Operational Improvements and Sustainable Air Transport Development in the Global South

Bruno Garcia Franciscone
COPPE/UFRJ, Federal University of Rio de Janeiro, Brazil
bruno.franciscone@gmail.com

Elton Fernandes
COPPE/UFRJ, Federal University of Rio de Janeiro, Brazil
tglcoppe@gmail.com

Abstract

There is a clear inequality between air transport systems development in Global North countries from the Global South ones. It is possible to observe this inequality when analyzing each region's route network and the total number of flights. This article aims to analyze how the adherence to The Carbon Offset Scheme for International Aviation (CORSIA) which comprises a market-based measure to stabilize emissions from 2020 onwards by international civil aviation can restrict growth and impact air transport expansion in developing countries, focusing on the BRICS countries. Considering a bibliographical review, the article highlights how ICAO developed measures to reduce CO2 emissions, including operational, technical, and alternative fuel measures, consisting of CORSIA in a complementary market measure. Additionally, based on the methodology developed by ICAO, the estimated reduction in CO2 emissions from implementing operational measures in Brazil was calculated using the annual number of arrivals and departures at airports. Operational measures are more in line with developing countries' United Nations' sustainable development goals, which have a broader sustainable development view of society. They are the best short-term option since Technological measures have a high implementation cost, and their incorporation into aircraft fleets takes a long time using SAF strongly depends on reducing associated production costs and developing a supply chain that allows its production to scale. As BRICS countries implement operational measures in their air transport systems, there is an increasing gain in efficiency and a reduction in CO2 emissions. Market measures such as CORSIA can restrict the expansion of air transport infrastructure in developing countries, consequently impacting their economic growth.

Keywords: BRICS, Reduction of CO2 Emissions, Air Transport, Tourism

Introduction

Until the end of the 1990s, bilateral agreements dominated the aviation market, but the American liberal wave, which emerged in 1997, influenced the entire world. This wave resulted in liberalism in the national aviation markets that escaped the traditional and merged concept of sovereignty and paved the way for new companies, international routes, and airports' privatization, among other actions. (Singh, 2019). Even in developing countries, commercial air transport has a noticeable development, abandoning the closed borders vision. These countries have become active players in the global economy and the air transport network.

The maturity level of its air transport system is crucial for the economy of a country. It is well known that there is a bidirectional correlation between air transport development and economic growth, especially in developing countries. Air transport development is essential for, among other purposes, facilitating world trade, promoting tourism, attracting foreign investment, generating direct and indirect employment and income from the airports' construction, and, later, during the operations of these airports, which favors economic growth. (Pisa, 2018). In addition, it generates "spill-over effects" such as increased employability for metropolitan regions where efficient air services are available (Zhang; Graham, 2020). The International Civil Aviation Organization (ICAO) recognizes that the development and expansion of air transport are crucial for economic growth and social inclusion (Hasan et al., 2021). Regulators and policymakers need to ensure that regulating the air transport industry also serves the interests of society and local communities to promote the mentioned social inclusion (Marazzo; Scherre; Fernandes, 2010).

Despite the remarkable growth of the air transport system in developing countries, influenced by the liberal wave that influenced the aviation market around the world, its maturity level is still much lower than that of the air transport systems in developed countries. An indicator associated with the economic development of countries is air connectivity. It comprises the route networks' concentration and ability to interconnect origin and destinations and transport passengers since these characteristics create more expressive economic benefits for tourism and other activities. (Dimitrios; Maria, 2018). There are many routes and a high flow of air traffic between the Global South and Global North countries. Among the Global South countries, the number of routes and traffic flow is much lower. This stronger connection through a more robust route network between countries in the Global South and Global North reproduces historical ties linked to colonialism, migration patterns, and sources of significant tourism markets with former countries that had colonies (Njoya; Knowles, 2020).

The causes of the difference in air connectivity between developing and developed countries are mainly the high operating costs, the influence of governments, low-quality standards, and some inefficient state-owned companies hamper the even more significant growth of the sector (Njoya; Knowles, 2020). Despite several economic uncertainties, air transport activity has grown about 2.5 times more than the Gross Domestic Product (GDP) in the last two decades. However, the air transport infrastructure has grown at a different rate, which has caused congestion and delays. Developing countries, in particular, need to build a more robust aeronautical infrastructure to mitigate capacity issues to meet demand needs (Dimitrios; Maria, 2018). Despite these infrastructure problems, developing countries have grown above the world average in air transport activities because regulatory reforms have expanded access to markets' investment flows and reduced costs (Njoya; Knowles, 2020).

The demand consideration for air transport is vital. It depends on social and economic factors and not just the price of services. Therefore, an increase in GDP and changes in society's consumption patterns can increase demand for air transport. (Park, Seo, Ha, 2019). Still, according to Park, Seo, and Ha (2019), the more outstanding the debt of developing countries, the less investment in air transport infrastructure since there is a reduction in public capital investment, which leads to the cancellation or postponement of projects. In addition, as in these countries, several areas, such as health and education, need more infrastructure, and competition for investments exists. Often, the money planned for investment in infrastructure ends up spent on other demands considered more urgent. This *modus operandi* creates a vicious circle that undermines long-term economic growth.

Tourism, as mentioned above, is one of the crucial economic activities favored by air transport development, and that can contribute to economic growth. Even for developed countries, tourism is an essential source of foreign exchange to generate a positive balance of payments and revenue rates for guest nations. In addition, tourists allocate resources to purchase goods and services that generate spill-over benefits in other sectors of the economy and generate seasonal and permanent jobs for unskilled labor. Several studies have shown that tourism promoted economic growth in Europe, South America, Bahrain, Pakistan, Asia, and Africa (Pisa, 2018).

The development of air transport impacts tourism, but it is not the only factor. Other factors contributing to promoting tourism at a specific destination are the economic conditions of the origin and destination locations, logistical costs, commercial regulations, and the capacity and performance of the supply chain. The passenger's profile can influence passengers' decisions in choosing a particular destination, the distance to the final destination, the modes of transport, and the price of services (Pisa, 2018).

Additionally, it is essential to highlight that it is not just investment in air transport infrastructure and a significant number of flight arrivals in a country that impacts economic growth, but a lot of other factors like the expenses tourists make, political instability, anti-terrorist wars, direct and indirect regulatory barriers, inadequate infrastructure, underdeveloped human capital, non-transparent business policy, neglect of export-oriented sectors, poor situations concerning law and order (Usmani; Akram, 2021). Other relevant factors are the underutilization of the infrastructure because of the lack of auxiliary services and adequate support and the geographic, political, governance, and technological development situations (Park; Seo; Ha, 2019).

Despite the economic growth, fostering air transport activity globally promotes increased greenhouse gas (GHG) emissions. The Intergovernmental Panel on Climate Change (IPCC) estimates that Carbon Dioxide (CO2) emissions from air transport account for about 2% of total emissions from the use of fossil fuels. When considering the emissions of other GHGs, this percentage rises to 6%. Although this percentage seems low, its impacts are intense since emissions occur at high altitudes, between 25,000 and 41,000 feet, where most commercial aviation flights operate (Lee, 2017). Besides CO2 emissions, air transport activities generate nitrogen oxide (NOx) emissions, contributing to ozone formation when emitted at high altitudes (ICAO 2019, a). In addition, the condensation trail formation can induce Cirrus-type cloud formation that intensifies the effects of global warming (ICAO 2019, a). The CO2 impacts are well understood; however, there is uncertainty about the non-CO2 emissions impacts. Therefore, it is necessary to develop methodologies to assess the effects of GHG and polluting gases and understand how these gases interact (Van Fan et al., 2018).

The environmental impacts of air transport activities intensify in the long term since growth forecasts for commercial aviation operations were to triple between 2020 and 2050, which may no longer occur because of the impacts of the COVID-19 pandemic (Gössling; Humpe, 2020). The reduction in the number of flights in Europe reached 89% in April 2020, compared to the number of flights in the same month of the previous year (Nizetic, 2020). In the United States, there was a reduction in passenger flights by 96% in April 2020 compared to April 2019 (USDT, 2020). The CO2 emissions by international aviation were reduced by 45% because of this sharp decrease in flights worldwide during the COVID-19 pandemic. Considering only the reductions related to international civil aviation activities, this reduction reached 72%. However, the number of flights grew again worldwide after the critical phase of the COVID-19 pandemic and has now surpassed 80% of movements in the pre-pandemic period in most parts of the world (Liu et al., 2020).

ICAO developed the Carbon Offset Scheme for International Aviation (CORSIA), a market measure to complement the basket of measures for offsetting CO2 emissions not reduced through implementing technological, operational, and sustainable fuel (SAF) measures. There are three phases in CORSIA implementation. Entry into the program will be mandatory in the second phase, in 2027, for all states with a share of over 0.5% of the world's revenue tonne kilometer (RTK) or that are part of 90% of the accumulated worldwide RTK. The BRICS (Brazil, Russian Federation, India, China, and South Africa) countries that should enter the mandatory phase of the scheme are Brazil, China, India, and Russia. The program should last until 2035 when alternative fuel production likely scales and allows extensive use in aviation. One hundred fifteen countries have joined CORSIA (ICAO, 2022b).

This article analyzes the differences between air transport infrastructure and the expenditures and receipts from international tourism activities in the BRICS and G7 countries (Canada, United Kingdom, France, United States, Italy, Germany, and Japan). It also aims to show the impacts that adherence to CORSIA by BRICS countries can have on the air transport development in these countries and on their economic growth. In addition, it points out that implementing operational measures by the BRICS in the Global Air Navigation Plan improves the efficiency of air transport in these countries. Implementing these operational measures makes air transport activities more sustainable and aligned with the "United Nations' sustainable development goals." Lastly, this article details the following methodology established by ICAO, the CO2 emissions reduction estimates in Brazil, by implementing operational measures.

Following this introduction, Section 2 presents the research methodology used. Section 3 presents, based on World Bank Data, some features comparing the BRICS and G7 countries regarding air transport infrastructure, international tourism activities, and air transport seat supply. Section 4 shows the measures undertaken by ICAO to mitigate GHG gas emissions from international civil air transport, including operational, technological, and market measures. Section 5 highlights the basket of ICAO measures for reducing CO2 emissions by international civil aviation. It points out how the ICAO Global Plan for Air Navigation (GANP) has favored implementing the operational measures of the BRICS air transport activities as members of the ICAO Council, helping to reduce CO2 emissions. It also shows a CO2 reduction estimate in Brazil and the implementation of air-side operational measures provided for in the GANP. Section 5 discusses the research data and analysis and resumes the conclusions.

Methodology

The methodology used in this article consisted of, first, using data from the World Bank, comparing some features related to the expenditures and receipts from international tourism, air transport infrastructure, and air connectivity between BRICS and G7 countries to highlight the existing differences between the two sets of countries and evidence the need for improvements in the air transport system of the BRICS countries. Afterward, a bibliographical review was done to evidence how the ICAO developed operational, technical, alternative fuel measures and a complementary market measure named CORSIA to reduce international aviation CO2 emissions. Finally, the calculation presented of the estimated reduction in CO2 emissions from implementing operational measures in aerodromes in Brazil used a methodology developed by ICAO, contained in Doc 9988, that uses annual departures and arrivals in the aerodromes as input.

Comparative features between BRICS and G7 countries

There is a noticeable difference in the air transport infrastructures of the Global North and Global South countries. Differences between BRICS and G7 countries show that. It is important to emphasize, however, that only the infrastructure provision, as already mentioned, may not be a guarantee of promoting economic growth. Because of this, it is also essential to analyse businesses' revenues and expenses. International tourism is an example. The number of seats available on flights departing and arriving from the countries is another. These examples help to understand the displacement patterns at international airports. All the analyses in this section used data extracted from the World Bank database. Figure 1 shows the results obtained by dividing the number of international airports by the population of each country. The figure shows that, except for Russia, all other BRICS countries have fewer international airports per million inhabitants than the G7 countries. This reduced number of airports shows that even in large countries in the Global South, as is the BRICS case, there are few cities able to attract international flights. Another feature to explore further is that the Global South countries' international airports' connections are mainly with Global North countries' international airports. The lack of direct air transport connections between Global South countries reduces the potential for people-to-people exchange, making travel between Global North and South more accessible.

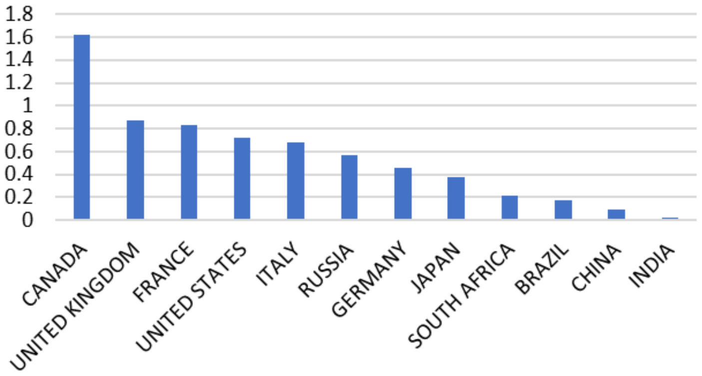

Figure 1: Number of International Airports per Millions of People

Source: Data Adapted from World Bank, 2023

Analysing the amounts spent and received concerning international tourism activities by the G7 and BRICS countries shown in Figures 2 and 3, it is possible to see that the G7 countries handle 56% of expenditures on international tourism and get around 84% of total revenue from activities related to international tourism. The unbalance shows the need for improvements in understanding people's reasons for spending much more resources in the Global North than in the Global South. Further research about media, infrastructure, business strategy, and other related topics may help Global South countries to improve their international tourism, considering Global South countries' partners.

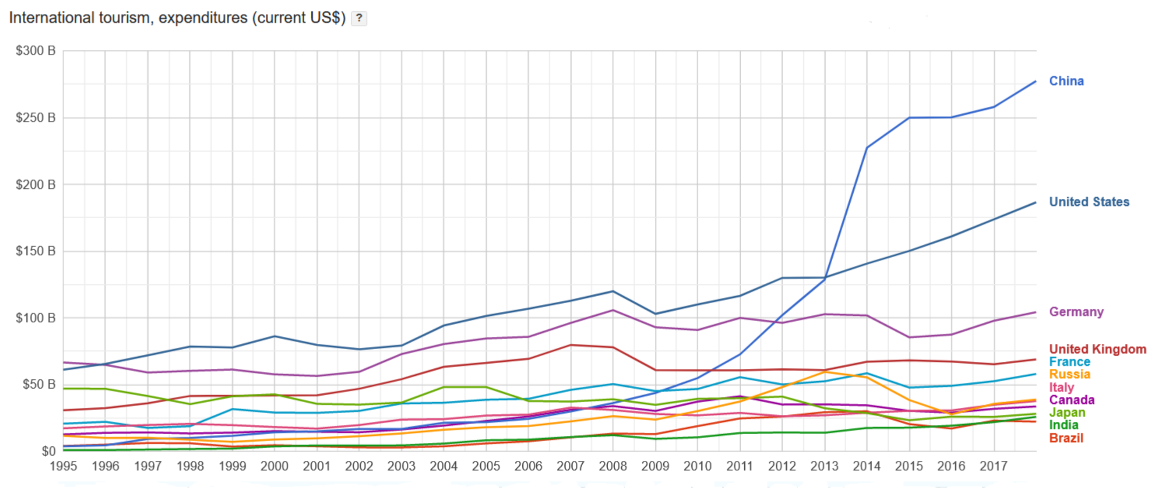

Figure 2: Expenditure on International Tourism: G7 and BRICS Countries

Source: World Bank, 2023

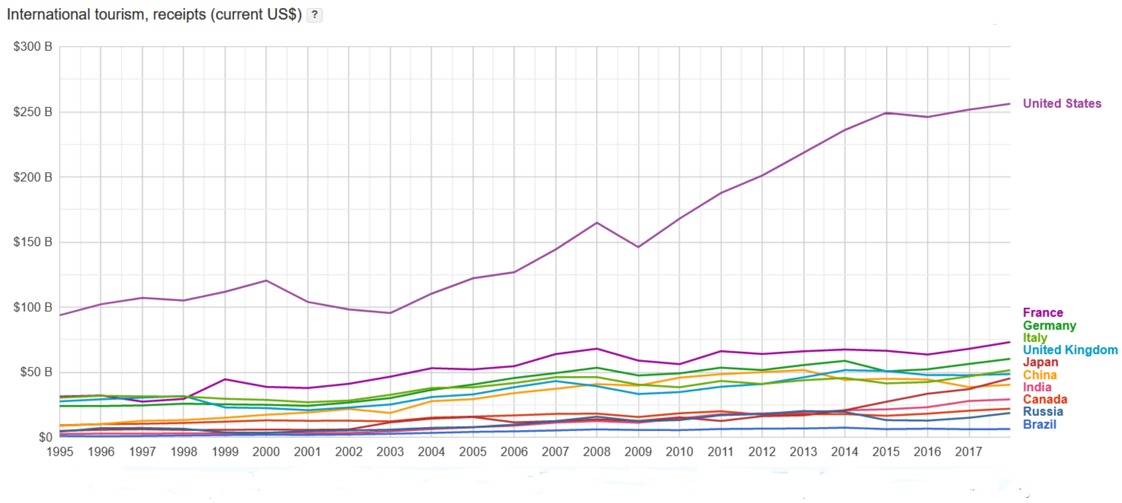

Figure 3: Receipts from International Tourism: G7 and BRICS Countries

Source: World Bank, 2023

Considering the number of seats available in 2019 on direct flights between BRICS and G7 countries, it is possible to see in Figure 4, that the number of seats on flights from BRICS countries to G7 countries corresponds to 68,049,553, about 89% of the total seats. The number of seats available on flights between BRICS countries was 7,693,155, with only 11% of the total seats. Considering that one of the BRICS arrangement pillars is "people-to-people exchange and cultural integration," this feature shows the need for deepening the knowledge about what makes people choose the destination and what we can do to improve the international air transport between Global South countries.

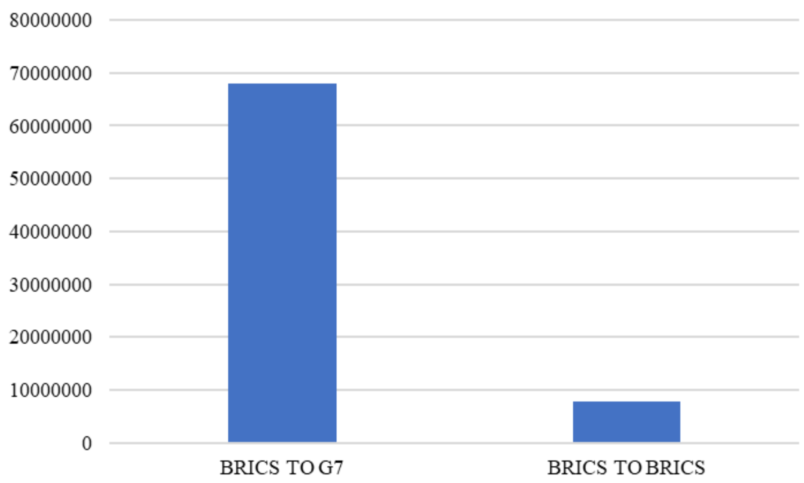

Figure 4: Total Number of Seats Available in 2019 for Flights between G7 and BRICS Nations

Source: Data adapted from World Bank, 2023

These few features, having BRICS and G7 countries as examples, show an unbalanced global scenario between Global North and Global South countries. This paper explores measures around air transport related to the BRICS in the direction to air transport sustainability in this unbalanced scenario.

ICAO basket of measures to reduce CO2 emissions and the implementation of GANP operational measures on the BRICS countries

Several international agreements seek to mitigate GHG emissions. Among them, the Kyoto Protocol and the Paris Agreement stand out. They consider principles of justice. Countries with higher per capita GHG emissions may contribute more to emission reductions. Paris Agreement signatory countries must address the problem of greenhouse gas emissions from their domestic aviation activities through Nationally Determined Contributions (NDC). On top of all, the GHG emissions reduction by International Civil Aviation is the responsibility of ICAO (Gössling; Humpe, 2020).

ICAO Basket of Measures to Reduce CO2 Emissions

The development of CORSIA by ICAO complemented the basket of measures to offset the amount of CO2 emissions not reduced through operational and technological measures and the use of sustainable fuels. The implementation of CORSIA, which is a market-based measure, is taking place in three phases, and entry into the program will be mandatory from 2027 for all States that have a share of 0.5% of the world's revenue tonne kilometer (RTK) or that are part of the 90% of RTK accumulated globally. The expectation is that this program will last until the year 2035 when the production of alternative fuels will scale and be used ostensibly in aviation. Currently, 115 countries have joined CORSIA (ICAO, 2022b).

The operational measures proposed by ICAO are related to optimizing operational procedures, and air traffic management (ATM) measures to reduce GHG emissions (Lyle, 2018). The Global Air Navigation Plan (GANP) contains most of the existing operational measures and will be available soon. The operational implementations in the GANP aim to achieve an interoperable global navigation system that guarantees acceptable levels of operational safety and ensures more environmentally sustainable and economical operations. ICAO estimates that GANP implementations will generate an emission reduction of millions of tons of CO2 (ICAO, 2019b).

The availability of resources by the States and their operational needs will guide the implementation of operational measures. Additionally, multisectoral plans and agreements between various public and private stakeholders are required, such as regulatory bodies, aircraft operators, air navigation service providers, and aircraft manufacturers (ICAO, 2019b). However, the straightforward implementation of operational measures *per se* does not guarantee the reduction of CO2 emissions because as air traffic grows, congestion levels intensify, ATM efficiency decreases, and GHG emissions intensify due to increased fuel consumption by the aircraft. This decrease in efficiency is especially true around airports with a high volume of arrivals and departures, inside terminal airspaces, and along congested flight corridors. Therefore, in addition to operational measures, ATM efficiency should be optimized by implementing performance monitoring mechanisms with defined goals for each flight›s phases (ICAO, 2014).

The implementation of technological measures is essential for the reduction of CO2 emissions by aviation. Extraordinary advances have been taking place over the last few decades. About 80% of the aircraft in operation are more efficient in fuel consumption per passenger kilometer than the aircraft in operation in the 1960s. The ongoing advances include engines that improve the bypass ratio and lighter and more heat-resistant materials to compose the aircraft fuselage. In addition, advances in electric and hybrid aircraft technology will allow for lower consumption of fossil fuels and, consequently, a reduction in CO2 emissions (ICAO, 2022a). Although technological measures contribute significantly to reducing emissions, their costs are high, and incorporating these technologies in aircraft fleets may take time (Hasan et al., 2021). As for measures associated with using SAF, they are the most important for reducing CO2 emissions by aviation. However, although technologies for producing these fuels are already available, they are produced in small quantities, and the production costs still need to be lowered. Producing SAF on a scale can mitigate environmental issues and improve social and economic issues in developing countries, as long as this production does not impact food security (ICAO, 2022a). According to a conservative but optimistic point of view, about 5.7% of all arable land in 2050 will be available for biofuel production worldwide, which will be enough to supply about 92% of the estimated demand for 2100 (da Cunha Dias et al., 2021). However, to promote an increase in SAF production, it is necessary to promote the use and regulation, through policies and laws, in addition to financial and technical support from governments, for the production and certification of these fuels (ICAO, 2022a).

Regarding market measures, CORSIA stands out as a relatively simple global compensation scheme for emissions related to international air transport. In its original conception, the emissions baseline would be the measurements undertaken in 2019 and 2020. However, due to the drastic reduction in flows related to international air transport, ICAO readjusted CORSIA by removing measurements from the emissions baseline relating to 2020, considering only those relating to 2019 (Zhang et al., 2021). However, the program may last until 2035, when SAF production will likely scale and production costs will be significantly reduced, making its use viable in international air transport (Lyle, 2018). None of the BRICS countries volunteered to enter the program's first phase. However, except for South Africa, the other BRICS countries will enter the mandatory phase of the program as they are part of 90% of the (revenue tonne-kilometers) accumulated in the world. Figure 5 shows the participation of countries in CORSIA.

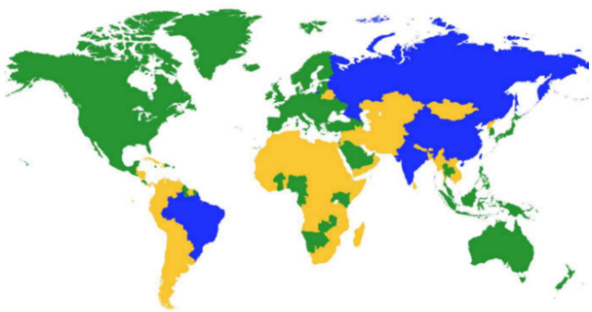

Figure 5: Countries Participating in CORSIA's First Phase (green), Second Phase (blue), and Non-Participants Countries (yellow)

Source: ICAO, 2023

In CORSIA, each country is responsible for monitoring, verifying, and reporting its operators' offset data and emissions. Some countries, particularly developing countries, however, feel that the principles of carbon-neutral growth should not apply to them. There is also some apprehension in the aviation community that existing restrictions due to inadequate or inefficient air transport infrastructure added to new environmental restrictions may severely restrict the growth of the air transport sector in these countries (Lyle, 2018). Adequate air transport infrastructure favors the movement of people and goods between different regions. So, restrictions that limit the growth in the number of international flights in developing countries will also impact the development of air transport infrastructure in these countries and, consequently, their economic growth (Polyzos; Tsiotas, 2020).

It is important to note that according to a 2022 IPCC report, more than the implementation of CORSIA is necessary to effectively reduce CO_2 emissions and achieve the targets defined by the Paris Agreement. To achieve the aspirational goals of neutral carbon growth, the CORSIA eligibility criteria need to be improved, and airlines need to be encouraged to invest more in technologies that will allow the reduction of emissions (Wonzy et al., 2022). The ICAO Council is currently reviewing the feasibility of developing a Long-Term Aspirational Goal (LTAG) for international aviation. This analysis considers an assessment of proposed targets considering impacts on the growth of countries and the costs of their implementation for the States (ICAO, 2018). A working group composed of professionals from all over the world and of recognized competence is gathering information from internal and external sources for ICAO. This work will help identify and evaluate existing, planned, and innovative operational, technological, and SAF use measures in international air transport that may contribute to reducing CO2 emissions. Based on this collected information, the ICAO specialists will create scenarios combining technological, operational, and use of SAF measures to analyze the data and make forecasts of future demands, considering the target of increasing energy efficiency by 2% per year and carbon neutron growth from 2020. The specialists will also estimate the costs and economic impacts of implementing the measures mentioned above on the growth of the air transport sector, especially for developing countries (ICAO, 2022c).

The development of GANP and the Implementation of Operational Measures by BRICS Countries

After the end of World War II, civil aviation began a vertiginous expansion, especially in the United States. Aircraft became bigger and faster. As a result, it became necessary to incorporate new technologies to allow air traffic control to maintain an efficient and safe flow of aircraft (Wickens, Mavos, and Mcgee, 1997). However, in Europe and the rest of the world, the regulation of the air transport sector was very rigid, and airlines needed government subsidies to function, which made the civil aviation market commercially inefficient and uncompetitive, favoring the formation of cartels (Dobson, 2017).

The American liberal wave strengthened in the late 1990s and influenced aviation markets worldwide. New airlines and international routes emerged in the European Union, and airports began privatizing (Singh, 2019). Due to these changes, the growth of European air transport activity was very intense. However, the challenge arose to integrate European airspace to make air traffic management more efficient and reduce frequent delays (Dobson, 2017).

The air transport industry then grew more intensely than most other industries. Because of this, the ICAO Council created the FANS Committee (Future Air Navigation Systems) to study, identify, and evaluate new technologies with potential use in civil aviation and to make recommendations for future developments in air navigation for the next 25 years. The works developed by this Committee were the basis for developing the Global Air Navigation Plan (GANP). This plan consists of recommended implementations of new technologies and operational concepts intending to create the most homogeneous and interoperable global airspace possible (ICAO, 2002). The implementations recommended in this plan are related to the Air Traffic Management area. Its implementation methodology consists of gradual and harmonized implementations that allow for achieving greater global harmonization, increasing the capacities of airports and airspace, and simultaneously reducing environmental impacts (ICAO, 2019b).

All the BRICS countries develop implementations of operational measures foreseen in the GANP. The Ministry of Transport of Russia and South Africa, the Airport Authority of India, the Civil Aviation Administration of China, and the Department of Airspace Control in Brazil (DECEA) carry out several initiatives.

Implementation of Operational Measures on the Air Transport in Brazil and CO2 Emissions Reduction Estimates

In Brazil, the Department of Airspace Control (DECEA) regulates civil aviation activities regarding the use of airspace. In 2012, DECEA created the SIRIUS Program, aligned with GANP, to present a strategic vision for the evolution of the National Air Traffic Management Systems (ATM) to meet the local peculiarities. Several projects contemplate the implementation of airside operational measures. Among them are the Optimization of the National Airspace, Evolution of Air Traffic Flow Management, and Flexible Use of Airspace (DECEA, 2022). Regarding the National Airspace Optimization project of the SIRIUS Program, Brazil implemented and continues to implement the performance-based navigation concept (PBN). This concept envisages the use of Global Satellite Navigation Systems (GNSS) and systems embedded in aircraft that allow them to fly freely between any coordinates, allowing more direct and efficient routes with this, a reduction in CO2 emissions (ICAO, 2016).

Along with PBN, implementing two other concepts is frequent: Continuous Climb Operations (CCO) and Continuous Descent Operations (CDO). They consist of the elaboration of PBN arrival and departure procedures that allow aircraft to climb and descend without stopping in intermediate steps, whenever possible, using engine thrust and speed regimes that reduce fuel consumption and, consequently, CO2 emissions. (ICAO, 2019a). Although little data refers to actual flights that perform arrival trajectories with CDO in the literature, there is a consensus understanding that descent trajectories with greater angles of descent are more efficient for reducing fuel consumption. Some data show a strong correlation between the fuel flow of aircraft in general and the angle of descent when it varies between 2.5° and 3.0°. However, an opposite correlation trend occurs for greater descent angles, and the fuel flow decreases (Turgut et al., 2018).

As for the concept of CCO when applied in airport departure procedures, accurate data from operations demonstrate a reduction of up to approximately 30% in fuel consumption due to the non-leveling of the aircraft in intermediate segments that allow the use of optimal powers and speeds until they reach cruising levels (Villegas Díaz et al., 2019). Despite the individual advantages of applying the concepts of CCO and CDO, their joint use needs to be carefully analyzed, especially for congested airports. It is crucial to ensure an optimal distribution between procedures using the CDO and CCO concepts to reduce impacts on airport capacities (Pérez-Castán et al., 2018). In Doc 9988, “Guidance on the Development of States’ Action Plan on CO2 Emissions Reduction Activities,” ICAO presents a methodology that makes it possible to estimate the reduction in CO2 emissions from implementing operational measures. This methodology allowed calculating the estimate of CO2 emissions reduction obtained by the implementation of operational measures contemplated in the projects of the SIRIUS Program, considering the year 2021 as a base.

The calculations required using an estimate of aircraft fuel consumption and the annual movement of aircraft at airports with airside operational measures implemented. The information about the status of the implementation of operational measures in the Brazilian aerodromes is available on the website AISWEB. CGNA provided the number of airport movements in the year 2021. Calculations of CO2 emission reduction estimates considered the variety of aircraft operating in Brazilian airspace and, due to this, vary between low and high ends. Several operational measures implemented in Brazil, provided for in the GANP, have a calculation methodology established in Doc 9988 and contribute significantly to reducing CO2 emissions. These operational measures are Continuous Descend Operations (CDO), Continuous Climb Operations (CCO), Standard Terminal Arrival Routes (STAR), Performance Based Navigation - Standard Instrument Departures (PBN-SID), Radius to Fix PBN Procedures, Required Navigation Performance Procedures – Authorization

Required (RNP-AR). The implementation of all these measures is within the scope of the National Airspace Optimization project.

One hundred fifty aerodromes have implemented PBN departures associated with the CCO concept. In 2021, at these aerodromes, there was an approximate movement of 1.25 million aircraft departures. The calculations pointed to a fuel consumption reduction between 90,000 and 187,000 tons, according to the rules of thumb shown in Table 1 (considering that in all aerodromes, 80% of the departure aircraft performed CCO and 100% flying PBN SID). Multiplying these values by 3.16 (the conversion factor), it is possible to find the mass of CO2. Based on the mass of fuel, the estimated reduction in CO2 emissions is between 284,000 and 590,920 tons of CO2.

Table 1: Rule of Thumb for CCO and PBN SID Fuel Consumption Reduction Estimation Calculations

Measure	Rule of thumb	Example
Measures to improve fuel-efficient departure and approach procedures: CCO (CAEP/10 Report 2016)	Use IFSET or FS= 90 – 150kg (0.09 – 0.15 tonnes) of fuel number of CCOs	A State averages 2.000.000 flights per year. Currently, 50 of its airports offer CCO, which accounts for approximately 20.000 departure movements. Expert judgment estimates that CCO is performed by 80% of the departures, a total of 160.000 departure movements. The annual savings can be estimated as: - 0.09 * 160.000 = 14.400 tonnes of fuel saved (low-end range) - 0.15 * 160.000 = 24.000 tonnes of fuel saved (high-end range)
Measures to improve fuel-efficient departure and approach procedures: PBN SID (CAEP/10 Report 2016)	Use IFSET or FS = 0kg to 30kg of fuel (0 to 0.03 tonnes) * number of departure movements on PBN SID	A State averages 1.000.000 flights per year. Currently, 50 of its airports have implemented PBN SID which is estimated to be used by 200.000 departure movements. Expert judgement is that 100% of these departures fly PBN SID. The annual savings can be estimated as: - 0.0 * 200.000 = 0 tonnes of fuel saved (low-end range) - 0.03 * 200.000 = 6.000 tonnes of fuel saved (high-end range)

Source: Author

Thirty-three aerodromes have implemented PBN STAR associated with the CDO concept. STAR is aircraft arrival trajectories for aerodromes with a considerable volume of traffic. The total movement of aircraft approaching these aerodromes was approximately 892,460 in 2021. Based on the rules of thumb in Table 2, the estimated reduction in fuel consumption was between 36,590 and 63,364 tons of fuel, which, based on the already-mentioned factor, generates an estimated reduction in CO2 emissions between 115,624 and 200,230 tons (considering that in all aerodromes 35% of the arriving traffic movement perform CDO and 100% perform PBN STAR).

Thirteen aerodromes in Brazil have PBN arrival procedures associated with radius to fix sections, consisting of circumference arcs that tend to reduce the number of miles flown by aircraft. The total movement of arrivals to these aerodromes in 2021 was 389,980. The estimated calculation of fuel consumption reduction, using the rule of thumb of Table 3, is between 11.738.413 and 23.301.335 tons of fuel, which, multiplied by the factor 3.16, results in CO2 emissions reduction between 37.093.385 and 73.632.219 tons of CO2 (considering 50% of arrivals at all airports fly this approach procedure and the breakdown of traffic at all airports 10%, 80% and 10% in relation to small, medium and heavy aircraft).

Table 2: Rule of Thumb for CDO and PBN STAR Fuel Consumption Reduction Estimation Calculations

Measure	Rule of thumb	Example
Measures to improve fuel-efficient departure and approach procedures: CDO (CAEP/10 Report 2016)	Use IFSET or FS= 60kg (0.06 tonnes) of fuel number of CDOs	A State averages 1.000.000 flights per year. Currently, 10 of its airports offer CDO, which accounts for approximately 4.800.000 arrival movements. Expert judgment estimates that CDO at these airports is performed by 100% in off-peak hours, which accounts for approximately 35% or 1.680.000 traffic movements. The annual savings can be estimated as: - 0.06 * 1.680.000 = 100.800 tonnes of fuel saved
Measures to improve fuel-efficient departure and approach procedures: PBN STAR (CAEP/10 Report 2016)	Use IFSET or FS = 20kg to 50kg of fuel (0.02 to 0.05 tonnes) * number of arrivals on PBN STAR	A State averages 1.000.000 flights per year. Currently, 50 of its airports have implemented PBN STAR which is estimated to be used by 250.000 arrival movements. Expert judgment is that 100% of these departures fly PBN STAR. The annual savings can be estimated as: - 0.02 * 250.000 = 5.000 tonnes of fuel saved (low-end range) - 0.05 * 200.000 = 12.500 tonnes of fuel saved (high-end range)

Source: Author

Table 3: Rule of Thumb for Radius to Fix PBN Procedures Fuel Consumption Reduction Estimation Calculations

Measure	Rule of thumb	Example
Implementation of radius to fix PBN procedures	Use IFSET or FS= [(Total movements * 0.1 * fuel savings for small aircraft (11 – 40kg)) + (total movements * 0.8 fuel savings for medium aircraft (62 – 121 kg)) + total movements * 0.1 * fuel savings for heavy aircraft (95 – 187 kg))] * 0.5	An airport with 100.000 arrival movements is planning to implement radius to fix procedures. It is assumed that 50% of arrivals to this airport will fly this approach procedure. Procedure. The breakdown of traffic at this airport is estimated to be: 10%: 80%: 10% in relation to small: medium: heavy aircraft. The annual fuel savings can be estimated as: - ((100.000 * 0.1 * 11 kg) + (100.000 * 0.8 * 62 kg) + (100.000 * 0.1 * 95 kg)) * 0.5 = 3.010 tonnes of fuel saved (low end range) - ((100.000 * 0.1 * 40 kg) + (100.000 * 0.8 * 121 kg) + (100.000 * 0.1 * 187 kg)) * 0.5 = 11.950 tonnes of fuel saved (high end range)

Source: Author

Finally, twelve aerodromes in Brazil have RNP AR APCH-type arrival procedures, which are PBN arrival procedures that require special authorizations for their execution by aircraft crews due to particular characteristics. The total number of aircraft arrivals using these procedures in 2021 was 376,343. Based on the rules of thumb in Table 4, we arrive at an estimate of fuel consumption reduction between 358,466 and 442,203 tons, which from the conversion factor provides an estimate of CO2 emissions reduction between 1,132,754 and 1,397 .362 tons of CO2 (considering 50% of arrivals at all airports fly this approach procedure).

Table 4: Rule of Thumb for RNP AR APCH Procedures Fuel Consumption Reduction Estimation Calculations

Measure	Rule of thumb	Example
Implementation of RNP AR APCH procedures for reducing approach minima and the possibilities of missed approach/diversion	Use IFSET or FS= total arrival movements * 0.5 * 0.005 * fuel savings (381 – 471 kg)	An airport with 100.000 arrival movements is planning to implement an RNP AR APCH procedure. It is assumed that 50% of arrivals to this airport will fly this approach procedure. It is estimated that in the event of a missed approach or diversion the average extra fuel burn used ranges from 381 – 470 kg. It is assumed that the minima are sufficiently reduced to require an aircraft to carry out a missed approach or diversion in 0.005 operations. The annual fuel savings can be estimated as: - 100.000 * 0.5 * 0.005 * 381 kg = 95.25 tonnes of fuel saved (low end of range) - 100.000 * 0.5 * 0.005 * 470 kg = 117.5 tonnes of fuel saved (high end of range)

Source: Author

Therefore, in 2021, the estimated reduction in CO2 emissions due to the implementation of airside operational measures in Brazil was between 37.8 and 75.8 million tons. However, it is essential to emphasize that the estimates mentioned above and presented in Figure 6 only include operational measures associated with aerodromes and do not include those associated with the airspace itself. So, operational measures such as the Flexible Use of Airspace (FUA) and Direct Routes, among others, were not included in the calculations. They also do not include operational measures associated with aerodromes but which do not contribute significantly to the reduction of CO2 emissions because they have yet to be implemented on a large scale, being present only in a few airports. Among these measures, we can highlight the Arrival Manager (AMAN), Airport Collaborative Decision-Making (ACDM), and Automatic Dependent Surveillance-Broadcast (ADS-B).

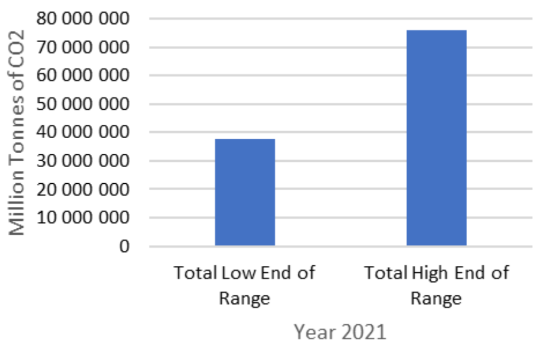

Figure 6: Total CO2 Emissions Reduction Estimate from Operational Measures in the Year 2021

Source: Author

Discussion and conclusions

The CO_2 emissions from all air transport worldwide account for only 2% of total emissions, considering all other sources. However, its effects are enhanced as these emissions occur at high altitudes. These impacts will probably increase, given that despite the impact of the COVID-19 pandemic on air transport activity worldwide, its growth will be exponential in the long term. Reducing GHG emissions is possible by implementing operational, technological, and market measures and using SAF. However, each of these measures has peculiar characteristics that can facilitate or hinder their implementation.

Implementing technological measures and using sustainable fuels have the most significant potential for reducing CO_2 emissions. However, technological measures have a high implementation cost, and their incorporation into aircraft fleets takes a long time. Using SAF strongly depends on reducing associated production costs and developing a supply chain that allows its production to scale. As for market measures, ICAO launched CORSIA, which comprises a global compensation scheme to reduce CO_2 emissions from air transport, establishing as a baseline the number of international flights carried out in each State between 2019 and 2020. Because of the COVID-19 pandemic, ICAO decided only to consider flights performed in 2019 to form the baseline. The implementation of operational measures is worldwide, as they appear in the Global Air Navigation Plan that guides their implementation in ICAO signatory countries.

The BRICS countries, primarily members of the ICAO Council, have been implementing several operational measures that increase the efficiency of air transport operations. The Ministry of Transport of Russia and South Africa, the Airport Authority of India, the Civil Aviation Administration of China, and the Department of Airspace Control in Brazil (DECEA) carry out several based on their national plans inspired by GANP. The increase in efficiency caused by the implementation of operational measures generates a reduction in fuel consumption and, consequently, in CO_2 emissions.

The article presented an estimate of the reduction in CO_2 emissions in Brazil in 2021 due to the operational implementations made by DECEA on the air side associated with several aerodromes in the country, based on the methodology established by ICAO that uses the annual number of movements at the aerodromes where these operational measures were implemented and allows calculating the estimated fuel savings obtained and, consequently, the estimated reduction in CO_2 emissions. These operational measures generally result in more continuous climb and descent trajectories and more direct cruise flights, in addition to increasing the accessibility of airports in bad weather conditions, which prevents aircraft from performing holdings in the airspace, emitting CO_2, while awaiting improvements in these conditions.

Considering CORSIA and the BRICS countries, only South Africa volunteered to participate in the pilot phase and the scheme's first phase. However, except for South Africa, all other BRICS countries must participate in the second phase of CORSIA in 2027, as they are part of 90% of the RTK accumulated in the world unless they present a difference to ICAO that justifies their non-participation. Since the air transport infrastructure development and the increase in flights can promote economic growth and social inclusion, schemes such as CORSIA may constrain growth strategies in developing countries, such as BRICS countries, by raising the operational costs of the air transport systems, which already need more and sometimes adequate infrastructure.

Some strategies could be adopted to mitigate the effects of CORSIA on the development of air transport. The BRICS countries impacted by these measures could, together, present the so-called difference to ICAO, justifying their non-participation in the compulsory phase of the scheme due to evident inequalities between the air transport systems of the Global South and the Global North. In return, these countries could promote policies to encourage the production and use of SAF, as well as increase investment in the implementation of operational measures that align with the "United Nations' sustainable development goals.

It is necessary to consider alternative measures to achieve the efficiency of operations and reduction of GHG emissions in these countries through evaluations based on the efficiency of operations and not on the volume of emissions generated. With this, it will be possible to allow a sustainable expansion of air transport activities in the BRICS countries, favoring their economic growth. In addition, expanding the air transport infrastructure in these countries and assuring favorable conditions for people to spend their resources on them will foster tourism activities and economic growth.

As mentioned, there is a big difference between the air transport infrastructure and connectivity of G7 and BRICS countries. The number of international airports per million inhabitants in the BRICS countries is lower than in the G7 countries, except for Russia, which has a higher number than Japan and Germany. Additionally, observing the expenditures and receipts related to international tourism activities among the BRICS and G7 countries, it is possible to notice that while the G7 nations handle 56% of expenditures on international tourism, they receive about 87% of total revenue. The seats made available in 2019 between direct flights from the BRICS countries to the G7 countries were almost ten times greater than those made available for direct flights between the BRICS countries themselves. Thus, there is evidence of a preference by populations of the BRICS countries to take tourist trips to the G7 countries to the detriment of trips to other BRICS countries.

However, increasing the number of airports in BRICS countries to accommodate more flights will not promote economic growth per se. Visitors must have favorable conditions to spend resources on goods and services in these countries. We must consider that demand for air transport is associated not only with the accessibility and price of services but also with changes in society's consumption patterns and GDP growth. It is noteworthy that even if consumption patterns change and more people can travel, they prefer to travel to countries in G7 nations or other destinations in developed countries rather than BRICS and other developing countries. The migration patterns in international tourism activities are related to historical ties between metropolises and colonies, and due to this, outbound tourism from BRICS to the Global North is more significant than outbound tourism among the countries of the block. The change in these preferences may involve the adoption of policies among the BRICS countries to promote international tourism activities among them, as well as actions to build human capital and maintain environments conducive to attracting tourists both from other BRICS countries and from other countries around the world.

Furthermore, it is necessary to disseminate a more positive image of BRICS countries, highlighting their natural beauties and other attractions. It should be noted, however, the importance of promoting sustainable tourism without generating impacts that degrade the environment and destroy the social fabric, especially in small and more isolated locations. It is also important to highlight that the economic growth process would be even more effective if the BRICS countries promoted outbound tourism between themselves, encouraged by establishing a preferential visa regime and through cooperation programs for workforce training and technology transfer, among other actions.

Future studies should consider more advanced techniques that use specific tools and systems to obtain more precise estimates on the reduction of CO2 by Brazilian air transport based on more accurate operational data since these calculations, in addition to simplifications of reality, only considered some airside operational measures implemented in Brazil associated with aerodromes. Other operational measures not directly associated with the aerodromes but with portions of airspace, such as Direct Routes and Flexible Use of Airspace, were not considered. It is essential to highlight that the calculated CO2 emissions reduction is a reasonable approximation of the benefits associated with airside operational measures. It is essential in addition to analyze why the population of the BRICS nations are not interested in traveling to other BRICS countries and try to find out ways of promoting international tourism activities inside the arrangement. Finally, it is important to expand the analysis of the feasibility of creating a Global South Air Transport Belt including the new countries that are joining the BRICS.

References

da Cunha Dias, T. A., Lora, E. E. S., Maya, D. M. Y., & del Olmo, O. A. (2021). Global potential assessment of available land for bioenergy projects in 2050 within food security limits. Land use policy, 105, 105346. https://doi.org/10.1016/j.landusepol.2021.105346

DECEA 2022a. Sirius Brasil. The Aviation of the Future has Begun. Available: https://sirius.decea.mil.br/en/ [Accessed 02 Sep 2022]

Dimitrios, D., & Maria, S. (2018). Assessing air transport socio-economic footprint. International Journal of Transportation Science and Technology, 7(4), 283-290. https://doi.org/10.1016/j.ijtst.2018.07.001

Dobson, A. (2017). A history of international civil aviation: from its origins through transformative evolution. Routledge. https://doi.org/10.4324/9781315180601

Gössling, S., & Humpe, A. (2020). The global scale, distribution and growth of aviation: Implications for climate change. Global Environmental Change, 65, 102194. https://doi.org/10.1016/j.gloenvcha.2020.102194

Hasan, M. A., Mamun, A. A., Rahman, S. M., Malik, K., Al Amran, M. I. U., Khondaker, A. N., ... & Alismail, F. S. (2021). Climate change mitigation pathways for the aviation sector. Sustainability, 13(7), 3656. https://doi.org/10.3390/su13073656

ICAO 2002. Doc9750 2ed. Global Air Navigation Plan for CNS/ATM Systems.

ICAO 2014. Doc10031 1ed. Guidance on Environmental Assessment of Proposed Air Traffic Management Operational Changes.

ICAO 2016. Doc 9613 4ed. Performance-based Navigation (PBN) Manual.

ICAO 2018. Resolution A40-18: Consolidated statement of continuing ICAO policies and practices related to environmental protection - Climate change. Available: https://www.icao.int/enviromental- protection/Documents/Assembly/Resolution_A40-18_Climate_Change.pdf [Accessed 30 Aug 2022]

ICAO 2019a. Environmental Report. Available: https://www.icao.int/environmental- protection/Documents [Accessed 16 Dec 2022]

Van Fan, Y., Perry, S., Klemeš, J. J., & Lee, C. T. (2018). A review on air emissions assessment: Transportation. Journal of cleaner production, 194, 673-684. https://doi.org/10.1016/j.jclepro.2018.05.151

ICAO 2019b. Global Air Navigation Plan. 6ed Available: https://www4.icao.int/ganpportal/ [Accessed 31 Aug 2022]

ICAO 2022a. Committee on Aviation Environmental Protection (CAEP). Available: https://www.icao.int/environmental-protection/pages/caep.aspx [Accessed 26 Aug 2022]

ICAO 2022b. Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)Available: https://www.icao.int/environmental- protection/pages/caep.aspx [Accessed 29 Aug 2022]

ICAO 2022c. Report on the Feasibility of a Long-Term Aspirational Goal (LTAG) for International Civil Aviation CO2 Emission Reductions. Available: https://www.icao.int/environmental-protection/LTAG/Documents [Accessed 30 Aug 2022]

ICAO 2022d Uniting Aviation. Available: https://unitingaviation.com/news/general- interest/the-icao-assembly-has-elected-new-council-member-states-for-a- three-year-term/ [Accessed 16 Dec 2022]

Lee, J. W. (2017). A New Global Approach to Mitigating Emissions from International Aviation: the International Civil Aviation Organization's 39th Assembly (2016). Chinese Journal of Environmental Law, 1(1), 104-110. https://doi.org/10.1163/24686042-12340007

Liu, Z., Ciais, P., Deng, Z., Lei, R., Davis, S. J., Feng, S., ... & Schellnhuber, H. J. (2020). Near-real-time monitoring of global CO2 emissions reveals the effects of the COVID-19 pandemic. Nature communications, 11(1), 1-12. https://doi.org/10.1038/s41467-020-18922-7

Lyle, C. (2018). Beyond the ICAO's CORSIA: Towards a more climatically effective strategy for mitigation of civil-aviation emissions. Climate Law, 8(1-2), 104-127. https://doi.org/10.1163/18786561-00801004

Polyzos, S., & Tsiotas, D. (2020). The contribution of transport infrastructures to the economic and regional development. Theoretical and Empirical Researches in Urban Management, 15(1), 5-23.

Marazzo, M., Scherre, R., & Fernandes, E. (2010). Air transport demand and economic growth in Brazil: A time series analysis. Transportation Research Part E: Logistics and Transportation Review, 46(2), 261-269. https://doi.org/10.1016/j.tre.2009.08.008

Mishra, P. K., Rout, H. B., & Sahoo, D. (2021). International Tourism and Economic Growth: Empirical Evidence from BRICS Countries. https://doi.org/10.46222/AJHTL.19770720.202

Nižetić, S. (2020). Impact of coronavirus (COVID-19) pandemic on air transport mobility, energy, and environment: A case study. International Journal of Energy Research, 44(13), 10953-10961. https://doi.org/10.1002/er.5706

Njoya, E. T., & Knowles, R. D. (2020). Introduction to the special issue: Air transport in the Global South. Journal of Transport Geography, 87, 102814. https://doi.org/10.1016/j.jtrangeo.2020.102814

Park, J. S., Seo, Y. J., & Ha, M. H. (2019). The role of maritime, land, and air transportation in economic growth: Panel evidence from OECD and non-OECD countries. Research in Transportation Economics, 78, 100765. https://doi.org/10.1016/j.retrec.2019.100765

Pérez-Castán, J. A., Comendador, F. G., Rodríguez-Sanz, A., Montes, R. B., Valdés, R. A., & Sanz, L. P. (2018). Impact of continuous climb operations on airport capacity. Transportation Research Part C: Emerging Technologies, 96, 231- 250. https://doi.org/10.1016/j.trc.2018.09.008

Pisa, N. (2018). Causal relationship between air transport, tourism and economic growth: joinpoint regression and granger causality analysis. Euro Economica, 37(02), 164-176

Singh, A. (2019). Understanding Aviation Law Through the Evolving Concept of Sovereignty Beyond the Traditional Deep Blue Skies. Available at SSRN 3615130. https://doi.org/10.2139/ssrn.3615130

Turgut, E. T., Usanmaz, O., Cavcar, M., Dogeroglu, T., & Armutlu, K. (2019). Effects of descent flight-path angle on fuel consumption of commercial aircraft. Journal of Aircraft, 56(1), 313-323. https://doi.org/10.2514/1.C033911

Villegas Díaz, M., Gómez Comendador, V. F., García-Heras Carretero, J., & Arnaldo Valdés, R. M. (2020). Environmental benefits in terms of fuel efficiency and noise when introducing continuous climb operations as part of terminal airspace operation. International Journal of Sustainable Transportation, 14(12), 903-913. https://doi.org/10.1080/15568318.2019.1651924

Wickens, C. D., Mavor, A. S., McGee, J., & National Research Council. (1997). Panel on human factors in air traffic control automation. Flight to the future: human factors in air traffic control.

Usmani, G., Akram, V., & Praveen, B. (2021). Tourist arrivals, international tourist expenditure, and economic growth in BRIC countries. Journal of Public Affairs, 21(2), e2202. https://doi.org/10.1002/pa.2202

Zhang, F., & Graham, D. J. (2020). Air transport and economic growth: a review of the impact mechanism and causal relationships. Transport Reviews, 40(4), 506- 528. https://doi.org/10.1080/01441647.2020.1738587

Zhang, J., Zhang, S., Wu, R., Duan, M., Zhang, D., Wu, Y., & Hao, J. (2021). The new CORSIA baseline has limited motivation to promote the green recovery of global aviation. Environmental Pollution, 289, 117833. https://doi.org/10.1016/j.envpol.2021.117833