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Compensation and reduction of carbon dioxide emissions in international aviation

Abstract: Sustainable development, i.e. the coherence of economic and social progress with environmental protection, are goals that must be achieved in order to prevent global environmental degradation. Reducing the emission of harmful compounds and noise is a current problem raised in various sectors of the economy. Through the ICAO International Civil Aviation Organization, the aviation sector worldwide is committed to meeting its commitments to reduce air emissions from aircraft. Despite the dynamic development of the unmanned aerial vehicle sector, manned aviation remains the leading means of passenger and cargo transport in civil aviation. In view of the emission of compounds having a negative impact on the environment by airplanes, it was deemed necessary at the global level to take steps aimed at a real limitation of the functioning of aviation, which is destructive to the nature.

The International Civil Aviation Organization (ICAO) has developed a program that introduces a new approach to reducing negative effects on the environment called CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation). The article presents the principles of its operation and implementation, as well as the project phases. The practical impact of the CORSIA program on aircraft operators and examples of costs for operators related to the implementation of the project were indicated. The aspect of mutual coexistence for the CORSIA program and the EU CO2 emissions trading system (EU-ETS) was also raised. European Emissions Trading Scheme - also known as the "Community carbon market" or the ETS. It is the first, by 2017, the largest and currently the largest, after China, CO□ emissions trading system in the world.

Keywords: CORSIA, EU ETS, CO2; Emission; Civil aviation; Sustainable development of aviation

In 2016, aviation was responsible for 3.6% of total EU-28 GHG emissions and 13.4% of transport emissions, making aviation the second most important source of transport GHG emissions after road traffic. Greenhouse gas emissions from aviation in the EU have more than doubled since 1990 when they accounted for 1.4% of total emissions. As emissions from sources other than transport decrease, aviation emissions become more and more significant. European aviation was responsible for 20% of global CO2 emissions in 2015. Aviation is also an important source of air pollution, especially nitrogen oxides (NOX) and particulate matter (PM). In 2015, it was responsible for 14% of all NOX emissions from transport in the EU and 7% of total NOX emissions in the EU. In absolute terms, NOx emissions from aviation have doubled since 1990, and their relative share has quadrupled as other sectors of the economy have achieved significant reductions. Carbon monoxide (CO) and sulfur oxides (SOX) emissions from aviation have also increased since 1990, while emissions from most other modes of transport have decreased.

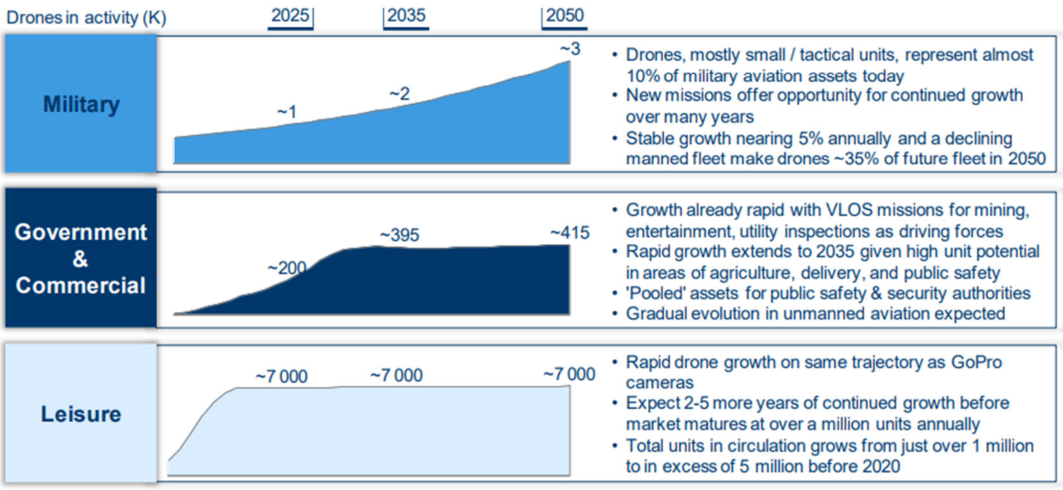
The use of sustainable aviation fuel is currently minimal and is likely to remain limited in the short term. Sustainable aviation fuels can make a significant contribution to mitigating the current and expected future environmental impact of aviation. There is interest in 'electro fuels' as potentially emission-free alternative fuels. However, several research and demonstration projects in this area have been discontinued due to high production costs and the long time required for the widespread use of these solutions. Fuels must be certified to be used on commercial flights. The EU has the potential to increase its aviation biofuel production capacity, but take-up by airlines remains limited due to various factors, including cost over conventional aviation fuel and low priority in most national bioenergy policies. Scheduled flights using aviation biofuel blends are already operated from several airports in the EU, albeit with a very low percentage of total incremental use of this type of fuel. Recent environmental policy changes and industry initiatives aim to have a positive impact on the uptake of sustainable aviation fuels in Europe.

Over the last quarter of a century, international passenger aviation has tripled in size and long-term projections for the future predict a similar level of growth for the next 25 years. The development of aviation brings significant benefits to both national and European and global economies, which at the same time entails correspondingly greater negative social and environmental effects.

According to the provisions, from January 1, 2019, all aircraft operators will be required to monitor CO2 emissions from international flights.

1. Requirements for monitoring CO2 emissions 2018-2020
Source: [5]

An alternative to manned aviation generating noise and pollution is unmanned aerial vehicles (drones). It is indicated that the UAV sector is the most dynamically developing sector in aviation in the last decade. An important factor in this state of affairs is the widespread access to drones for a wide range of society and their affordability. UAV use for both commercial and recreational purposes continues to grow. It is estimated that by 2035 the European drone market will generate revenue of €10 billion per year.



2. Total size of the drone fleet (forecast until 2050)
Source: [4]

Forecasts of the Polish Ministry of Infrastructure also indicate a successive increase in the size of the unmanned aerial vehicle market and its importance for the national economy and real impact on shaping Poland's position as a dynamically developing European center in drone technologies.

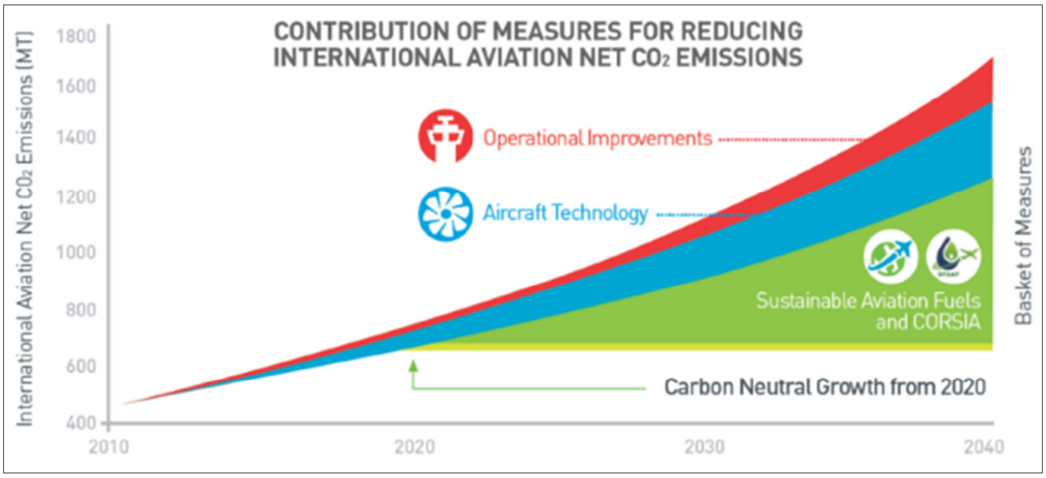
3. Forecasts for the drone market in Poland - The value of the drone market broken down into various industries based on data from the Ministry of Infrastructure
Source: [8]

Despite the significant reduction of the impact of adverse effects on the natural environment by replacing manned aircraft with unmanned aviation and the rapid development of the drone sector, it is not expected to equal the share of both types of aircraft in air operations. Due to the socially reported level of demand for air traffic, the transport capacity of manned aircraft and the limitations of drones, a sustainable aviation policy is necessary, in which the priority is to reduce the negative effects on the environment.

The currently dominant discourse on the ecological modernization of aviation, with an emphasis on technology and responsible environmental management, is the background for maintaining the economic benefits of the aviation sector. Given the requirements to reduce the nuisance of aircraft, the international CORSIA program, i.e. the Carbon Compensation and Reduction Program for International Aviation, was developed.

ICAO has agreed on two aspirational goals for the international aviation sector (Fig. **3**):

- 2% annual improvement in fuel efficiency by 2050
- carbon neutral growth from 2020 (CNG 2020)
- ICAO has identified the following areas that can contribute:
- to achieve global aspirational goals:
- technology and standards related to aircraft
- improved air traffic management and operational improvements
- development and implementation of sustainable aviation fuel
- CORSIA.



4. Contribution of measures to reduce NET CO2 emissions in international aviation
Source: [7]

The new CORSIA emissions reduction methodology is a global system introduced by ICAO. CORSIA's goal is to help address the annual increase in total CO2 emissions from international civil aviation.

The first edition of ICAO Annex 16, Volume IV, which contains CORSIA, was adopted by the ICAO Council on June 27, 2018, and entered into force on January 1, 2019, as specified in the Adoption Resolution. The main objective of the mechanism is to maintain a zero increase in CO2 emissions in international civil aviation from 2021, compared to the emissions from 2019-2020. The commitments to offset and reduce CO2 emissions came into force in 2021, but the first obligations on the part of air carriers and states began to apply already in 2019 and concerned, among others, emission monitoring. In accordance with the adopted solutions, the participants of the mechanism are air operators performing international transport with aircraft with a maximum take-off weight (MTOM) above 5,700 kg, emitting more than 10,000 tons of CO2 per year, excluding humanitarian, medical, and firefighting flights. CORSIA includes 3 phases of project implementation (Figure **4**) and monitoring with reference periods.

5. CORSIA Deployment Period Diagram
Source: [6]

Base period
As shown in Figure **6**, from January 1, 2019, all aircraft operators are required to monitor CO2 emissions from international flights (only). Aircraft operators must monitor and report fuel consumption from international flights to determine annual CO2 emissions in accordance with a qualifying monitoring method approved by the country to which it is assigned. To simplify the estimation and reporting of CO2 emissions from international flights to operators with low levels of activity in meeting their monitoring and reporting requirements, ICAO has developed the CORSIA CO2 Estimation and Reporting Tool (CERT).

CERT supports aircraft operators in two ways: estimating CO2 emissions and filling out Emission Monitoring Plans and Emission Report templates. CERT also supports all aircraft operators in determining whether their CO2 emissions are below the exemption threshold for CORSIA reporting requirements (≤ 10,000 tonnes of CO2 per year). Aircraft operators that emit at least 500,000 tonnes of CO2 per year in 2019 and 2020 from international flights are not eligible to use CERTs to monitor and report emissions and must choose one of five eligible fuel consumption monitoring methods (five methods are equivalent and there is no hierarchy of method selection) CERT functionality is very similar to the Small Emitters Tool used in the EU ETS.

The Emissions Monitoring Plan is a collaborative tool between the State and the aircraft operator that identifies the most appropriate methods for monitoring CO2 emissions and the operator's specific baseline and facilitates the reporting of the required information to the State.

The development of an Emissions Monitoring Plan consists of the following three steps:

1. Preparation and Submission - The aircraft operator submits the emission monitoring plan for consultation and review by the State to which it is assigned.
2. Review and approval - the state reviews and approves the Emissions Monitoring Plan
3. Corrections and updates – the aircraft operator resubmits the Emissions Monitoring Plan for review and approval by the state if a significant change is made to the information contained in the Emissions Monitoring Plan.

Once the fuel consumption has been monitored by the aircraft operator following the approved emission monitoring plan, the CO2 emissions shall be calculated based on fuel combustion. ICAO CORSIA CERT automatically estimates CO2 emissions. An aircraft operator using one of the fuel consumption monitoring methods should calculate its CO2 emissions using the following equation:

$$\mathbf{CO_2 = \sum M_{\mathit{f}} * FCF_{\mathit{f}}}$$

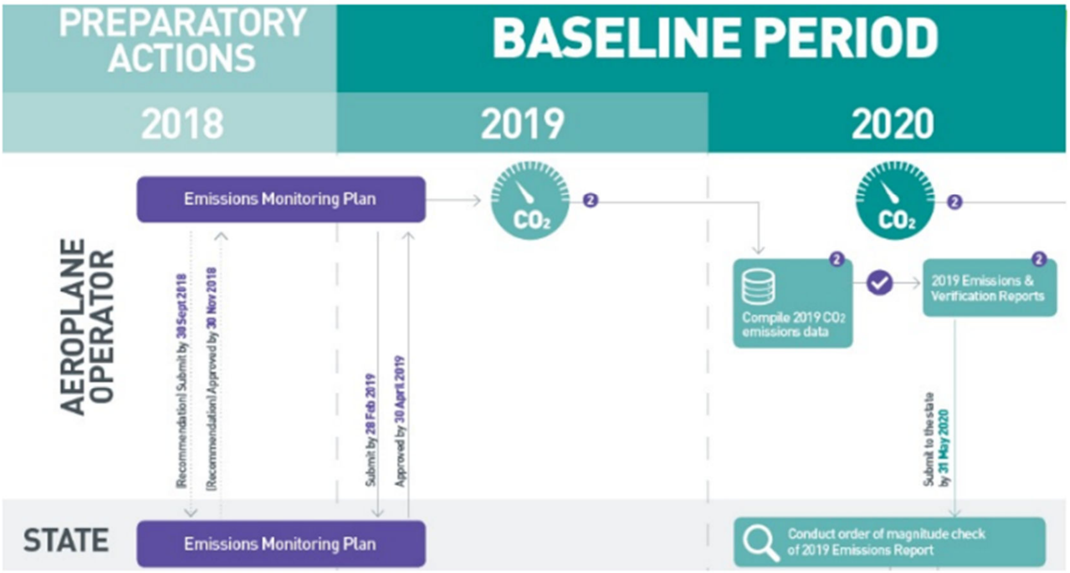
CO2 emissions = Mass (M) of fuel * Fuel conversion
Fuel Type Factor (FCF) Fuel Conversion Factor:

- 3.16 kg CO2/kg fuel for Jet-A fuel
- 3.10 kg CO2/kg fuel for AvGas or Jet-B fuel

According to Table **1**, the first part of the implementation is voluntary (2021-2026) and consists of a pilot phase (2021-2023) and a first phase (2024-2026). The second part is mandatory and is called the second phase (2027-2029, 2030-2032, 2033-2035. Compensation requirements must be met every 3 years after each compliance cycle).

Aircraft operators must monitor, verify and report fuel consumption in accordance with the approved monitoring plan. Their annual emission offset requirements are calculated by the respective state.

Verification of CO2 emission data in CORSIA is carried out by verification agencies (verifier). Aircraft operators must engage a third-party verifier to verify their annual CO2 emissions report. Verification is an independent procedure that is used to verify that a product, service, or system meets requirements and specifications and is fit for purpose. Verification ensures that the final report submitted to the State is satisfactory. Internal pre-verification is recommended.



6. CORSIA introduction baseline period diagram
Source: [6]

Tab.1. Implementation phases

Pilot phase 2021-2023	**Voluntary** Baseline: average 2019-2020 Annual deduction applies to: 2020 or the year in question (countries are free to choose) Netting requirements: 100% sector rate
First phase 2024-2026	**Voluntary** Baseline: average 2019-2020 The annual deduction applies to: the year in question Netting requirements: 100% sector rate
Second phase 2027-2035	**Mandatory** Baseline: 2019-2020 average The annual deduction applies to: the year in question Compensation requirements: at least 20% individual rate from 2030, at least 70% from 2033

CORSIA verification of measured values and process

Verification of CO2 emission data in CORSIA is carried out by verification agencies (verifier). Aircraft operators must engage a third-party verifier to verify their annual emissions report. Verification is an independent procedure that is used to verify that a product, service, or system meets requirements and specifications and is fit for the purpose.

Verification ensures that the final report submitted to you is satisfactory. Internal pre-verification is recommended. The aircraft operator must engage a third-party accredited verifier.

CORSIA Compensation Requirements

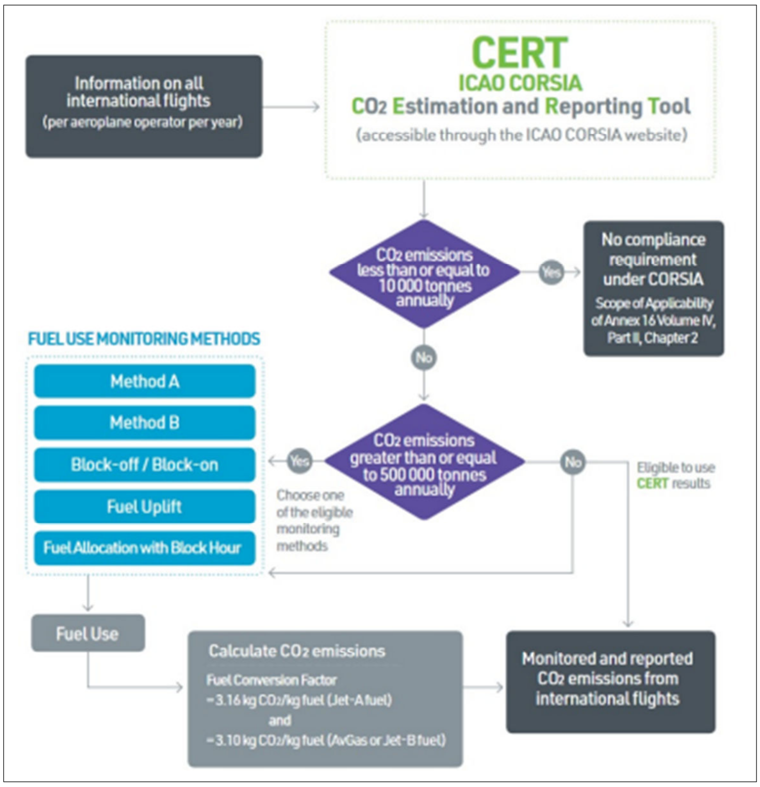
1. The State shall calculate the compensation requirements assigned to the aircraft operator's annual emissions

Operator's annual emissions **X** **Growth factor** **=** **CO^2 compensation requirements**

In a given year from 2021, the Growth Factor is the percentage increase in the number of emissions in relation to the base value and is calculated by ICAO. The Growth Factor changes annually, taking into account both the growth of the sector's emissions and individual operators.

2. The operator shall report the use of Sustainable Aviation Fuels (SAF) for the three-year compliance period.
3. The State calculates the benefits of using the SAF and informs the operator of its final CO2 offset requirements for the three-year compliance period.
4. The operator purchases and cancels eligible credits corresponding to its final CO2 offset requirements for the compliance period.
   - Generate: emission reduction projects generate emission credits.
   - Purchase: Credits are purchased on carbon markets per base tonne

1 emission unit = 1 tonne of CO2 = 1 shift



7. Decision tree diagram for emissions monitoring (2019-2020)
Source: [1]

- Cancel: Operators cancel CORSIA-eligible credits. Cancellation is held on a registry designated by the CORSIA Emisible Emission Unit Program..
- Publish: Operators submit data for each aircraft eligible for CORSIA
  Unit Scheme Registry to make cancellation notices visible on the public registry website.

3. The operator provides the verified ATS Cancellation Report to the state, which checks the Report and informs ICAO.

Emission credits (displacements) represent emission reductions generated by projects elsewhere. They are generated by each design/mechanism/schematic. The generation of credits is calculated as the difference between the production of emissions in the business-as-usual scenario and after the reduction project is implemented.

Emission reduction projects generate credits that are traded on the carbon market in the same way as other commodities. Emission credits are traded per tonne. The supply and demand of credits will affect the price of credits.

Compensation time frame:
2019 – 2020 - No compensation requirements, all countries "participate"
2021 – 2026 - Voluntary participation
2027 – 2035 - Mandatory participation of countries with high aviation activity

Impact of CORSIA on aircraft operators

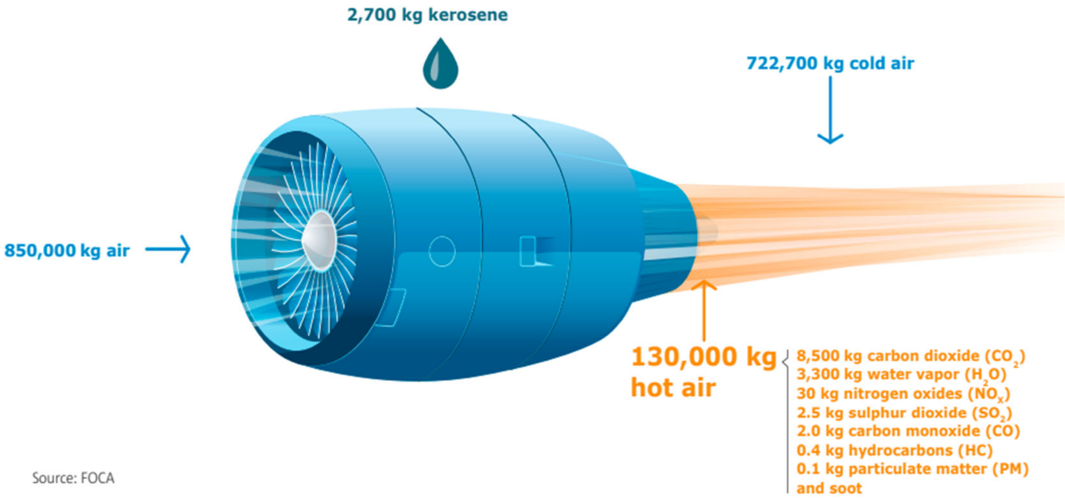
A similar system to CORSIA is currently used in the EU - the EU Emissions Trading Scheme (EU Emissions Trading Scheme) as the cornerstone of EU climate change policy and a key tool for the cost-effective reduction of greenhouse gas emissions. This European system is based on a non-CORSIA principle and principles. The scope of the EU ETS remains unchanged until 2023. The new monitoring plan template common to EU ETS and CORSIA is currently not available, which means that European aircraft operators are uncertain whether the systems will not be duplicated in one operation. This would significantly worsen the performance of mainly European aircraft operators compared to operators from other parts of the world. Another problem is cost forecasting. As in the case of the EU ETS, under CORSIA it will be difficult to estimate the costs of offset programs in a specific period (every 3 years).
The EU ETS operates in annual cycles - the amount of CO2 released is calculated and a report is created. The report is then verified by a verification agency. At the beginning of each year, the aircraft operator must submit a report for the previous year, based on which the amount of emission allowances needed is determined. By the end of April, the carrier must have permissions on his account and return them. This process is more difficult in CORSIA. From 2021, three-year cycles have been established. The defining baseline is set for the years 2019 and 2020. For the period 2021-2023, aircraft operators must report CO2 growth compared to the baseline. The data must then be verified and sent to ICAO, which will process it for a year. The number of offsets that will need to be purchased will be known in 2025. This procedure is then repeated regularly until 2035.

If aircraft operators do not constantly build up financial reserves above these costs, they may have problems paying their liabilities (financial exposure to offset programs) at a time when it is necessary to participate in CORSIA offset programs.

Different rules are set for new aircraft operators to be established after 2020. These operators have not established any reference point. So they have a rule that for the first three years they will pay nothing for emissions, and after these three years, they will pay for all emissions. Not just an increase from the baseline, as is the case with current carriers who will determine the baseline based on the number of emissions emitted in 2019-2020. Therefore, emerging aircraft operators will have an advantage over existing ones.

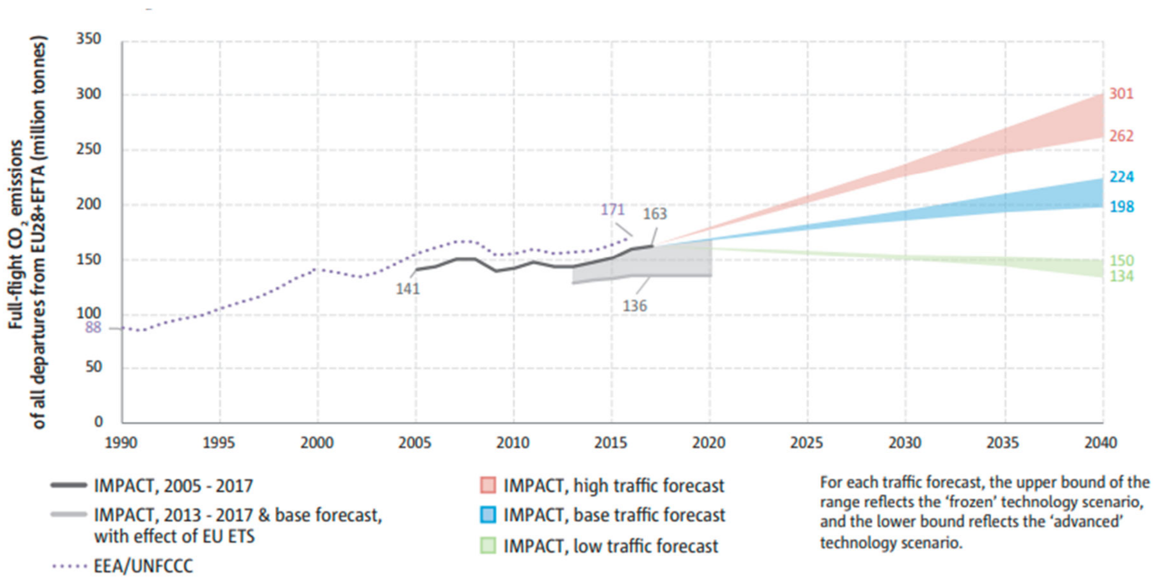
Aircraft emissions

The main pollutants emitted by aircraft engines during operation are carbon dioxide (CO2), nitrogen oxides (NOX), sulfur oxides (SOX), unburned hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM), and soot (Figure **8**).



8. Emissions from a typical twin-engine jet on a one-hour flight with 150 passengers on board
Source: [3]

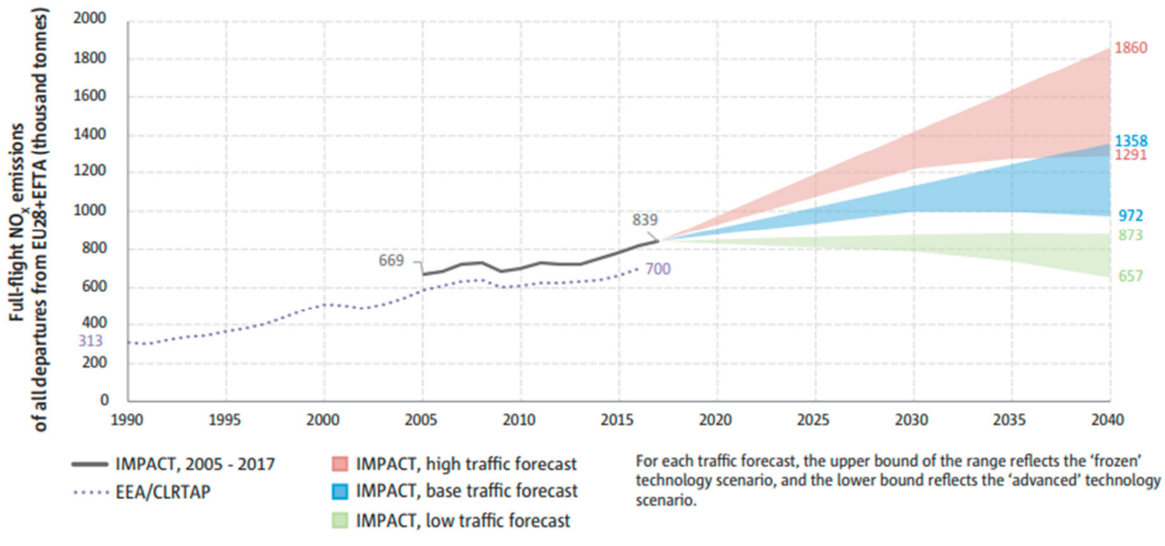
CO2 and NOX emissions continue to rise. According to data reported by Member States of the United Nations Framework Convention on Climate Change (UNFCCC), CO2 emissions of all flights departing from the EU-28 and EFTA increased from 88 to 171 million tonnes (+95%) between 1990 and 2016. In comparison, CO2 emissions estimated using the IMPACT model reached 163 million tonnes (Mt) in 2017, which is 16% more than in 2005 and 10% more than in 2014. Over the same period, the average fuel burn per passenger-kilometer for airliners, excluding business aviation, decreased by 24%. This decreased at an average rate of 2.8% per year between 2014 and 2017. However, this increase in efficiency was not enough to offset the increase in CO2 emissions due to the increase in the number of flights, aircraft size, and distance flown. Future CO2 emissions under the baseline traffic forecast and high-tech scenario are expected to increase by a further 21% to respond to 198 million tonnes in 2040. The annual purchase of allowances by aircraft operators under the EU Emissions Trading System (ETS) since 2013 resulted in a reduction of 27 Mt net CO2 emissions in 2017, which should increase to around 32 Mt by 2020.



9. CO2 emissions from aviation in the years 1990 - 2040
Source: [2]

In recent years, NOX emissions have shown a stronger upward trend than CO2. They increased from 313 to 700 thousand. tonnes in 1990-2016 according to the data of the Convention on Transboundary Air Pollution (CLRTAP) of the United Nations Economic Commission for Europe, and by 25% in 2005-2017 according to estimates from the IMPACT model. Contrary to the CO2 trend, projections indicate that the scenario of advanced NOX engine technology could lead to a downward trend after 2030. However, NOx emissions will still reach around 1 million tonnes in 2040 according to the baseline traffic forecast (+45% compared to 2005).

The impact of COVID pandemic and drastic restrictions on air travel had a positive impact on the level of pollutant emissions into the environment. Despite this advantage, there is no other beneficial effect of the time restrictions on air mobility caused by COVID. Thus, data showing the level of air traffic in the period until 2020 can be considered the optimal sample for conducting analyzes in the context of future changes in the aviation market.



10. NOx emissions
Source: [2]

Examples of current and future emission allowance costs

The cost of emission allowances per flight hour of a Boeing 737 800 aircraft:
3.15 tonnes of CO_2 is released from one tonne of B738 fuel burned. An average of 2.45 tons of fuel is used per hour of flight. Over 7.7 tons of CO_2 are emitted per hour of flight. The price of allowances is currently around EUR 25 per tonne of CO_2. The cost of one hour of flight is currently EUR 193 only on emission allowances.

Comparing the cost of emission allowances with the price of fuel (Boeing 737 800):
The average fuel price is now \$750 a ton. Emission allowance costs are currently around EUR 78 per tonne of fuel = around USD 87. In the last 3 years, the price of emission allowances has increased 5 times. Now the cost of emission allowances is 1/7 of the price of fuel. If emission allowances continue to grow at this rate, the cost of emission allowances may reach 1/2 of the price of fuels in a few years. This is a significant cost that must translate into the price of air tickets.

Aviation biofuels

The American Association for Testing and Materials (ASTM *International, formerly the American Society for Testing and Materials*) has developed standards for the approval of new aviation biofuels, and now six production pathways have been certified for blending with conventional aviation fuel. They include:

• **FT-SPK** (Fischer-Tropsch Synthetic Paraffinic Kerosene),
Fischer-Tropsch synthetic paraffin kerosene. Biomass is processed into synthetic gas and then into aviation biofuel. The maximum mixing ratio is 50%.

• **FT-SPK/A** is a variant of FT-SPK where the alkylation of light aromatic compounds creates a hydrocarbon mixture containing aromatic compounds. The maximum mixing ratio is 50%.

• **HEFA** (Hydroprocessed Fatty Acid Esters and Free Fatty Acid
hydrogenated fatty acid esters and free fatty acids). Lipid feedstocks such as vegetable oils used cooking oils, tallow, etc. are converted with hydrogen into green diesel, which can be further separated to produce aviation biofuel. The maximum mixing ratio is 50%.

• **HFS-SIP** (Hydroprocessing of Fermented Sugars - Synthetic Iso-Paraffinic kerosene) hydroprocessing of fermented sugars - synthetic isoparaffin kerosene). With the help of modified yeast, sugars are converted into hydrocarbons. The maximum mixing ratio is 10%.

• **ATJ-SPK** (Alcohol-to-Jet Synthetic Paraffinic Kerosene)
synthetic alcohol paraffin kerosene dehydration, oligomerization, and hydroprocessing are used to convert alcohols such as isobutanol into a hydrocarbon. The maximum mixing ratio is 50%.

• **Co-processing**
Biocrust up to 5% of the volume of lipid raw material in oil refining processes. This pathway was approved in April 2018 and added to Annex A1 of ASTM D1655, Standard Specification for Aerospace Turbine Fuels.

Additional tracks are currently in the ASTM certification process. Determining the level of maturity of the available aviation biofuel production pathways, both from a technological and commercial point of view is a major challenge. Despite the dynamics of the sector, only a few ASTM-certified tracks deliver the fuel on a commercial scale. The technological maturity of each production path can be determined by the Technology Readiness Level - TRL, which ranges from 1 for basic ideas to 9 for a real system proven in an operational environment. In addition to technology readiness, the commercial development of a specific fuel may vary due to various factors (e.g. certification issues, cost issues). To better elucidate the progress of a specific fuel production pathway towards full commercialization, the US Alternative Fuels for Commercial Aviation Initiative developed a fuel readiness level (FRL) system that has been endorsed by ICAO. The FRL also ranges from 1 for basic ideas to 9 for established production capacities but is aligned with the approval of international aviation fuel standards.

Summary

Based on current calculations, CORSIA would be "cheaper" for European aircraft operators compared to the EU ETS (based on offsets that are currently on the market). Since the EU ETS is a financially beneficial program for the EU, it is not envisaged to completely abolish this system. This system is used to finance environmental programs in individual EU countries. ICAO's CORSIA program still leaves unanswered questions, e.g. whether there will be enough approved offset programs or whether offset program verification will not be abused in countries with weak internal controls. Of course, there is a need for a system like CORSIA that will start to deal with the number of increased CO2 emissions not only in the EU but around the world. Only technological progress (e.g. development of engines with lower fuel consumption) will not stop the expected increase in CO2.

At the same time, the collapse in the aviation industry caused by the COVID pandemic, the financial problems of many aviation entities, and the consequences of a combination of many factors limiting the possibility of development and creating an increase in the potential for reducing the impact of aviation on the environment, postponed the prospect of changes. It is necessary to return to the level of air traffic and make up for the losses incurred to realistically implement solutions, technologies, and aviation biofuels on a large scale because only such a way can guarantee real changes in the impact of aviation on the natural environment.

Source materials

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