billion tons of CO₂ each year – around 2.5% of total global emissions.

Aviation emissions are growing in absolute terms, maintaining a steady trend towards annual growth (excluding quarantine measures). Moreover, when we analyze the specific indicators - the amount of CO₂ emissions per ton-kilometre of cargo transported by different modes of transport (Table 1) – it is clear, that aviation is the main polluter among all other modes of transport.

Table 1. CO₂ emissions per ton-kilometre by different modes of transport

Transport	gCO ₂ / ton-kilometre (according to specific research articles)				
	Kraemer, 2007	Watt, 2008	Guidelines, 2011	STREAM, 2017	MSC, 2019
Road transport	92	51-91	62	102	45
Rail transport	23	19-41	22	10-18	18
Barge transport	-	-	31	21-38	-
Short sea	14	10-15	16	15	-
Pipelines	-	-	5	-	-
Airfreight	607	673-867	602	-	560

Each of these studies (Table 1) confirms that air transport in specific terms is ten times greater than all other modes of transport in terms of its CO₂ emissions. That is, with the increase in the volume of cargo transportation by air, the level of emissions will increase. The authors proposed an approach in which, due to the lack of common unified statistics on CO₂ emissions by different modes of transport, an analysis of global data of leading researchers on this topic was performed. A structured, detailed study of this research deserves a separate publication, and in accordance with the objectives of this article, the authors pay special attention to highlighting the "trend" of fundamentally higher CO₂ emissions when transporting cargo by air, given that air cargo is one of the most important and valuable in the global logistics system.

Thus, air transport, which is currently the most expensive and not environmentally friendly in terms of relative indicators, will become more expensive, given the specific emissions and the use of carbon pricing to achieve zero carbon. That's why retention of competitive advantages for the aviation industry, taking into account the environmental factor, has to consider a number of features.

Firstly, aviation CO₂ emissions from domestic flights are counted in a country's emission accounts whereas international flights are not, instead they are counted in their own category: 'bunker fuels'. As was claimed by GRAVER ET AL., (2019), policymakers cannot determine the precise amount of carbon emissions associated with flights departing from individual countries, nor can they distinguish the proportion of emissions from passenger and freight and all freight operations, or from domestic and international flights. So, the issue of registration, monitoring and control of CO₂ emissions from international flights requires cooperation at the level of governments and international organizations, which in turn requires a long term duration to negotiate, find a common solution, develop a methodology and implement tools.

Secondly, aircraft significantly pollute both the areas around airports and across their routes of flight.

The operations of aircraft are usually divided into two main parts (RYPDAL, 2020): 1) The Landing/Take-off (LTO) cycle which includes all activities near the airport that take place below an altitude of 1000 m. This therefore includes taxiing-in and out, take-off, climb-out, and approach landing, and 2) Cruise which here is defined as all activities that take place at altitudes above 1000 m. No upper limit of altitude is given. Cruise, in the inventory methodology, includes climb to cruise altitude, cruise, and descent from cruise altitudes.

During the take-off of the aircraft, approximately 50% of emissions in the form of micro particles, including many heavy metals, are immediately dispersed in the areas adjacent to the airport. The rest is in the air for several hours in the form of aerosols, and then also settles on the ground.

On the other hand, CO₂ emissions produced when cruising are generally emitted into the high atmosphere, and this is thought to have a greater greenhouse effect than CO₂ released at sea level. The emissions are therefore adjusted by multiplication by a factor of 2.00 to give 180 kg CO₂ equivalent per hour.

Thus, the emissions from aviation should be divided into two types depending on the period of their occurrence (during LTO and cruise time), each of which is characterized by factors that increase the negative impact on the environment. Emissions of up to 1000 metres (LTO cycle) are harmful to the atmosphere and soil in the areas adjacent to the airport (thus they must be considered when designing the location of airports near cities). Emissions produced at a cruise height altitude due to their direct presence in the upper atmosphere have a greater destructive force for the ozone layer.

Thirdly, the lack of development and implemented modern decarbonization technologies in aviation. As shown by OVERTON (2019), a significant improvement in the efficiency of aircraft and flight operations has been achieved over the last 60 years, while automobiles, production of electricity, and the industrial and agricultural sectors have each

made serious technological achievements to decrease their climate change impacts.

We can make the same conclusions from *ENERGY TECHNOLOGY PERSPECTIVE* (2020) that outlines the pathways for the different elements of the transport sector in the optimistic scenario for sustainable development (Fig. 1). The electrification- and hydrogen- technologies provide the opportunity for some modes of transport to decarbonize within decades (motorcycles by 2040; rail by 2050; small

trucks by 2060). Other transport sectors, including aviation, will be much more difficult to decarbonize.

Nowadays, scientists (*CECERE ET AL., 2014; FULTON, 2015*) are researching the potential for hydrogen as a fuel, or battery electricity, to run planes, ships and large trucks but this is limited by the range and power required. The size and weight of batteries or hydrogen fuel tanks would be much larger and heavier than current combustion engines.

Fig. 1. CO₂ world emitters estimated input 2000-2070 (Source: Energy Technology Perspectives, 2020)

At the same time, not only scientists but the world's leading aircraft companies are investing in research and development and offering advanced solutions to decrease their emissions. Boeing has developed the 777X craft – which is its newest family of twin-aisle airplanes, the largest and most fuel-efficient jet of its kind. With an optimized wingspan of more than 72 metres – longer than today's 777 – and a simple folding wingtip, the 777X delivers greater efficiency, significant fuel savings and complete airport compatibility. Smart design and innovative new technologies on the 777X, including its fourth-generation carbon-fibre composite wing, all new engines and natural laminar flow nacelles, together will help the airplane to achieve 10% lower fuel use and emissions and 10% lower operating costs to comparable aircraft in the market. Boeing began the flight-testing phase of its rigorous test program in January 2020 according to their “Sustainability and Innovation for The Future (2020). Introducing the Boeing ecoDemonstrator Program” (*SUSTAINABILITY..., 2020*).

As shown previously, the decarbonization of aviation as a transport sub-sector will require long-term planning and government support, as claimed in *ENERGY TECHNOLOGY PERSPECTIVES* (2020). R&D of alternative powertrains and fuels is needed

to reduce costs and improve performance, and measures to develop associated infrastructure. Moreover, more than 60% of the emissions reductions by 2070 will come from technologies that are not commercially available today according to *ENERGY TECHNOLOGY PERSPECTIVES* (2020).

Ukraine has the potential of the aviation industry which allows it to increase the development and production of aviation equipment, including regional passenger and transport aircraft, aircraft engines and units, on-board electronic equipment focused on the use of satellite communication systems, navigation and surveillance, helicopters and small aircraft, in particular unmanned aircraft. Therefore, when considering the prospects for the development of the country's aviation industry, it is necessary to consider all environmental factors.

According to the Strategic Environmental Assessment Report on Project of Aviation Transport Strategy of Ukraine for the period up to 2030, emissions in the transport category in 2017 amounted to 35.0 million tons of CO₂-eq. Thus CO₂ emissions had decreased by 68.12% compared to 1990 (109,8 millions of tons of CO₂-eq.) (Table 2). But since 2017 there has been a significant increase in emissions, the largest contribution of which belongs to automobile transport.

According to the data in Table 2, CO₂ emissions from air transport in Ukraine are many times lower than for other modes of transport (123 times less than road, 2.5 times less than rail, water is half as low). However, these figures are not explained by the use of the latest technologies and approaches, but by the correspondingly low volume of air traffic compared to other modes of transport as shown in Table 3.

Despite the small share of aviation in the cargo turnover of the country, Ukraine has been following global trends and gradually harmonizing its legislation with the rest of the world in the field of environmental protection and reducing its harmful impact. Ukraine has adopted a strategy for the revival of its aircraft construction up to 2030,

the purpose of which is to restore the stable development of the aircraft industry and to create conditions for the formation, by 2030, for the profitable and high-tech production of aircraft, which will gradually increase the development and sale of new competitive models of planes, upgraded passenger and transport aircraft, helicopters, small aircraft, unmanned aerial vehicles, and other aircraft. In addition, Ukraine decided to voluntarily participate in CORSIA, a global sectoral market measure designed to offset CO₂ emissions from international civil aviation, in order to stabilize such emissions from 2020. CORSIA is implemented in stages, starting with the participation of states on a voluntary basis, followed by the participation of all states, except the liberated ones, and starting from 2030.

Table 2. CO₂ emissions from transport between 1990-2018 in Ukraine, millions of tons of CO₂-eq.
(Source: State statistics Service of Ukraine)

Categories	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018
Transport, total	109.8	48.6	34.4	39	40	40.1	39.2	39.4	35.8	31.1	32.9	35	175
Civil aviation	0.7	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	1
Automobile	59.7	20.4	15.6	21.9	28.7	28.2	29	28.8	26.6	22.8	24	24.7	123.5
Railway	3.8	1.3	1.4	0.9	0.5	0.5	0.4	0.4	0.5	0.4	0.5	0.5	2.5
Water	3.3	0.4	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5
Other modes	42.3	26.4	17.1	15.8	10.5	11.1	9.6	10	8.6	7.7	8.2	9.5	47.5

Table 3. Ukrainian cargo turnover for 2018-2019 by modes of transport

Transport type	2018		2019	
	Cargo turnover, mln. t-km	% of total	Cargo turnover, mln. t-km	% of total
Rail	186344.1	56.15	181844.7	53.65
Road	42569.5	12.83	48906.3	14.43
Water	3363.0	1.02	3387.8	0.99
Pipeline	99239.9	29.90	104528.1	30.84
Aviation	339.7	0.10	295.6	0.09
Total	331856.2	100	338962.5	100

Analysis of the currently adopted National Economic Strategy 2030 as well as the National Transport Strategy shows a lack of specifically defined targets for emission reduction from aviation.

In order to present scenarios for the development of the aviation industry we forecast aviation CO₂ emissions by 2030, by considering certain sectoral and general strategies adopted at the state level, as well as international commitments made by Ukraine under international instruments to combat global climate change. For this purpose, we build a forecast for freight and passenger traffic, based on official statistics, and calculate the estimated CO₂ emissions, using the methods of pairwise regression and scenarios. We introduce the following limitations and assumptions to:

1) focus on trends and tendencies, not on absolute values, as statistics are not complete and exhaustive (Ukraine only recently started work on the formation of a register of pollutants), as well as possible duplication of indicators (as some cargo is transported on passenger flights);

2) calculate the future CO₂ emissions from aviation using normative emissions per ton-kilometre (607 gr/tkm) and passenger-kilometre (117,5 gr/pass.km);

3) build forecasts of cargo and passenger flows on the basis of statistics from 2014, after the signing of Ukraine's cooperation agreement with the EU and the beginning of the armed aggression of the Russian Federation, which led to the structural and quantitative values of these indicators;

4) assume that the negative impact of Covid-19 on air freight did not occur, so the forecast could not be adjusted (Fig. 2);

5) consider the impact of the Covid-19 factor on passenger traffic in the model, we introduce adjustments with the assumption that the gradual restoration of passenger traffic will occur in 2024 and will develop according to the trend of 2015-2019 (Fig. 3).

Results for the forecast of total aviation CO₂ emissions in Ukraine, provided in Table 4, are assumed to be the 'business as usual' scenario (BAU Scenario). Thus, the projected level of CO₂ emissions from the aviation industry in 2030 will be 7.29 million tons. We calculated the projected values of CO₂ emissions in 2030, using the measures for achieving aviation decarbonization, proposed in [DESTINATION 2050 REPORT](#) (2021) (Table 5).

Demand impacts, shown in Table 5, are the consequence of higher costs associated with the use of sustainable aviation fuels and economic measures, which are modelled to increase ticket prices, and thereby suppress demand.

To model aviation decarbonization scenarios for Ukraine we used the results of authors' forecasts of the BAU Scenario (Table 5) and apply decarbonization methods provided in the [DESTINATION 2050](#) (2021) with a correction on forecasting terms, were analyzed and calculated only those parameters, the result of which is expected to be introduced by 2030 relative to the BAU scenario (as the forecast data on aviation emissions were calculated by 2030). The modeling results are shown in Fig. 4.

Fig. 2. Forecast for air freight transportation for Ukraine

Fig. 3. Forecast for air passenger transportation for Ukraine

Table 4. Turnover and CO₂ emissions forecast for Ukraine to 2030

Year	Cargo		Passenger turnover		Total aviation
	Turnover, mln.tkm	CO ₂ emissions, mln.t	Turnover, mln. pass.km	CO ₂ emissions, mln.t	CO ₂ emissions, mln.t
2015	210,90	0,13	11362,40	1,34	1,46
2016	225,90	0,14	15525,10	1,82	1,96
2017	272,70	0,17	20345,70	2,39	2,56
2018	339,70	0,21	25889,30	3,04	3,25
2019	295,60	0,18	30241,80	3,55	3,73
2020	316,20	0,19	10106,90	1,19	1,38
2021	356,55	0,22	15525,10	1,82	2,04
2022	379,48	0,23	20345,70	2,39	2,62
2023	402,41	0,24	25889,30	3,04	3,29
2024	425,34	0,26	30297,50	3,56	3,82
2025	448,28	0,27	35109,80	4,13	4,40
2026	471,21	0,29	39922,10	4,69	4,98
2027	494,14	0,30	44734,40	5,26	5,56
2028	517,07	0,31	49546,70	5,82	6,14
2029	540,00	0,33	54359,00	6,39	6,71
2030	562,93	0,34	59171,30	6,95	7,29

Table 5. Reductions in CO₂ emissions for Ukraine, up to 2030, compared to the BAU scenario

Applied measures	Change in CO ₂ emissions in 2030 compared to the BAU scenario		Level of CO ₂ emissions in 2030
	%	mln.t CO ₂	mln.t
Sustainable aviation fuels-induced demand impacts	2	0,1459	7,1484
Economic measures-induced demand impacts	1	0,0729	7,2214
Total reduction in CO ₂ emissions due to demand impacts	3	0,2188	7,0755
Improvements in aircraft and engine technology, kerosene-powered aircraft	7	0,5106	6,7837
Improvements in ATM and aircraft operations	5	0,3647	6,9296
Sustainable aviation fuels	3	0,2188	7,0755
Economic measures	27	1,9695	5,3249
Total reductions in CO ₂ emissions due to sustainability measures	42	3,0636	4,2307
Total combined reductions in CO ₂ emissions	45	3,2824	4,0119

Fig. 4. Modelled CO₂ emission data according to scenarios provided for Ukraine

As shown in Fig. 4, the BAU scenario, i.e. the complete absence of any measures to decarbonize the aviation industry, will lead to the highest level of CO₂ emissions. This, in turn, significantly reduces the competitiveness of the Ukrainian aviation industry in the world market, as the requirement for meeting environmental friendly targets of transport leads to higher environmental payments and, consequently, higher prices for transportation (emissions reduction due to demand impacts is minor).

The demand impact scenario shows a small reduction in CO₂ emissions, caused by usage of sustainable aviation fuels and implemented economic measures. The sustainable measures scenario provides significant changes in achieving decarbonization of the aviation industry due to the application of the following actions:

1) Improvements in aircraft and engine technology leading to a reduction as a result of a newer generation of aircraft entering the market.

2) Improvements in ATM and aircraft operations are estimated to be able to make an important contribution to reducing aviation's CO₂ emissions in the short to medium term. This direction envisages a 1.5% reduction in CO₂ emissions from improved flight planning by 2025 and 1% from flight management system updates in the period from 2025 to 2035.

3) Use of sustainable aviation fuels. Aviation uses more fuel than all other industries combined. Aviation is a key factor in the global economy, but this growing industry accounts for about 2-3% of global CO₂ emissions. The level of uptake of sustainable aviation fuels is still relatively limited by 2030, mainly due to its expected availability.

4) Economic measures assign a price to greenhouse gas emissions, ensuring that producers take the climate costs of their emissions explicitly into account in their business decisions. The prices of allowances and carbon credits will increase over time, as the most cost-effective measures are taken first. This will eventually lead to a price whereby carbon removal projects become economically attractive to investors.

The combined emission reductions scenario was based on the assumption that both the demand impact factors and sustainable measures would be applied simultaneously and would give the best result in terms of aviation decarbonization.

4. Discussion and conclusions

1) Transport is a part of the largest polluter in terms of CO₂ emissions – the energy sector. To decrease emissions by reduction of transport use

(as can be done in the energy sector by energy savings) is impractical, because the current market model requires the permanent engagement of the transport sector across both global and local supply chains. Thus, we need to look for new technologies and approaches, especially considering that a significant improvement in the efficiency of aircraft and flight operations has been achieved over the last 60 years, while other sectors such as automobiles, electricity production, industrial and agricultural, have each made significant green technological achievements.

2) The drop in air emissions, caused by Covid-19 restriction measures is temporary, as clear trend towards a return to previous years' emissions were shown. That's why the task of complying with the Paris Agreement has not lost relevance. In any case, the impact of a sharp reduction in air traffic in connection with the pandemic should be investigated when official statistics for that period appear.

3) The volume of emissions from air transport as part of the global volume is from 2.5 to 3% per year. However, the specific weight per 1 ton-kilometre is 560-867 gCO₂, which is ten times higher than for road transport, which is recognized as the main transport polluter (almost 2/3 of transport emissions come from road vehicles). This proves the global importance of reducing the harmful effects on the environment primarily from aviation and confirms the world trend in transport policy which is aimed at encouraging the use of rail and water transport which has fewer emissions.

4) It is unlikely that the zero targets for CO₂ emissions will be achieved by 2050 by the general transport sector, and the aviation sector in particular, by gradually increasing different types of carbon pricing (Emissions Trading System, Carbon Tax, Offset Mechanism, RBCF, Internal carbon pricing). The second important direction is R&D in the aviation industry, aimed at complete decarbonization of the sector. As more than 60% of the reduction in emissions from aviation by 2070 will come from technologies that are not commercially available today, it's reasonable to promote effective public-private partnerships between the main players in the business and the world's governments. The most appropriate forms of such collaboration should be explored separately by taking into account the results obtained from this study.

5) Ukraine is an active player in international policy against climate change (joint involvement in the CORSIA project, ratified the Paris Agreement, adopted a Low Emission Development Strategy until 2050 etc.). In terms of carbon pricing, Ukraine has already adopted a carbon tax to stimulate

industries to move to low-carbon technologies, and an ETS tool is under consideration. These measures will lead to an increase in the cost of transportation, but it is a part of Ukraine's commitments to international conventions and its Associative Agreement with the European Union. The problem of reducing emissions will become more and more relevant in the future, given the significant impact of aviation on climate change. Therefore, it is important to study separately the issues of the harmonious development of the aviation industry in Ukraine to ensure competitive advantages in the context of the decarbonization goals of the industry.

6) The results of the simulated scenarios for the level of emissions of CO₂ into the atmosphere from the aviation industry clearly demonstrate the need to plan, organize and implement decarbonization measures. First of all, due to the fact, that such projects in aviation are not only expensive, but also long-term with delayed results, i.e. to achieve zero emissions by 2050 it is necessary to start implementing measures in the very near future. Secondly, ignoring global trends to reduce emissions will lead to a deterioration in the competitiveness of the industry in the global market. Therefore, it is advisable to further study the priority of investing in decarbonization measures, including infrastructure projects.

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