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The Relationship Between Airline Transportation and Carbon Emissions: The Case of G20 Countries

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Abstract

Employing the panel data analysis, this research discusses the impact of air transportation on carbon emissions (CO_2) in G20 nations employing data from 1994 to 2021. The analysis revealed that there exists a positive but statistically insignificant relationship between air passenger transportation and freight transportation, and an adverse relationship between air passenger transportation and CO_2. In the research model, it was claimed that more economic growth, the use of fossil fuels, and trade openness would all result in higher CO_2 nevertheless, this rise in trade openness was deemed statistically insignificant. Furthermore, the causality results indicate that unidirectional causality was found between CO_2 emissions and trade liberalization, economic growth, the use of fossil fuels, and air freight transport. In contrast, bidirectional causality was found between CO_2 and air passenger transport. According to the findings, it might be suggested that policies like allowing sustainable aviation fuels to take a larger share of the air transportation market, creating technological advancements, initiating research and development, and supplying energy—the engine of economic growth—from clean and renewable sources such as wind and solar power are crucial steps for G20 nations to meet their zero emission targets and assure sustainability in the aviation industry.

1. Introduction

Both economic activity and the consumption of natural resources have expanded as a result of the world's population growth. Growing economic activity has also put strain on the environment, harmed natural systems, and put all life on Earth in danger. Fossil fuel use and the disastrous greenhouse gas emissions from agriculture, particularly CO_2, have become the prelude to many disasters, raising average temperatures and contributing to climate change and global warming. Many environmental issues, including those related to agriculture, water scarcity, human health, and the extinction of numerous species, are brought on by climate change. CO_2 emissions from the careless use of fossil fuels are the primary driver of climate change (Gyamfi et al., 2022; Zanjani et al., 2023; Binsuwadan, 2024). Since CO_2 are the most common emissions discharged into the environment and diverge by sector, they are of critical significance globally. Figure 1 shows how CO_2 were distributed by sector in the 2024 Report by Air Transport Action Group (ATAG).

As illustrated in Figure 1, the industrial sector has the largest CO_2 with a rate of 38%. The transportation industry comes in second with 15%. With 11%, agriculture comes in third, and the fuel generation industry comes in fourth with 10% (ATAG, 2024). Through linking various industries, the transportation sector is one of the major sectors that contributes both directly and indirectly to economic progress, as well as social interaction and cultural transformation.

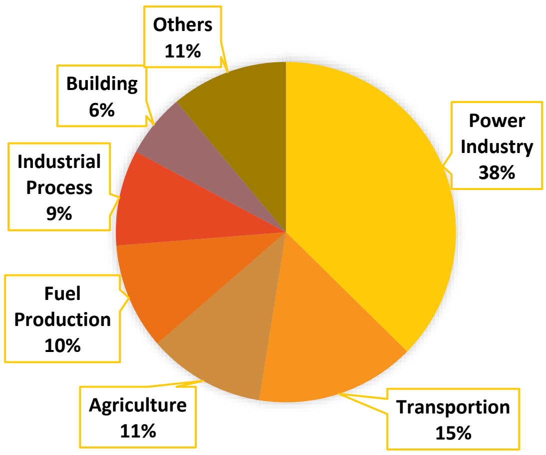

Figure 1. Distribution of CO_2 emissions by sectors

Notwithstanding these advantages, the transportation industry also affects the environment by releasing greenhouse gases, which results in air pollution and alterations to living environments (Kongbuamai et al., 2023; Dai et al., 2023). The various sub-sectors of the transportation sector—air, sea, land, and railway—have varying effects on CO_2 and contribute substantially to national economies. Figure 1 displays that 11% of the 15% CO_2 from the transportation industry as a whole come from land transportation, 2% from air travel, and

2% from other forms of transportation (such as the sea or the railroad) (ATAG, 2024). According to this research, travel by land, sea, train, and air-all of which are fundamental components of national economies has a direct impact on CO_2. Developments in the aviation industry have had an impact on nations' social, economic, and environmental spheres in recent years. In this context, the report published by ATAG includes information on the economic, social and environmental zones of the aviation sector and this information is supplied in Figure 2.

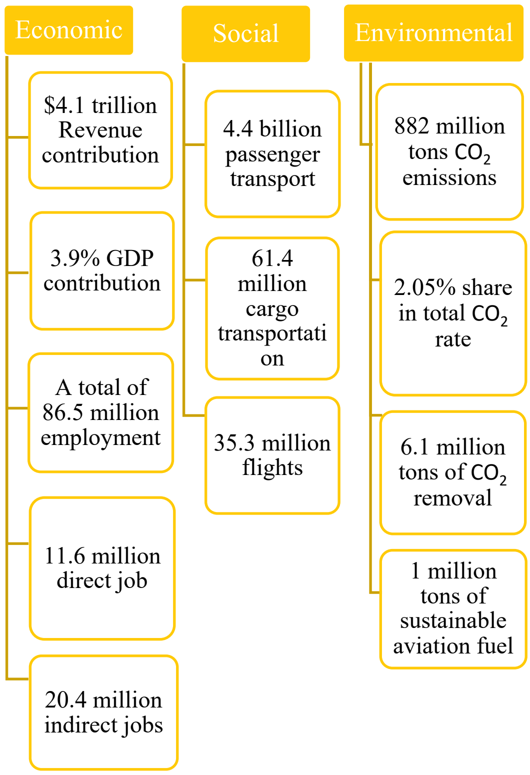

Figure 2. Data for the aviation industry in 2023

The economic, social, and environmental data of the aviation industry has been displayed in Figure 2. Based on the evidence, it can be argued that the aviation industry has contributed significantly to the economy by creating jobs and generating large incomes, as well as to society by transporting both passengers and goods. However, in terms of the environment, it has been calculated that the aviation industry contributes 883 million CO_2 overall, accounting for 2% of all transportation-related CO_2. Nonetheless, it has been noted that in order to guarantee sustainability in aviation, sustainable fuels are utilized. Sustainable fuel consumption has not been the only notable advancement in sustainability in the aviation industry. In 2015, the idea that the environment should be integrated into every field was put into practice by the United Nations (UN). Accordingly, the Sustainable Development Goals (SDGs) were determined to ensure economic, social and environmental sustainability. The 7th Sustainable Development Goal, "Clean and Affordable Energy," aims to expand access to clean energy and integrate clean energy sources into production to meet both economic and environmental goals (UN, 2021; Ritchie, 2020). Agreements worth $45 billion have been achieved in the aviation industry for the use of sustainable aviation fuel in 2023 in order to achieve this goal. Critical measures made to ensure sustainability encompass the use of 80% alternative fuels, the compatibility of aircraft engines and fuselages with fuels, and agreements with 50 airlines and 98 airports for the use of sustainable aviation fuel. In order to maintain sustainability in the aviation industry, sustainable aviation fuels are widely employed for a pair of reasons. These fuels, first and foremost, diminish the aviation industry's carbon footprint while powering the world's fleet of aircraft. Regarding the goal of achieving zero emissions by 2050, it is anticipated that the use of sustainable aviation fuels will cut CO_2 by 80% and even help reduce emissions by 53% to 71% (ATAG, 2024). Another explanation is that 3.5% of climate change is attributed to the aviation industry (Gyamfi et al., 2021; IPCC, 1999).

In contrast to these breakthroughs in the aviation industry, the Civil Aviation Organization (ICAO) predicts that by 2050, CO_2 produced by the air transport might go up to 2.6 billion tons or 22 percent of the global total, unless reduction implementations are put into practice. Compared to the current amount of CO_2 emissions, this is around eleven times greater, which is about 2 percent (Habib et al., 2021:12). In this regard, nations seeking long-term growth have a challenge to face since the aviation industry contributes 2% of environmental pollution. The study examines the relationship between air transport activities and CO_2 in G20 countries. G20 countries account for approximately 42.67% of the world's total economic output and are expected to account for approximately 44.56% of the total output by 2027 (Statista 2024b). G20 countries are among the countries that emit the most emissions in the world, parallel to their weight in the global economy, and are responsible for approximately 78% of total greenhouse gas emissions (OXFAM, 2023). For instance, nations with high CO_2 include the United States, Canada, and Australia. The CO_2 emissions per capita of G20 countries are given in Figure 3.

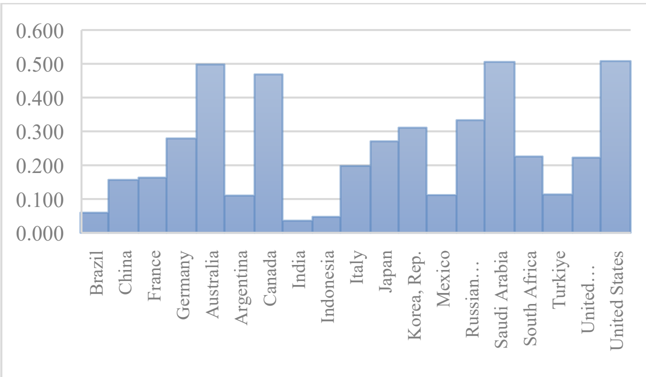

Figure 3. Periodic change in CO_2 per capita in G20 countries

Figure 3 highlights that, out of the twenty nations, the USA, Canada, Australia, and Russia have the largest CO_2 emissions per person. India and Indonesia have the lowest CO_2 emissions. In line with this information, uncovering the environmental processes in G20 countries and the economic dynamics behind them is important for the economic and environmental policies implemented in the world (World Bank, 2024).

Contrary to the studies in the literature, this study aims to contribute to the literature by examining the relationship between air transport activities and carbon emissions in G20 countries, which have global importance in terms of economic size and emission volume. In addition, current findings were obtained using 1994-2021 data covering the post-COVID-19 period and the results were interpreted by evaluating the indirect effects of the pandemic process. In this context, the outline of the study is as follows: Firstly, the introduction provides theoretical information about the topic. Sample empirical research on the topic is then discussed in the literature part, and the findings of the panel data analysis are presented under the third heading, which also points out the data and econometric approach. The gained results are discussed and policy recommendations are offered in the conclusion section.

2. Literature

An examination through of the literature demonstrates the fact that the majority of the research focuses on the variables that contribute to rising CO_2. Plenty of variables, such as population increase, urbanization, growth in the economy, and energy use, could exert a positive or negative effect on CO_2. The transportation industry also contributes significantly to CO_2. Even still, it might be argued that there is not as much research investigating the relationship between CO_2 and the transportation industry as there is in the literature today. Due to its increasing importance in recent years, the aviation industry was thus taken into account in this study, and its impact on CO_2 has been examined. The studies looking into the relationship between the aviation sector and CO_2 can be summarized as follows:

Hassan and Nosheen (2018) implemented three different models, Granger causality, vector autoregression (VAR), and ARDL techniques to examine the impact of air transport on CO_2, methane, and nitrogen emissions in Pakistan using data from 1990 to 2017. The research study concluded that passenger and air transportation operations led to a rise in CO_2, methane, and nitrogen emissions both in the short and long haul. Furthermore, energy demand, population density, and GDP per capita were found to raise all three emissions; however, trade and foreign direct investments had no noticeable effect on these three emissions.

Saleem et al. (2018) investigated the effects of population density, energy demand, and air-rail transportation on environmental deterioration using data from 1975 to 2015 in the next 11 nations. The analysis came to the conclusion that the environmental Kuznets line between CO_2, per capita income, and air-rail transportation is accurate. Additionally, it was remarked that population density and energy consumption raise greenhouse gas and CO_2.

Adedoyin et al. (2021) surveyed the relationship between air transportation and CO_2 emissions applying data from 1995 to 2016 in high-, upper-, and low-income nations. The researchers found that both high-income and low-middle-income nations CO_2 climbed as a result of air transportation. Additionally, they claimed that while energy consumption and coal rents had a favorable impact on CO_2 across all country groups, it had the opposite effect in upper-middle-income countries.

The effects of airline passenger and freight transport activities on CO_2 in 21 OECD nations were investigated by Hassan et al. (2021) applying panel data analysis and data spanning 1980–2018. In light of the results, it was concluded that economic growth and airline passenger transportation would result in higher CO_2 temporarily while lowering them over time. Additionally, it was brought up that energy use, international trade, and airplane freight transportation all contribute to higher CO_2 emissions.

Focusing on the data from 1979 to 2019, Kırcı Altınkeski et al. (2022) inquired the effect of air transportation on CO_2 emissions using the panel threshold value regression model for European nations. They concluded from the analysis that the detrimental effects of civil aviation on environmental quality will vanish once greenhouse gas mitigation technologies surpass a particular threshold value. It was claimed that the number of patents aimed at mitigating climate change has an asymmetric value and that economic expansion and energy consumption will raise CO_2.

Using data extending from 1983 to 2016, Ali et al. (2022) adopted the ARDL approach to investigate the relationship between air transportation and ecological footprint in China. The investigation revealed that while air transportation did contribute to CO_2 emissions in the short term, this rise dissipated over time. According to the researchers, economic complexity was not statistically significant, and energy efficiency decreased the ecological footprint over the long and short terms.

Chen et al. (2022) analyzed data from the countries that make up the G7 from 1990 to 2019 through the panel data analysis method to study the relationship between air transportation, eco-innovation, and environmental degradation. Consequently, the study inferred that eco-innovation and air transportation are crucial in mitigating environmental deterioration.

Considering data from 1998 to 2016, Chatti and Majeed (2022) implemented the Generalized Moments Method (GMM) to explore how transportation activities, including air transport, affected CO_2 emissions in 46 nations. The results demonstrate that information and communication technologies and passenger transportation activities can have a positive impact on environmental sustainability by lowering CO_2 emissions. The results further demonstrate that the air and rail passenger sectors make better use of internet connectivity.

Analyzing data from 1970–2020, Dursun (2022) researched the relationship between air transport and the ecological footprint in Finland and France. The study discovered that while Finland did not experience the effects of economic growth, air transport, and energy efficiency on the ecological footprint, France accomplished. According to the study, the Environmental Kuznets curve was also shown to be valid in France but invalid in Finland.

Working with the data from 1995 to 2016, Gyamfi et al. (2022) evaluated the impact of rail and air transportation on CO_2 emissions in E7 countries with the help of panel data analysis. The study has drawn the conclusion that while urbanization and railway mobility cut emissions, airline transportation and the burning of fossil fuels raise them.

Habib et al. (2022) used panel data analysis to investigate the heterogeneous impact of air transportation intensity and passenger and freight transportation activities on CO_2 emissions in G20 countries. According to the researchers, the intensity of air transportation, freight, and passenger travel all raised CO_2 emissions. Besides, they eventually arrived at the conclusion that while the model's inclusion of economic growth, urbanization, and tourism activities raised CO_2 emissions, an increase in oil prices decreased them.

Taking data from 1990 to 2018, Lin and Wu (2022) deployed the ARDL approach to assess the relationship between transportation, the environment, and health in China and the USA. As a result of the investigation, transportation activities and environmental pollution have been determined to be negatively correlated in the USA and positively correlated in China, respectively. Furthermore, it was found that environmental improvement increased health expenditures in the USA, while environmental improvement decreased health expenditures in China.

Taking the data into consideration that belongs to years from 1995 to 2018, Yaşar (2022) intended to delve into the relationship between information and communication technology, particularly air transportation, economic growth, and CO_2 emissions in Türkiye applying the ARDL approach. The results exhibit that while economic growth and information and communication technology raise CO_2 emissions both in the short and long terms, population growth raises CO_2 emissions in the short term but diminishes them in the long run. In addition, although it was ascertained that air transportation and information and communication technologies increase CO_2 emissions in the long term, it was stated that IT technologies are statistically insignificant.

Avotra and Nawaz (2023) employed the nonlinear autoregressive distributed lag (NARDL) approach to look into the way the air transportation affected CO_2 emissions and climate change in Pakistan focusing on the data from 1971 to 2021. According to the research, rising levels of energy consumption, per capita income, and air transportation all contributed to long-term increases in CO_2 emissions. However, it was alleged that oil pricing, trade, and the usage of renewable energy all lessen CO_2 emissions.

Implementing the GMM approach, Ghannouchi et al. (2023) investigated how three distinct transportation activities affected the environmental quality of 33 developed and emerging European nations. The investigation revealed that there was a negative correlation between railway transportation and CO_2 emissions in industrialized nations, but there was a positive correlation between maritime transportation and CO_2 emissions in all countries. In developing nations, however, there is a positive relationship between railway transportation and CO_2 emissions. Ultimately, it was concluded that the impact of air transportation on CO_2 emissions is extremely minimal and is considered to be insignificant.

The impact of transport by air on CO_2 emissions and the ecological footprint in APEC countries has been studied by employing the two separate models developed by Kongbuamai et al. (2023) using data lasting from 1992 to 2015. According to the findings, air transportation increased CO_2 emissions at a relatively low pace and ecological footprint at the expected rate. Plus, globalization—a component of both models—was found to have a positive impact on energy consumption but a negative impact on CO_2 emissions and the ecological footprint. Moreover, it was ended that economic growth has become the driving force of sustainable development.

Using data from 1999 to 2017, Xiong et al. (2023) applied the Different in Different (DID) technique to determine how airports affected CO_2 emissions in 280 Chinese cities. According to the examination, airport operations resulted in a 4.3% increase in CO_2 emissions. It was also found that per capita income, population density, and industrial structure all contributed to the increase in CO_2 emissions.

The study undertaken by Zanjana et al. (2023) investigated how air transportation influences CO_2 emissions for eight Middle Eastern oil-producing nations between 2013 and 2019. Ultimately, the analysis uncovered that while air transportation elevated CO_2 emissions across all regions, except in Iran and Qatar, the rate was larger than previously thought.

Aldegheishem (2024) used data for the period 1991-2023 and examined the effect of air transportation, foreign trade and economic growth on CO_2 emissions in Saudi Arabia using the ARDL method. The researcher stated that foreign trade, economic growth and air transportation increased CO_2 emissions in both the long and short term.

In order to identify the relationship between air transportation, economic growth, international commerce, energy consumption, and CO_2 emissions in the Gulf Union countries, Binsuwadan (2024) collected data from 1990 to 2020. The findings highlighted that air transportation contributed to higher energy consumption, and economic growth correlated to higher CO_2 emissions. Besides, it was asserted that population and foreign trade reduced CO_2 emissions, but this ratio was found to be statistically insignificant.

Beşer et al. (2024) searched for the implications of rail and air transportation on CO_2 emissions in Türkiye analyzing data from 1970 to 2020. The investigation disclosed that whilst rail transportation reduced CO_2 emissions, air transportation increased them. Also, research has indicated that economic growth is contributing to rising CO_2 emissions.

The effect of air travel on CO_2 emissions was investigated by Katircioğlu (2024) utilizing global and regional panel data for nations with varying income levels. Therefore, the study concluded that there was no statistically significant effect of air transportation on CO_2 emissions in high-income nations. Air transportation was found to be negatively correlated with CO_2 emissions in the Arab world, East Asia, the Pacific, the Eurozone, and the nations that make up the European Union.

Considering data from 1970 to 2018, Salhi et al. (2024) executed the ARDL method to look into the relationship between air transportation and ecological footprint in BICS nations. The study uncovered that, with the exception of Brazil and India, there was a positive correlation between air travel and ecological impact. Furthermore, industrialization was found to have a positive relationship with GDP in all countries except Brazil, but a negative correlation with ecological footprint and foreign direct investment in all nations except China. Lastly, it was mentioned that urbanization had a positive effect on all nations with the exception of South Africa.

Yıldız and Yıldız (2024) analyzed data from 1990 to 2018 and employed the Augmented Mean Group Estimator to investigate the impact of air transportation, economic growth, and the usage of renewable energy on CO_2 emissions in the G5 countries. Two distinct models have been applied in the study to assess the way freight and aviation transportation influenced CO_2 emissions. The results marked that while passenger transport was statistically insignificant, air freight transport was found to decrease CO_2 emissions. In addition, it was revealed that economic growth positively affects CO_2 emissions in both models, while energy consumption is affected negatively.

Most of the studies in the empirical literature have focused on specific country groups (OECD, G7, EU) or single country analyses. However, long-term analyses of the G20 countries, which are of critical importance at the global level in terms of economic size and emission volume, are quite limited. In addition, there are a limited number of studies that distinguish between passenger and freight transport and examine their effects on CO_2 emissions at different levels. The difference of this study from other studies in the literature is that it covers a critical group of countries such as G20 and provides a comprehensive analysis of the effects of air transport subcomponents on CO_2 emissions with up-to-date data by including the COVID-19 period. Contrary to these differences, the results obtained from the study, the conceptual framework and the econometric methods used are similar to other studies in the literature.

3. Data and Econometric Methodology

This paper discusses the data that belongs to the period of 1994-2021 and the impact of airline transportation on CO_2 emissions in G20 countries was surveyed through panel data analysis.

3.1. Data

The study employed CO_2 emissions per capita as a stand-in for CO_2 emissions. One of the primary explanatory factors was the quantity of passengers and cargo transported by air. The model also includes trade openness (as a percentage of GDP) and fossil energy use as control variables, as well as real GDP per capita as a stand-in for economic growth. The official World Bank database from 2024 provides the research data. Table 1 lists the variables implemented in the research.

Table 1. Research Variables

Dependent Variable	Explanation	Type	Data Source
LnCO₂	CO_2 emissions per capita	Natural logarithm was taken.	World Bank
Core Explanatory Variable			
LnAIRPASS	Air transportation, number of passengers carried	Natural logarithm was taken.	World Bank
LnAIRCARGO	Air transport, freight (million ton-km)	Natural logarithm was taken.	World Bank
Control Variable			
LnGDP	Real GDP per capita	Natural logarithm was taken.	World Bank
LnFOSSIL	Fossil fuel consumption (Terawatt-hour)	Natural logarithm was taken.	Our World in Data
OPENNESS	Trade openness	The ratio of total exports and imports of goods and services to GDP was taken.	World Bank

3.2 Econometric Methodology

While adhering to the body of current empirical literature, the study assessed the econometric relationship between the variables (Hassan and Nosheen, 2018; Habib et al., 2022; Gyamfi et al., 2022; Avotra and Nawaz, 2023; Ghannouchi and Aloulou, 2023; Aldegheishem, 2024; Beşer et al., 2024; Katircioğlu, 2024). The functional representation of the relationship between variables is as follows:

$$LnCO_2 = f(LnAIRPASS_{it},\ LnAIRCARGO_{it},\ LnGDP_{it},\ LnFOSSIL_{it},\ OPENNESS_{it}) \quad (1)$$

$lnCO_2$ was employed to represent environmental pollution, and its natural logarithm was carried out in the model. Within the context of air transportation activities, for passenger transportation $AIRPASS$, for cargo (load) transportation $AIRCARGO$, for economic growth GDP, for fossil energy consumption $FOSSIL$ variables were exercised and their natural logarithm was obtained. In addition, the model included the $OPENNESS_{it}$ variable to embody trade openness. The panel data relationship between the variables is manifested as follows:

$$lnCO_{2it} = \beta_0 + \beta_1 lnAIRPASSit + \beta_2\ lnAIRCARGOit + \beta_3 lnGDP_{it} + \beta_4 lnRENEWit + \beta_5 OPENNESS_{it} + \varepsilon_{it} \quad (2)$$

In the model, the constant slope and coefficient parameters are portrayed with "β_0 and β", the unit and time dimension in the estimated model are depicted with "i and t", and the error term is represented with "ε". In order to test the cross-sectional dependence of the series within the scope of the research, the Cross-Sectional Dependence (CDE) Breusch-Pagan (1980) LM test was conducted. The test statistics are given below (Pesaran, 2015):

$$\lambda_{LM} = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{p}_{ij}^2 \quad (3)$$

is computed as above. Here, $\hat{p}_{ij}^2$: i,j is the correlation coefficient of the residual (i and j. are between the remains of the units): $\hat{p}_{ij}$

$$\hat{p}_{ij} = \hat{p}_{ji} = \frac{\sum_{t=1}^{T} \hat{v}_{it}\widetilde{\hat{v}_{jt}}}{\left(\sum_{t=1}^{T} \hat{v}_{it}\right)^{1/2}\left(\sum_{t=1}^{T} \hat{v}_{jt}\right)^{1/2}} \quad (4)$$

Because it delivers reliable results in the presence of CDE and structural breaks, the panel unit root test has been used by Karavias-Tzavalis (2014), and the stationarity of the series was examined in the study. The test statistic offers two models. In the first model, a stationary series with a break in the means (intersection points) of the series may be practiced to test the null hypothesis of random walk against the alternative hypothesis (Chen et al., 2022c):

H_0: $y_{i,t} = y_{i,t-1} + \mu_{i,t}$

H_1: $y_{i,t} = \varphi y_{i,t-1} + (1-\varphi)\,[\alpha_{1,i}\, I(t \le b) + \alpha_{2,i}\, I(t > b)] + \mu_{i,t}$ (5)

On the other hand, it may be applied to test the null hypothesis of a deviant random walk in the second model, as in the first model, against the trend-stationary alternative, which is a break in the intercepts and linear trends at time b:

H_0: $y_{i,t} = y_{i,t-1} + \beta_i + \mu_{i,t}$ (6)

and

H_1: $y_{i,t} = \varphi y_{i,t-1} + \varphi\,[\beta_{1,i} I(t \le b) + \beta_{2,i} I(t > b)] + (1-\varphi)\,[\alpha_{1,i} I(t \le b) + \alpha_{2,i} I(t > b)] + (1-\varphi)\,[\beta_{1,i} t I(t \le b) + \beta_{2,i} t I(t > b)] + \mu_{i,t}$ (7)

In the next stage, the slope heterogeneity of the model to be estimated was reviewed via the Delta test suggested by Pesaran-Yamagata (2008). The demonstration of the Delta test is given below (Bersvendsen and Ditzen, 2021):

$$\tilde{\Delta} = \frac{1}{\sqrt{N}}\left(\frac{\sum_{i=1}^{N} \tilde{d}_i - k_2}{\sqrt{2k_2}}\right) \quad (8)$$

Since the Delta test estimated by Pesaran-Yamagata (2008) does not embrace autocorrelation and heteroskedasticity in the calculation, biased outputs may come out due to the presence of these two problems. Hence, the Delta (HAC) test developed by Blomquist and Westerlund (2013), which is resistant to heteroskedasticity and autocorrelation, was performed. The Delta (HAC) test representation is as follows:

$$\widetilde{\Delta}_{HAC} = \sqrt{N}\left(\frac{N^{-1}S_{HAC}-k_2}{\sqrt{2k_2}}\right) \quad (9)$$

In the study, the long-term effects of airline passenger and cargo transportation on CO_2 emissions were analyzed using the Augmented Mean Group (AMG) estimator proposed by Eberhardt-Bond (2009) and Eberhardt-Teal (2010). The AMG estimator representation is as follows (Çetin et al., 2023):

$$\hat{\beta}_{AMG} = N^{-1}\sum_{i=1}^{N}\hat{\beta}_i \quad (10)$$

The short-term causal relationship between variables has been investigated using the panel Granger causality test, which was initially developed by Juodis et al. (2021).

This test is implemented against homogeneous and heterogeneous alternatives, as well as allowing cross-sectional dependence and heteroskedasticity (Xiao et al., 2023). The model to be tested for Granger causality analysis is as follows (Juodis et al., 2021):

$$y_{i,t} = \phi_{0,i} + \sum_{p=1}^{P}\phi_{p,i}y_{i,t-p} + \sum_{q=1}^{Q}\beta_{q,i}x_{i,t-q} + \varepsilon_{i,t} \quad (11)$$

In openlight of all this information, models acceptable for the data set were picked and econometric analyses were covered in the findings section.

3.3. Findings

The descriptive statistics for the variables are presented in Table 2.

Table 2. Descriptive Statistics

	LnCO2	LnAIRPASS	LnAIRCARGO	LnGDP	LnFOSSIL	OPENNESS
Mean	1.892	17.627	7.667	9.570	7.858	49.517
Median	2.074	17.536	7.485	9.933	7.606	49.758
Max.	3.045	20.647	10.736	11.050	10.499	105.566
Min.	-0.235	14.711	2.716	6.377	6.223	15.635
Std. Dev.	0.805	1.092	1.374	1.109	0.928	17.3274
Skewness	-0.602	0.534	-0.005	-0.772	1.066	0.2570
Kurtosis	2.522	3.476	2.722	2.787	3.669	2.870
Jarque-Bera	37.275	30.352	1.708	53.894	110.854	6.230
Prob.	0.000	0.000	0.425	0.000	0.000	0.044
Observation	532	532	532	532	532	532

In Table 2, each variable has 532 observations in G20 countries for the period 1994-2021. In the research, the average value of the $lnCO_2$ series representing CO_2 emissions was calculated as 1.892, and the maximum and minimum values were computed to be 3.045 and -0.235. The core explanatory variables LnAIRPASS and LnAIRCARGO, passenger and cargo transportation average values turn to be 17.627 and 7.667, while their maximum values are 20.647 and 10.736, and their minimum values are 14.711 and 2.716 respectively. The maximum values of the control variables LnGDP, LnFossil and OPENNESS were calculated to be 11.050, 10.499 and 105.566, respectively, while the minimum values are 6.377, 6.223 and 15.635, respectively.

Within the scope of the research, firstly it was attempted to identify whether the series contained a cross-section dependency (CD) problem. Because the unit dimension is smaller than the time dimension (N<T), the CD Breusch-Pagan (1980) LM test was utilized to analyze the series, as illustrated in Table 3.

Table 3. Breusch-Pagan (1980) LM Test

	LM Statistics	Prob.
LnCO2	2145.254	0.000
LnAIRPASS	2527.384	0.000
LnAIRCARGO	1051.401	0.000
Ln GDP	3128.099	0.000
LnFOSSIL	2703.740	0.000
OPENNESS	1593.374	0.000

Following the results of the tests described in Table 3, it was noticed that every series had a CD condition. Thus, the stationarity of the series was analyzed using the Karavias-Tzavalis (2014) unit root test, which takes into account the CD and structural breaks.

Table 4. Karavias-Tzavalis (2014) Unit Root Test

Variables	Bootstrap Critical Value	Test Statistics	Prob.	Date of Break
LnCO_2	-0.731	-3.535	0.000***	2008
LnAIRPASS	11.980	-21.809	0.000***	2020
LnAIRCARGO	0.517	-9.968	0.000***	2020
Ln GDP	7.527	-16.336	0.000***	2020
LnFOSSIL	3.449	-10.822	0.000***	2020
OPENNESS	-0.967	-10.508	0.000***	2020

***, ** and * represent significance at p≤0.01, p≤0.05 and p≤0.10 levels.

Table 4 summarizes the findings of the Karavias-Tzavalis (2014) unit root test. The calculated test statistics values of all series were found to be smaller than the Bootstrap critical value and therefore stationary at the level. In this respect, it may be commented that all series are stationary at the level of 1% significance level. The slope-heterogeneity of the estimated model was examined using the Delta test suggested by Pesaran-Yamagata (2008) and developed by Blomquist-Westerlund (2013) to be robust against autocorrelation and heteroskedasticity. The Delta test results indicated in Table 5 depict that the estimated model exhibits heterogeneous properties.

Table 5. Slope-Heterogeneity Analysis

	Pesaran-Yamagata (2008)		Blomquist-Westerlund (2013)	
	Statistics	Prob.	Statistics	Prob.
Delta	20.318	0.000	21.741	0.000
Delta adj.	23.461	0.000	25.105	0.000

By the AMG estimator, the long-term regression relationship between the stationary series at the level was calculated. The AMG estimation results may be found in Table 6.

Table 6. AMG Estimation

Variables	Coefficient	Std. Deviation	z- Statistics	Prob.
LnAIRPASS	-0.015	0.009	-1.66	0.096*
LnAIRCARGO	0.002	0.013	0.17	0.869
LnGDP	0.185	0.058	3.16	0.002***
LnFOSSIL	0.827	0.041	19.77	0.000***
OPENNESS	0.0004	0.0003	1.39	0.165
WALD (chi-square)	1276.65			
PROB	0.000***			
ULKE	19			
GOZLEM	532			

***, ** and * represent significance at p≤0.01, p≤0.05 and p≤0.10 levels.

According to AMG's estimated results in Table 6, transporting passengers by air exerts a negative effect on CO_2 emissions in the long term. Accordingly, as the number of passengers transported by air increased, CO_2 emissions decreased. It was established that the amount of cargo transported by air produced no discernible impact on CO_2 emissions. The findings demonstrated that, over time, economic growth and the use of fossil fuels raised CO_2 emissions in the countries included in the study and contributed to the ongoing deterioration of the environment. It was also ended that the effect of trade liberalization on CO_2 emissions was insignificant.

The Granger causality test, suggested by Juodis et al. (2021), was implemented in the subsequent phase of the investigation to explore the short-term causal relationship between the variables. The test results are displayed in Table 7.

Tablo 7. Juodis et al. (2021) Panel Granger Causality Analysis

Dependent Variable: LnCO_2		**HPJ Wald Test**	206.543
		Prob.	0.000***
	Coefficient	**Std. Deviation**	**Prob.**
LLnAIRPASS	-0.071	0.011	0.000***
LLnAIRCARGO	0.034	0.010	0.001***
LLnGDP	-0.011	0.038	0.765
LLnFOSSIL	0.219	0.040	0.000***
LOPENNESS	0.0007	0.000	0.053**
BIC Criteria	Lags=1, BIC= -3284.3201		

***, ** and * represent significance at p≤0.01, p≤0.05 and p≤0.10 levels.

The test results in Table 7 announce that there is causality from all series except economic growth to CO_2 emissions. Plus, univariate causality analyses were conducted in the causality relationship between the variables by taking into account the directing effect of other variables. Table 8 includes Panel Granger Causality Analysis.

Table 8. Juodis et al. (2021) Panel Granger Causality Analysis (Univariate analysis)

			Jackknife Estimator Results	
Null Hypothesis (H0)	**HBJ Wald Test**	**Prob.**	**Coefficient**	**Prob.**
LLnAIRPASS≠>LLnCO_2	16.562	0.000***	-0.041	0.000***
LLnAIRCARGO≠>LLnCO_2	0.011	0.915	0.001	0.916
LLnGDP≠>LLnCO_2	2.201	0.137	-0.068	0.138
LLnFOSSIL≠>LLnCO_2	0.000	0.999	-0.00001	1.000
LOPENNESS ≠>LLnCO_2	0.0001	0.992	-4.51E-06	0.992
LLnCO_2 ≠>LLnAIRPASS	4.480	0.034**	0.261	0.034**
LLnCO_2 ≠>LLnAIRCARGO	21.233	0.000***	0.356	0.000***
LLnCO_2 ≠>LLnGDP	4.054	0.044**	0.043	0.044**
LLnCO_2≠>LLnFOSSIL	9.241	0.002***	0.160	0.002***
LLnCO_2≠>L1OPENNESS	114.092	0.000***	16.130	0.107
LLnCO2≠>L2OPENESS			-26.592	0.007***
LLnCO2≠>L3OPENNESS			28.196	0.004***
LLnCO2≠>L4OPENNESS			3.457	0.788

***, ** and * represent significance at p≤0.01, p≤0.05 and p≤0.10 levels.

It is evident from the results in Table 8 that there is a reciprocal causal relationship between CO_2 emissions and the number of passengers transported by air. It is possible to argue that laws pertaining to CO_2 emissions and air passenger transportation are related in this regard. Likewise, it has been settled that there is unidirectional causality from CO_2 emissions to the amount of cargo carried by air, economic growth, fossil energy consumption and trade liberalization.

4. Conclusion

The sustainability of the environment has been threatened over the past few years by the growing environmental issues brought on by greenhouse gas emissions, such as climate change and global warming. Emissions that pollute the environment most frequently are CO_2 emissions. When contemplating the sectoral distribution of CO_2 emissions, it was affirmed that the transportation sector ranks the second most polluting one globally. There are a number of factors that may exert a direct impact on environmental pollution, including the fact that 92% of the vehicles used in the transportation sector are powered by petroleum, noise pollution, the usage of heavy metals, the rise in the number of private vehicles, and the presence of required infrastructure. One of the sub-sectors of the transportation sector, the aviation sector is also of economic, social and environmental importance due to its direct connection with tourism and other sectors. It is possible to voice that the aviation sector causes more damage to the environment than sea and railway transportation types, as it directly impacts global warming.

In this study, data belonging to the period between 1994 and 2021 were made use of and the effect of airline transportation on CO_2 emissions in G20 countries was considered utilizing panel data analysis. The analysis result displayed that a negative relationship exists between airline passenger transportation and CO_2 emissions, and a positive but insignificant relationship was found with freight transportation. This result appears to be similar to the results obtained from the studies of Chen et al. (2022), Habib et al. (2022), Chatti and Majeed (2022), Lin and Zao (2024). The reduction of CO_2 emissions in passenger transport in G20 countries could be attributed to various reasons. In the G20, many nations have pledged to achieve zero emissions by 2050. To guarantee sustainability, they have implemented measures like CO_2 offset agreements and use of sustainable fuels in aviation. Under these circumstances, these factors might be regarded as crucial to minimize CO_2 emissions. Another noteworthy aspect about lessening CO_2emissions in air transportation is the decline in passenger flights during the COVID-19 pandemic and the tariff policies imposed on long-distance flights or tickets in many G20 nations.

Another prominent finding is that economic growth and CO_2 emissions and fossil fuel usage are positively correlated. These findings align with those found in previous research such as those conducted by Gyamfi (2022), Habib et al. (2022), Avotra and Nawaz (2023), and Binsuwadan (2024). Energy demand escalates as a result of higher levels of urbanization and industrialization brought on by economic growth as well as advancements in transportation infrastructure. It is unavoidable that CO_2 emissions may rise if fossil fuels like coal and oil are used to meet the growing demand for energy. Lastly, a positive but statistically negligible impact of trade openness on CO_2 emissions was discovered. The results are comparable to those of the research done by Binsuwadan (2024) and Hassan and Nosheen (2018).

It is possible to put forward several policy recommendations as to achieve zero emissions in the aviation sector, minimize environmental damage and ensure sustainability in light of the results obtained from the research. The first of these suggestions is that G20 nations ought to recognize air transport as a catalyst for sustainable development and should propose and implement new laws that support air passenger transport. Secondly, the reduction of CO_2 emissions in the aviation sector may be facilitated by the development of technological innovations, the inclusion of R&D activities and fuel efficiency increasing applications. Thirdly, new agreements and collaborations should be constructed to promote the use of sustainable aviation fuels in place of traditional fossil fuels. Sustainable aviation fuels are produced without harming ecosystems. Accordingly, due to the protection of biodiversity, the negative impact on the environment might be minimized. Fourth, environmentally friendly transport activities can be carried out by introducing a tax on short-haul flights and encouraging applications such as high-speed trains and electric buses in order to promote air transport over short distances. Finally, G20 countries should set internationally binding targets to reduce carbon emissions through a joint declaration to reduce emissions.

As a consequence, it is of great importance for the environment that G20 countries adopt environmentally friendly regulatory policies, encouraging the use of sustainable aviation fuels. Last but not least, it is not possible for countries to ignore the goal of economic growth. Consequently, supplying energy from clean and renewable energy sources like solar and wind—the engines of economic growth meant to bring about sustainable economic growth and be more environmentally conscious—may benefit the economies and the environment of G20 countries.

Conflicts of Interest

The author/s declare that there is no conflict of interest regarding the publication of this paper.

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