International Journal of Aeronautics and Astronautics
https://dergipark.org.tr/en/pub/ijaa

2025, VOL:6, ISS:2, 67-78 e-ISSN: 2757-6574

Research Article / Araştırma Makalesi

The effect of air transportation quality between air cargo and climate & energy sustainability / Hava taşımacılık kalitesinin hava kargo ile iklim ve enerji sürdürülebilirliği arasındaki etkisi

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Received	Revised	Accepted
Dec 30, 2024	Oct 15, 2025	Nov 18, 2025

Keywords
Air cargo,
Air transport quality,
Climate and energy,
Sustainability

Anahtar Kelimeler
Hava kargo,
Hava taşımacılık kalitesi,
İklim ve enerji,
Sürdürülebilirlik

ABSTRACT

Air cargo plays a critical role in world trade. The intense competition in international markets requires reliable and faster means of transportation. This necessity increases the importance of air cargo. Significant portion of the world trade in terms of value is carried by air. This is because higher added value and time sensitive goods increasingly demand for air cargo and this results in higher cargo traffic transported by air. The increase looks to continue well into the future in line with the expectations of the industry. To accommodate the growth, the continuous development of the quality of air transportation infrastructure is inevitable and this creates in return an adverse effect on climate and energy sustainability. The study focuses on this negative effect and aims to examine whether air transportation quality is mediating air cargo and climate & energy. The research is based on cross country data analysed via Baron and Kenny mediator method, regression and Sobel test. The result of the analysis shows that the quality of air transportation is a partial mediator between air cargo with climate and energy. The increase of air cargo traffic has an adverse effect on climate & energy and by introducing air transportation quality in the relationship, the earlier negative effect of air cargo on climate and energy falls but still keeps its statistical significance. To sustain climate & energy, policies should control the rapid rise of air cargo on the one hand, and the development of air transportation quality on the other.

ÖZET

Hava kargo, dünya ticaretinde kritik bir rol oynamaktadır. Uluslararası pazarlardaki yoğun rekabet, güvenilir ve daha hızlı taşıma ve teslimat gereksinimlerini beraberinde getirmektedir. Bu zorunluluk, hava kargonun diğer taşıma türlerine göre önemini artırmaktadır. Dünya ticaretinin değer bazında önemli bir kısmı hava kargo yoluyla taşınmaktadır. Bunun nedeni, katma değeri yüksek ve zamana karşı duyarlı malların hava kargoya olan talebinin giderek artması ve bunun sonucunda daha yüksek bir hava kargo trafiğinin oluşmasıdır. Sektör tahminleri bu artışın gelecekte de devam edeceğini göstermektedir. Bu büyümeye uyum sağlamak için hava taşımacılığı altyapı kalitesinin geliştirilmesi ise kaçınılmazdır. Ancak, bu gelişme ekonomik kalkınmayı güçlendirirken, iklim ve enerji sürdürülebilirliğini tersine zayıflatmaktadır. Bu çalışma özellikle bu kritik zayıflatıcı olumsuz etkiye odaklanmakta ve hava taşımacılık altyapı kalitesinin, hava kargo

Citation: Çelebi, Ü. (2025). The effect of air transportation quality between air cargo and climate & energy sustainability. *International Journal of Aeronautics and Astronautics, 6* (2), 67-78.

ile iklim ve enerji sürdürülebilirliği ilişkisine aracılık edip-etmediğini incelemeyi amaçlamaktadır. Bu araştırma, ülkelerarası verilerin Baron ve Kenny aracılık yöntemi, çoklu regresyon ve Sobel testi ile analizine dayanmaktadır. Analiz sonucu, hava taşımacılığı altyapı kalitesinin, hava kargo ile iklim ve enerji sürdürülebilirliği arasında kısmi bir aracı rol üstlendiğini göstermektedir. Hava kargo trafiğinin artması iklim ve enerji üzerinde olumsuz bir etkiye sahiptir. Bu ilişkiye hava taşımacılık kalitesi dâhil edildiğinde ise hava kargonun iklim ve enerji üzerindeki daha önceki olumsuz etkisi azalmaktadır, ancak bu etki azalsa da etkinin istatistiksel olarak anlamlılığının hala devam ettiği görülmektedir. Bu sonuç bize, iklim ve enerji sürdürülebilirlik politikalarında, hem hızla artan hava kargo trafiğinin, hem de hava taşımacılık altyapı kalitesinin birlikte hesaba katılıp, kontrol edilmesi gerektiğini göstermektedir.

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1. Introduction

IATA, International Air Transport Association (2023), reports that as low as one percent of world trade in terms of weight and volume is carried by air cargo, but this rate reaches up to thirty-five percent when the value of the products is taken into account. IATA (2023) also expects that international trade carried by air cargo would go up to reach six trillion US dollars in 2025. It is as well estimated that eighty percent of cross border e-commerce has already been carried out until now by air cargo and competent bodies expect the rate of increase of air cargo transportation and traffic to continue well into the future (IATA, 2023).

Air cargo plays a crucial role in trade and economic growth of countries. The intense competition in international markets requires reliable and fast transportation. This necessity increases the importance of air cargo with respect to other transportation modes. Higher added value and time sensitive goods increasingly demand for air cargo resulting in higher traffic in air cargo transportation. To accommodate this rate of high growth, the development of the quality of air transportation infrastructure – airports, aircrafts, flights network – is inevitable. However, while this development strengthens economic development, it weakens climate and energy sustainability in return (Graver et al., 2019; ACI, 2023; ICAO, 2024). It is this critical negative effect that this study focuses on and aims to examine whether air transportation quality mediates air cargo and climate and energy sustainability. The results show that air transport quality plays a partial mediating variable role in the relationship between air cargo and climate & energy sustainability: With the inclusion of air transport quality development in the analysis, the previous negative impact of air cargo on climate and energy sustainability decreases, but it still keeps its statistical significance.

These findings would make a significant contribution to literature in two main ways: First, it shows that increase of air cargo traffic has a negative impact on climate and energy sustainability. Second, this negative effect is realized partially through the mediating role of air transportation quality development. As far as the policy implications are concerned, policy makers should therefore take into account and control both the rise of air cargo traffic and the development of air transportation quality together. To demonstrate the study findings well in order this paper is structured in the following respective ways: First part is the literature review. Second part is the development of the hypotheses of the research model. Third part outlines the research model and the method of study. Fourth part presents the research sample and measures. Fifth part demonstrates the outcome of the test results. Last part concludes the study.

2. Literature Review

2.1. Air cargo and air transport quality development worldwi

International air cargo traffic is closely related to world trade. Increased level of world trade over the past decades

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has been the main power behind the rising air cargo traffic (Belobaba et al., 2016; Morrell and Klein, 2019). Figure 1 shows the remarkable rise of air cargo traffic worldwide over a long-time horizon reaching almost two hundred twenty million-ton km in 2021 (World Bank, 2024; UN, 2024).

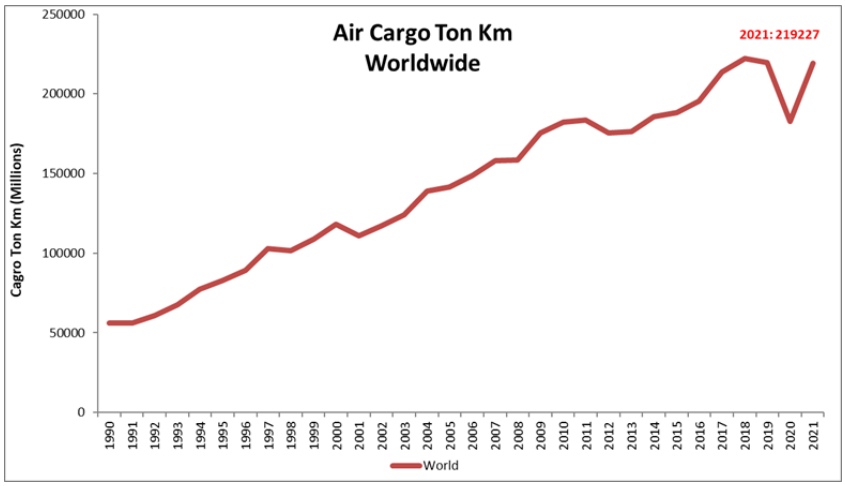

Figure 1. Air cargo ton km depending on the years (World Bank and UN Sustainable Development Goals)

In fact, as far as Figures 1 and 2 are concerned, this remarkable rise in air cargo traffic worldwide is a direct result of a fast increase in the number of flights in and out of airports globally. Figure 2 reflects that the total number of international air flights peaked in 2019 with thirty-eight million flights equalling over two and half time increase in the last three decades since 1990, disregarding the sharp drop though in 2020 and 2021 due to pandemic but the figure is expected to grow again strongly thereafter (World Bank, 2024).

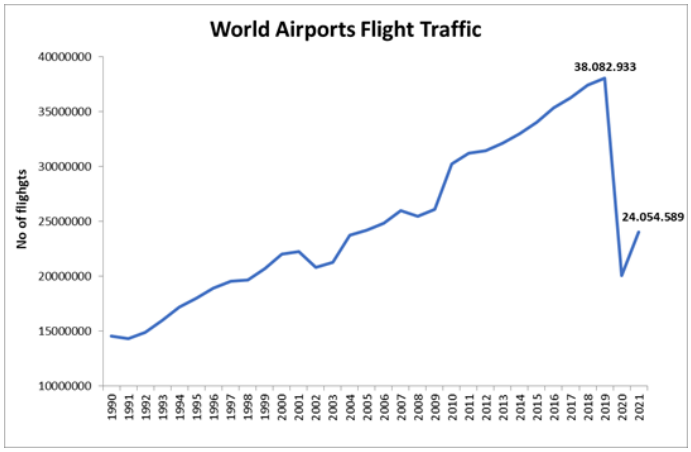

Figure 2. Flight traffic of airports worldwide depending on the years (World Bank)

This growth of cargo traffic benefits from increasing number of aircrafts and flights worldwide. Air cargo transportation is carried out not only by cargo aircrafts but also by passenger aircrafts. In fact, nearly half of the air cargo transportation worldwide is carried by passenger aircrafts (Morrell and Klein, 2019). Figure 3, outlines the number of aircraft fleets worldwide both for freight and passenger standing at twenty-four thousand in 2024 but forecasted to reach over forty-three thousand in 2044, doubling the number in the next twenty years (Airbus, 2025).

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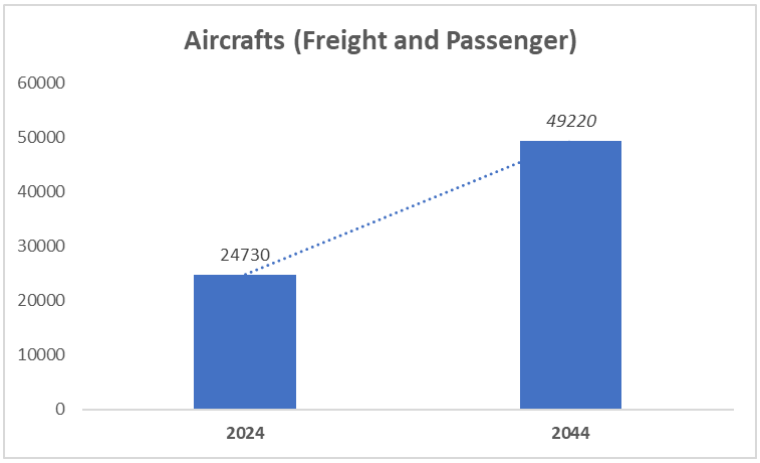

Figure 3. Aircrafts fleet worldwide (Airbus)

Higher numbers of air cargo traffic, flights and aircrafts require continuous improvement to the condition and extensiveness of airports as a result. In that sense the number of airport pairs accommodating ever increasing level of air cargo traffic has doubled since 2000 (Boeing, 2025). Table 1 outlines that the number of airports worldwide which reached over forty-seven thousand in 2025. (IATA, 2023; UN, 2024; World Bank, 2024).

Table 1. Airports, flights and air cargo statistics worldwide (Source: World Bank, 2024 and CIA, 2025**)**

	2020	**2021**	**2025**
Airports	-	-	47.000
Air flights	20.000.000	24.000.000	-
Air Cargo Ton Km	182.000.000	219.000.000	-

2.2. The relationship between climate change and energy consumption

The level of air cargo traffic growth is positive from the point of economic and human wellbeing. Sustainable society index (SSI, 2023), reports this positive outcome both the former and the latter as part of triple bottom line sustainability depicted in Figure 4. However, the same increase is not true for the environment. Environment lagged behind in the same figure where economic and human wellbeing improved between 2000 and 2018.

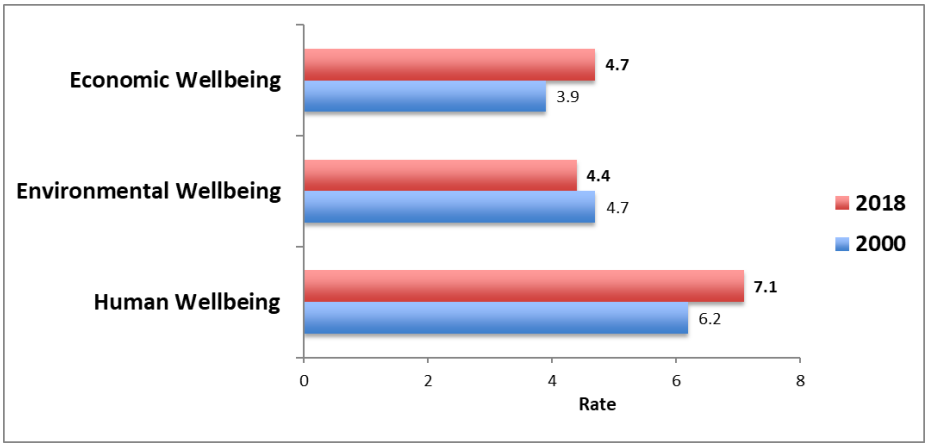

Figure 4. Riblet surface and position of two pitot rakes (Takahashi et al., 2023).

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In fact, Figure 5 shows that while economic and human sustainability progressed by 0.8 and 0.9 points respectively, that of environment in contrast worsened by minus 0.3 points same period which contradicts official statements (SSI, 2023).

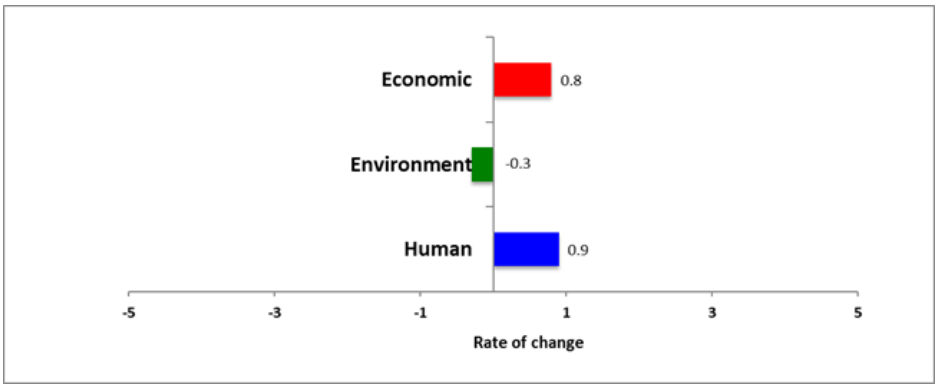

Figure 5. Sustainability Triple Bottom Line (Sustainability Society Index)

Environmental sustainability is in return composed of natural resources and climate & energy. Figure 6 indicates that compared to the steady trend of natural resources, climate and energy face more volatility over the same period.

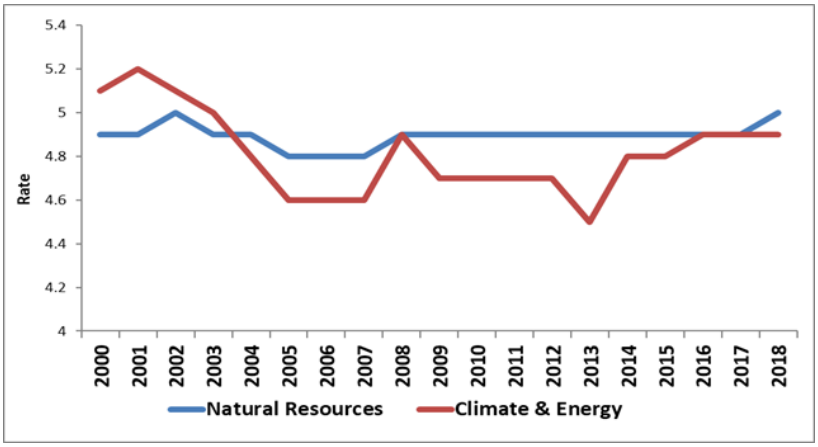

Figure 6. Natural Resources and Climate & Energy (Sustainability Society Index)

The latter – the subject matter of this study as being the dependent variable – is in turn evaluated by four sub-dimensions: These are renewable energy, greenhouse gases, energy savings and energy use. Figure 7 at first instance strikes couple of points. First is to do with the renewable energy that is lagging behind. Second is to do with both the renewable energy and the energy savings that are behind the energy use and the greenhouse gases and they both need to be taken care (SSI, 2023).

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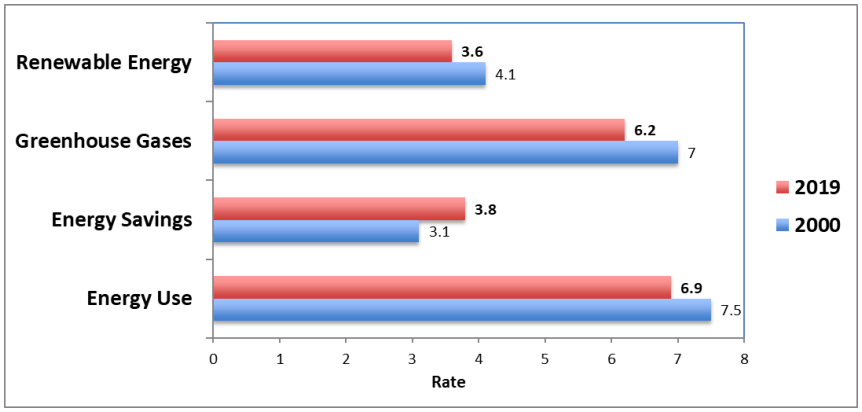

Figure 7. Climate and Energy Sustainability (Sustainability Society Index)

2.3. Similar studies in the literature

While the increase in air cargo traffic is positive for economic and human/social welfare, it has negative effects on environment. Fifteen percent of greenhouse gas emissions worldwide comes from the transportation sector (Larson, 2021). It is estimated that commercial aviation accounts up to three percent of greenhouse gas emissions, in which around nineteen percent of it is related to air cargo transportation on its own (Graver et al., 2019).

Air transport quality development is intended to bring positive effects through economies of scale to reduce unit costs and increase productivity. However, this may in turn lead to anti-competitive effects (Cho and Lee, 2020). The increase in the number of terminals makes the operation more complex causing duplication and waste. Wider distances between the number of different terminals also increase delays and reduce accessibility causing in turn negative effects on climate and energy sustainability (Graham, 2023).

3. Research Hypotheses

According to the literature, the hypotheses were developed based on the inter-relationships of variables to carry out the model.

3.1. Air cargo and air transportation quality

Air cargo has an advantage over other transportation modes due its ability to move products faster. A day of improvement in the transportation lead-time drives the increase of the global commerce by an equivalent of 6.3 per cent; a day of delay vice versa equals increased tariffs of commerce by 0.6 to 2.3 per cent (Hummels and Schaur, 2013). Faster transportation by air cargo therefore positively influences commerce worldwide and therefore the global air cargo traffic. In order to meet the traffic increase in return, infrastructure development of air transportation is inevitable. The higher the cargo traffic in air means the higher the investment to develop air transportation quality by building more airports, producing more aircrafts and performing more flights network. This positive relationship leads to form our first as hypothesis:

H1: Air cargo influences positively the quality of air transportation.

3.2. Air transportation quality and climate & energy

Continuing from the first hypothesis, while increased investment to develop air transportation is favorable to economic development, it cannot be said the same for climate and energy. Because ever increasing number of airports, aircrafts and flights worldwide are but only to increase even more the carbon emissions despite efforts to decarbonize (Kou et al., 2022; Echeverria et al., 2023). Next hypothesis therefore indicates this inverse relationship as follows:

H2: Air transportation quality negatively influences climate and energy

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3.3. Air Cargo and Climate & Energy

In line with precedent hypothesis, higher investment going into develop air transport is only but enables ever more cargo traffic and higher carbon emissions in the air. Without necessary actions to mitigate, climate and energy sustainability is to be continuously at risk with no sign of improvement. Road maps to decarbonize would only fall short of essential remedies (Beccarello et al., 2023). Similar to second hypothesis, this third hypothesis indicates an inverse relationship:

H3: Air cargo negatively influences climate and energy

4. Research Methods

Hypotheses were tested by Baron and Kenny (1986) method. This method is developed to test if an effect of independent variable on the dependent variable is actually taking place through another variable called mediator variable. It is one of the research methods used by researchers in social sciences for mediator variable analysis and this study is based its analysis on it to test the hypotheses. To complement this method both multi co-linearity and Sobel test are also conducted (Baron and Kenny, 1986). Baron and Kenny's mediator analysis first and foremost require certain conditions and steps to be in place: First, any alteration in independent variable should cause an alteration in dependent variable. Second, any alteration in mediator variable should cause an alteration in dependent variable. Third, as mediator variable introduced in the inter-relationships between independent variable and dependent variable, independent variable's precedent effect on dependent variable should disappear and become statistically meaningless or the effect should be reduced while keeping its significance still. According to steps outlined by Baron and Kenny, the research model is carried out to test the hypotheses in Figure 8.

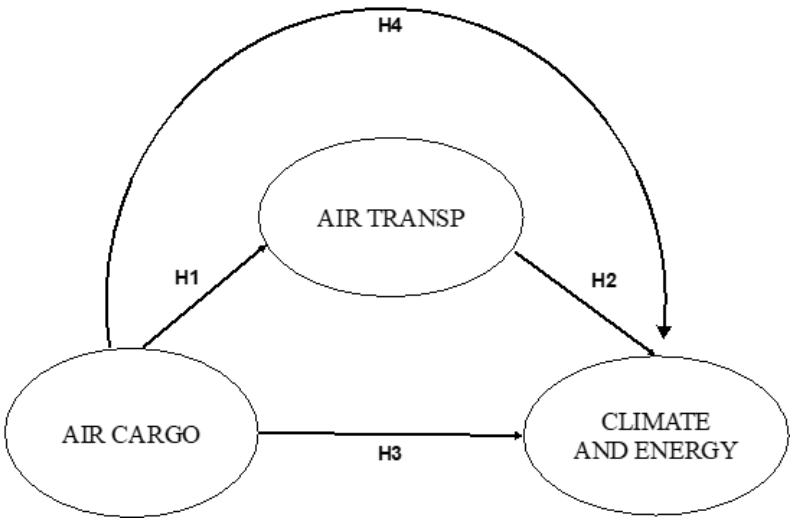

Figure 8. Research Model

Air Cargo, Air Transp. and Climate & Energy incorporate the main variables of the research model. According to the methods based on the hypotheses and model of the research, regression equations are developed:

Model I: $C\&E = \beta 0 + \beta\ 1.\,AIRCRG + \varepsilon$ (H3)

Model II: $AIRTRNSP = \beta 0 + \beta\ 1.\,AIRCRG + \varepsilon$ (H1)

Model III: $C\&E\ = \beta 0 + \beta\ 1.\,AIRCRG + \beta 2.\,AIRTRNSP + \varepsilon$ (H2 and H4)

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5. Research Data and Measurement

This study is based on the quantitative analysis of the secondary data of 62 countries, for the years 2007, 2010, 2012, 2014 and 2016, consisting of total 248 observations. The data availability and restriction were the primary factor for selecting this time period and country sample. Data sample deemed sufficient for the purpose of this research aiming to establish one-time linear relationships between the variables. Air transportation quality, air cargo ton km and climate & energy indicators are used as the variables of the research: the data for air transportation quality derived from World Economic Forum (WEF) The Global Enabling Trade Report (WEF, 2021); Air Cargo Ton-km from the World Bank; Climate & Energy from SSI Index – TH Köln.

AIRCRG is an air cargo traffic indicator expressed in million-ton km and published by the World Bank. It contains volume of cargo, express and diplomatic bags carried during each flight phase – the operation of an aircraft from take off to its next landing – measured in metric tons multiplied by kilometres travelled (one metric ton of cargo carried in one kilometre). For International Civil Aviation Organization (ICAO) statistical purposes, cargo includes express and diplomatic shipments but excludes passenger baggage. It is based on estimates from the ICAO, World Civil Aviation Statistics, and ICAO staff (World Bank, 2024).

AIRTRNSP is an indicator that measures the development of quality, condition, and extensiveness of air transport infrastructure. It is based on the World Economic Forum (WEF) Global Enabling Report, Executive Opinion Survey (EOS). These surveys – answered by industry experts – rank countries as 1=extremely underdeveloped, among the worst in the world; 7=comprehensive and efficient and is evaluated according to a scale among the best in the world (WEF, 2021).

C&E is the indicator to measure climate and energy sustainability variable which is itself being one of the categories of environment incorporating four sub-indicators published by the International Energy Agency: The first of these is energy use, which shows the use of oil equivalent to tons per capita; the second is energy savings, which shows the percentage change in the four-year use of energy; the third one is greenhouse gases, which shows annual CO_2 emissions per capita; the fourth and the last one consists of renewable energy indicators as a percentage of energy consumption (SSI, 2024).

6. Research Results

The mediator role of air transportation quality was analyzed by the Baron and Kenny method (Baron and Kenny, 1986). This method expects a significant relationship between all variables as a first step. Likewise, Pearson correlation analysis in Table 2. showed that there were significant correlations amongst the variables:

Table 2. Correlation statistics (Source: Author)

	AIRCRG	**AIRTRNSP**	**C&E**
AIRCRG	1		
AIRTRNSP	.522***	1	
C&E	-.422***	-.451***	1

Upon the correlation analysis that has produced significant results, we have also looked at the values of variance inflation factor (VIF) and of tolerance to detect any possible co-linearity problems that may have existed among the independent variables (IV) in the relationship with dependent variable (DV). Upon regression analysis, Table 3 shows that both values are within acceptable levels (Keith, 2015).

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Table 3. Multi Co-linearity statistics (Source: Author**)**

IV	Tolerance	VIF
AIRCRG, AIRTRNSP (DV: C&E)	0.727(>0.1)	1.376(<10)

The coefficients resulting from the regression analysis based on the model are shown in Table 4.

Table 4. Model regression statistics (Source: Author**)**

Inter-relations	Model I	Model II	Model III
AIRCRG → C&E	-0.420***	-	-0.254***
AIRCRG→AIRTRNSP	-	0.522***	-
AIRTRNSP → C&E	-	-	-0.319***
R2	0.177	0.273	0.251
Adjusted R2	0.173	0.270	0.245
F	52.790***	92.375***	40.972***

From Table 4, the values obtained were statistically significant and this meant that all the following hypotheses were supported:

H1: Positive effect of AIRCRG on AIRTRNSP ($\beta_{\text{model II}} = .522,\ p < 0.01$)

H2: Negative effect of AIRTRNSP on C&E ($\beta_{\text{model III}} = -.319,\ p < 0.01$)

H3: Negative effect of AIRCRG on C&E ($\beta_{\text{model I}} = -.420,\ p < 0.01$)

H4: The mediator variable role of AIRTRNSP between AIRCRG and C&E ($\beta_{\text{model III}} = -.254,\ p < 0.01$).

The result of the analysis shows that previous significant negative effect of AIRCRG on C&E (-.420) decreased now to -.254 because of the inclusion of independent variable in the analysis but its somewhat reduced effect still continues to be statistically significant.

One last step for verification of a mediator effect was the test called Sobel. Table 5 gives the result of the Sobel test based on the unstandardized regression coefficients and their standard errors and the results were also found to be statistically significant (Sobel, 1982). With the result that was obtained via Sobel test in Table 5, it was confirmed that AIRTRNSP was a partial mediator in the relationship between AIRCRG and C&E.

Table 5. Sobel test statistics (Source: Author)

Inter-relationships	SOBEL	P
AIRCRG → AIRTRNSP → C&E	0.727(>0.1)	1.376(<10)

The first hypothesis regarding the direct negative effect of air cargo on the air transport was supported.

The second hypothesis – testing the direct negative effect of air transportation quality on climate and energy – was supported: Expansion of the air transport (aircrafts, airports, air flights) to increase the extensiveness and condition of air transport in and out of countries is positive for economic development and yet it is detrimental to climate & energy. Literature and theory support this argument partially. While effectiveness and efficiency obtained by development of air transport infrastructure may positively influence climate and energy through reducing bottlenecks and waste, this development may negatively impact climate and energy in contrast. Especially duplications and misallocation of resources via unfeasible infrastructural projects may produce more harm to climate and energy sustainability than any good.

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The third hypothesis of the direct negative effect of air cargo on climate and energy was supported: Increased air cargo traffic in current state causes ever higher carbon emission negatively influencing climate and energy. Studies in the literature show that increased air cargo traffic necessitates improvement on the extensiveness and condition of air transport.
The fourth hypothesis regarding the mediator role of air transport quality between air cargo and climate & energy was supported: Condition and extensiveness of air transport infrastructure while positively affects air cargo ton km, both former and latter have also a negative effect on climate and energy sustainability. It is compatible with the literature.

7. Conclusion

Air cargo is growing and its growth is expected to continue. To meet this increasing traffic in air cargo, the improvement of quality of air transportation infrastructure is necessary. While this may be beneficial to the economic development, it has an opposite effect on climate and energy sustainability. This research has analyzed therefore to what extent air cargo traffic has a negative effect on the climate and energy sustainability and on this effect what role quality plays. While finding this negative effect, it has determined that the role of quality of air transportation is of a partially mediating nature.
The results indicate that the quality of air transportation partially mediates air cargo with climate and energy sustainability: by including the air transport quality in the analysis the previous negative effects of air cargo on climate and energy falls but does not completely disappear. The findings show that climate and energy sustainability necessitate policies to control the expansion of air transport infrastructure and growth of air cargo traffic side by side. Those policies are to balance the development of air transport infrastructure under ever increasing air cargo traffic, without compromising the sustainable environment to prevent climate change and to protect natural resources. They are to encourage improvements that will increase efficiency but strictly to avoid waste. The decarbonization roadmap targets set by Cargo Airlines and Airport Associations should be reflected in their corporate score cards and put under strict scrutiny by states. States in the meanwhile should consolidate their airport projects and license projects that prioritize multimodal transportation alternatives. Bi-modal transportation, particularly those based on air and rail for example, should be more encouraged.
The theoretical contribution of the findings obtained as a result of scientific testing of the conceptual model is that the condition and extensiveness of air transport does have a negative impact on energy and climate sustainability. The research also indicates that the negative effect of air cargo on climate and energy sustainability takes place partially through a mediator role of air transport quality. It is this finding that is believed to make a unique contribution to the theory. This result is consistent with the literature. However, the negative impact of the development of air transportation infrastructure quality on climate and energy sustainability differentiates this study from others. Because normally the development of air transport quality is expected to be positively affecting sustainability. This may be true, but only if the investments originally intended to would actually bring efficiency and effectiveness while avoiding duplication and waste. Striking a balance between the condition and extensiveness of air transport quality versus of its effectiveness and efficiency is therefore critical to sustain the climate and energy.
There were some limitations in the study. First, the quality of air transport indicator was limited to executive opinion surveys and this may have potentially reflected subjective opinions of the participants. To get more objectivity into the analysis, hard numbers for air transportation quality such as number of airports, aircrafts and flights may be of use to the test. Second, the study was limited to uncovering linear relationships only but data with longer time period may be reached out to see the time effect and differences that may have taken place over the years. Third, this study was limited to climate and energy sub-indicators reflecting environmental sustainability

https://doi.org/10.55212/ijaa.1608934

only partially. Bio-diversity as well as renewable water resources and consumption indicators may be added into the analysis to see a more complete picture on the effects on environmental sustainability.

Acknowledgment
I hereby thank the journal editors and reviewer's editing and comprehensive peer review.

Conflicts of Interest: The author(s) declare no conflict of interest.

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