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# Exposing the environmental impacts of air transportation on the ecological system: empirical evidence from APEC countries

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ABSTRACT

In the trend of globalization, economic and social benefits of air transportation (AIR) are not indisputable. However, AIR's environmental impacts are still a controversial issue. While previous studies had shown that air transportation contributed to air pollution by emitting $CO_2$, lack of studies consider the effects of air transportation on ecological system. Therefore, this study investigates the relationship between air transportation and ecological footprint as well as $CO_2$ emissions in the case of APEC countries, which is leading in the growth rate of air transport activities. Applying regression with Driscoll-Kraay standard errors for a data set from 1992 to 2015, our research provides evidence that: (i) air transportation increases $CO_2$ emissions but this impact is negligible; (ii) air transportation contributes significantly in reducing ecological footprint of APEC countries; and (iii) globalization reduces both $CO_2$ emissions and ecological footprint. In addition, Dumitrescu-Hurlin causality test helps to confirm the bidirectional causality relationship between air transportation and ecological footprint. Meanwhile, unidirectional causality runs from air transportation to carbon emissions. Based on these conclusions, some policy suggestions are given for APEC countries.

## 1. Introduction

Transportation is of paramount importance in contemporary society, facilitating economic growth, social connectivity, and cultural exchange. However, its environmental effects pose significant challenges, necessitating sustainable practices for a harmonious balance between societal progress and environmental preservation. Transportation systems emit greenhouse gases, contribute to air pollution, and disrupt habitats, highlighting the urgency of adopting sustainable alternatives to mitigate these environmental impacts [1,2]. Due to enhanced worldwide connectivity, the air transportation (AIR) business has grown dramatically in recent decades [3]. The air cargo allows global commerce and supply networks to run. Air transports goods were worth about $6.7 trillion, accounting for one-third of global commerce. Besides, tourism is one of the most essential variables in the aviation sector [4]. According to an study of International Air Transport Association, air cargo allows global commerce and supply networks to run. Air transports goods were worth

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about $6.7 trillion, accounting for one-third of global commerce. Besides, tourism is one of the most essential variables in the aviation sector [4]. Because of the advancements in aircraft technology, air transportation has steadily improved in recent years [5]. In 2018 (i.e., before COVID-19), 58% of foreign visitors travelled by plane, compared to 35% in 1980. Further, the aviation industry created 19.6 million direct jobs in tourism-related industries; when multiplier effects are taken into account, the overall impact is about 45 million employees and $1 trillion in global GDP [6]. With these developments, the influence of air transportation on local, regional, and worldwide ecological conditions is a significant concern. As a result, it is ideal to focus on the environmental and ecological effects of air transportation concisely.

Many studies [7–11] employed $CO_2$ emissions to quantify the quality of the environment. Transportation emissions accounted for 24.6% of global carbon emissions which was 80% more than emissions in the 1990s according to the International Energy Agency [12]. After road transportation, the aviation industry is the largest contributor to emissions among other forms of transport [13]. Because aviation accounts for 2.4% of worldwide $CO_2$ emissions due to fossil fuel usage, $CO_2$ is considered the most significant greenhouse gas (GHG) released in air travels. In 2018, about 920 million $CO_2$ (metric tons) were released throughout commercial aviation [14]. Global aviation emissions are forecast to expand by 322% between 2006 and 2050 under optimistic technological and operational improvement assumptions, as the aviation industry's growth rate is likely to outpace efficiency gains [15]. Moreover, aviation emissions are more detrimental to the environment than emissions from other sectors since they alter the atmosphere at high elevations [16].

Apart from $CO_2$ emissions, various frameworks had been created in the past few years to study the environmental effect of aviation. Jimenez et al. [17] suggested a numerical fleet-assessment model capable of dynamically simulating the US commercial aircraft fleet development. Tetzloff and Crossley [18] had created optimization software that found the best placement of present and future aircraft in a network of routes considering environmentally issues. The Club of Rome attempted to match resource consumption levels to Earth's potential to produce such resources. The measurement unit is the quantity of resources created over a year compared to the amount of resources consumed by the global population [19]. Other environmental evaluation approach includes life-cycle assessment [20], which compiles all ecologically important flows associated with a process or product, such as emissions, natural resources, materials, energy, and trash. In contrast, the ecological footprint (EF) is a considerably superior alternative [21,22] which is better than $CO_2$ emission in environmental investigations [23] while not being employed in air transportation environmental analysis yet. EF is a land-based indicator of sustainable development [24], covering the environmental impacts of both products and services creation [25]. According to the definition, it included different types of bio-productive land usage necessary to absorb the natural resources used and waste released within a particular population or area [26]. Surprisingly, the EF is the sole indicator that compares commercial, private, and government resource demands to what the Earth can regenerate [27]. EF is also used by the UN Environment Programme (UNEP) and the World Wildlife Fund (WWF) for policy reports [22] while it is neglected by researchers for air transportation environmental assessment.

Besides, globalization, economic growth (GDP) and energy consumption (ENU) are included in the analysis, in addition to ecological footprint and carbon dioxide emissions. Globalization is a significant interpretive element that influences the environmental impact [28]. Some academics believe that the onset of the globalization age has considerably contributed to the consumption of the ecological footprint [29]. A one percent rise in globalization results in a 0.89% rise in ecological impact in the long term. From this point of view, globalization's effects are harmful to the environment's quality [30]. Zaidi et al. [31], Saud et al. [32] and B. Yang et al. [33], among others, confirmed the opposing viewpoint that globalization's technical improvements had decreased energy-intensive manufacturing and contamination, resulting in more sustainable growth. The economic growth will result in increased ENU, which will result in increased carbon emissions [34]. ENU rises as a result of globalization. This enormous surge in ENU is causing a difficult-to-manage trade-off between economic development and environmental durability. Considering these factors provide a comprehensive model to evaluate air transportation's impacts concisely which according to the best knowledge of the authors, it is the first time to be considered.

The Asia Pacific Economic Cooperation (APEC), being among the world's most prominent organizations [9], is investigated in this study. According to APEC Secretariat(2021)[35], APEC nations calculated for 61% of world GDP, 60% of world power consumption, 47% of global commerce, and 38% of the global population. As a result, their actions may have a direct relationship on the GDP of numerous nations. $CO_2$ emissions are expected to rise in most APEC countries in the following years. In light of the present scenario, all nations should concentrate on carbon dioxide emissions and adapt their climate and energy policies accordingly [36]. Their yearly energy consumption growth rate (3.8%) is significantly faster than supply growth (3.4%). Expanding energy consumption suggests broadening their trading operations, which might exacerbate environmental issues in these countries [37]. Their economic success shows that the APEC economies have undergone significant economic progress due to globalization [31]. APEC nations' living standards have improved due to their economic integration. However, when globalization takes hold in any nation, considerable shifts in energy usage occur [29]. In these nations, the number of people using air transportation increased from over 770 million in 1992 to more than 2 billion in 2015. As a result, it is necessary to examine the link between economic development, globalization, energy consumption, and environmental measures (EF and $CO_2$ emissions) in these nations, taking into account the role of air transportation, which is the focus of our study [38].

Recent papers in the energy-environment literature had concentrated on the link between environmental quality, GDP, and ENU [7,10,22,31,39,40]. These researchs yielded a variety of conclusions and suggestions based on the unique characteristics of each region. Moreover, analyzing the processes of air transportation, globalization, GDP, and ENU's influences on the ecological footprint at different levels helps to improve our knowledge of the globalization-environment interaction. Overall, this research adds to the body of knowledge in the next ways: (i) The existing literature relied on $CO_2$ emissions to assess environmental quality, which is widely employed by academics owing to their exclusivity. This research used the EF to measure ecological harm since it is a more specific and broader metric while neglected in the AIR literature. The EF reveals the impact of human operations on the environment, and it is thought to be a more inclusive substitute for environmental measurement that generates a more extensive understanding of the case [41]. This is the first research to utilize EF and $CO_2$ emissions to quantify the environmental effect of air transportation, as opposed to prior studies that solely used $CO_2$ emissions. (ii) Even though many studies focus on other areas, the APEC countries were selected for this study because not only they are leading in terms of air transportation expansion in recent years, but also few studies have examined their challenges. In order to better understand the justification for air transportation, this investigation is expected to help decision-makers to find ecological impact. (iii) The recommended policy initiative was advised to assist decision-makers in exploring new avenues for developing and implementing comprehensive environmental-related policies.

The remaining sections of the research are divided into four parts. The methods part is presented in Section 2, the results are indicated in Section 3, and the conclusions are provided in Section 4.

## 2. Methods

### 2.1. Model specification and data sources

In the pursuit of the relationship among the ecological footprint, $CO_2$, air transportation, globalization, economic growth, and energy consumption, the present study employs the Environmental Kuznets Curve (EKC) framework which was hypothesized by Simon Kuznets [42], and further evidenced by Grossman and Krueger [43]. According to this hypothesis, environmental deterioration increases with economic developments at the initial stage, after a certain threshold level of economic progression, environmental degradation declines. Our study examines the EKC hypothesis and its relationship in the APEC countries including Australia, Canada, Chile, China, Indonesia, Japan, Korea Rep, Malaysia, Mexico, New Zealand, Peru, Philippines, Russia, Singapore, Thailand, the United States, and Vietnam. Meanwhile, Hong Kong, Papua New Guinea, and Brunei are excluded due to the unavailability of data. The panel data of these APEC countries covers the yearly data from 1992 to 2015. The empirical models, in our case, adopted 2 models. Model 1 used the ecological footprint (EF) as dependent variable, which is determined by economic growth (GDP), $GDP^2$, energy consumption (ENU), air transportation (AIR), and globalization (GLO). It expressed as:

$$EF = f\left(GDP, GDP^2, ENU, AIR, GLO\right) \tag{1}$$

Similarly, Model 2 determined the $CO_2$ as a dependent variable. The model can be designed as:

$$CO_2 = f\left(GDP, GDP^2, ENU, AIR, GLO\right) \tag{2}$$

The EF was obtained from the database of GFN [38], its unit is global hectare (gha) per person. The $CO_2$ is measured as carbon dioxide (metric tons per capita), and the GDP is the real GDP (constant 2010 US$) per capita. Also, the AIR is the number of passengers carried by air transport, and the ENU refers to the energy use (kg of oil equivalent per capita). These four variables were collected from the World Bank Development Indicator (WDI) [44]. Furthermore, the GLO is the index of the KOF Globalization, it derived from the Eidgenössische Technische Hochschule (ETH) Zürich [45].

Based on the single multivariable framework, we converted all the data into a natural logarithm form in order to allay the presence of autocorrelation and heteroscedasticity and to reduce the sharpness of data as suggested by Bekhet and Othman [46]. Thereafter, Equations (1) and (2) were rewritten as Equations (3) and (4) as follows:

$$\ln EF_{it} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{it}^2 + \beta_3 \ln ENU_{it} + \beta_4 \ln AIR_{it} + \beta_5 \ln GLO_{it} + \varepsilon_{it} \tag{3}$$

$$\ln CO2_{it} = \beta_0 + \beta_1 \ln GDP_{it} + \beta_2 \ln GDP_{it}^2 + \beta_3 \ln ENU_{it} + \beta_4 \ln AIR_{it} + \beta_5 \ln GLO_{it} + \varepsilon_{it} \tag{4}$$

where $\beta_0$ is a constant term, $\beta_1, \beta_2, \beta_3, \beta_4$, and $\beta_5$ denotes the long-run elasticities of economic growth, economic growth square, energy use, air transportation, and globalization, respectively. While, $\varepsilon_{it}$ and $t$ indicate error term and the time period of $t = 1, 2, 3, \ldots, n$.

Both models of EF and model of $CO_2$ require the technique of panel data analysis, a constructive econometric strategy for this study is formulated in the following section.

### 2.2. Econometric strategy

Panel data analysis starts with the examination of cross-sectional dependence. For this purpose, the Breusch and Pagan's [47] Lagrange multiplier (LM) and Pesaran's [48] cross-sectional dependence (CD) tests are prior used to check the presence of cross-sectional dependence among the underlying variables. Both LM and CD tests suggested that the confirmation of the existing of cross-sectional dependence in the data if there is the rejection of the null hypothesis.

Firstly, this study applied the Breusch and Pagan's [47] LM test, because N (number of cross-section units) is small and T (time period) is large in this case of data. The LM test can be captured through Equation (5):

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho}_{ij}^{2}, \tag{5}$$

where $\widehat{\rho}_{ij}$ refers to the pairwise correlation of the residuals between country i and j.

Concerning the cross-sectional dependence issue, a comprehensive estimator of the Pesaran's [48] CD test is tested and it can be designed as per Equation (6):

$$CD = \sqrt{\left(\frac{2T}{N(N-1)}\right)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho}_{ij}\right), \tag{6}$$

The next step of the analysis is to investigate the stationary level of the data. Due to the existence of the cross-sectional dependence in this study, the second-generation panel unit root test is more applicable than the first-generation panel unit root test. For this purpose, the cross-sectional Im-Pesaran-Shin (CIPS) and augmented Dickey-Fuller (CADF) unit root tests [49] are employed. These tests provide reliable and robust results during the problem of cross-sectional dependence and heterogeneity [50,51]. The CADF test can be estimated as:

$$\Delta y_{it} = a_i + \rho_i y_{it-1} + \rho_i \overline{y}_{it-1} + \sum_{j=0}^{k}\gamma_{ij}\Delta\overline{y}_{it-1} + \sum_{j=0}^{k}\delta_{ij} y_{it-1} + \varepsilon_{it}, \tag{7}$$

where $\Delta$, $a_i$, $\kappa$, and $\overline{y}_t$ denote the difference between parameters, intercept value, lag order, and mean value of CD for time t, respectively.

From Equation (7), the CIPS is designed based on the mean of CADF values, and the estimation model can be reformed as Equation (8):

$$CIPS = \left(\frac{1}{N}\right)\sum_{i=1}^{k} t_i(N,T), \tag{8}$$

Concerning the existence of cointegration, once the order of integration is confirmed, earlier techniques (Johansen, Kao et al., Pedroni's cointegration tests) were not applicable due to cross-sectional dependence in the data. To do that, the Westerlund panel cointegration test, by Westerlund [52], is more applicable. Based on the result of the P-values, there is cointegration in the whole panel if there is the rejection of the null hypothesis ($p < 0.1$) of the group statistics (Gt). In contrast, there is cointegration at least one cross-section if there is the rejection of the null hypothesis of the panel statistics (Pt). The Westerlund panel cointegration test can be calculated by using Equation (9):

$$\Delta y_{it} = \delta_i^{'} d_t + \alpha_i\left(y_{it-1} - \beta_i^{'} x_{i,t-1}\right) + \sum\nolimits_{j=1}^{P_i}\alpha_{ij}\Delta y_{i,t-j} + \sum\nolimits_{-q_i}^{P_i}\gamma_{ij}\Delta x_{i,t-j} + \varepsilon_{it}, \tag{9}$$

where $d_t$, $\alpha_i$, $P_i$,$q_i$ are the deterministic component, speed of error correction return to long-run equilibrium, lag order, lead order, respectively. $y_{it-1} - \beta_i^{'} x_{i,t-1}$ is cointegration, $i$ refers to the cross-sectional, and $t$ indicates time-series units.

After all fundamental analyses of panel data being investigated, the next step is to determine the long-run relationship. Therefore, this study used the Driscoll-Kraay standard errors test for this purpose. The Driscoll-Kraay standard errors test was initially developed by Driscoll and Kraay [53]. This estimator offers a favorable and robust result, regardless of whether there is balanced or unbalanced panel data, missing value, cross-sectional dependence, heteroscedasticity, and autocorrelations [53–55]. To achieve the study objective, the linear model of Driscoll-Kraay standard errors, therefore, was expressed in Equation (10):

$$y_{i,t} = x_{i,t}^{'}\beta + \varepsilon_{i,t}. \tag{10}$$

To accurately determine the long-run coefficient of the Driscoll-Kraay standard error approach, the estimation of the fully modified ordinary least squares (FMOLS), panel dynamic ordinary least squares (DOLS), and feasible generalized least squares (FGLS) methods have been applied accordingly. The FMOLS, DOLS, and FGLS methods were proposed by Pedroni [56,57], Kao and Chiang [58], and Parks [59], respectively. The FMOLS and DOLS methods provide consistent estimates for both endogeneity bias and serial correlation in non-parametric (FMOLS) and parametric (DOLS) ways [57,60]. Whereas, the FGLS is provided consistent estimates with regard to the cross-sectional problem [59,61,62]. Furthermore, the FMOLS performs good results in small sample data [57], the FGLS performs good results when the number of time periods (T) is exceeded or is equivalent to the number of cross-sections (N) [61].

The last step is to explore the causal relationship. Knowing the path of causal relations is necessary for policymakers in enacting effective policy. In doing this, the Dumitrescu-Hurlin panel causality test [63] is applied due to the benefit of overcoming the cross-sectional dependence and heterogeneity problem [32]. A modified version of Granger causality, the Dumitrescu-Hurlin panel causality test, is also flexibly applied for both T > N and T < N. The linear equation of the Dumitrescu-Hurlin panel causality test is computed below:

$$m_{i,t} = \varnothing_i + \sum_{i=1}^{n}\tau_i^{n} m_{i,t-i} + \sum_{i=1}^{n}\delta_i^{n} Z_{i,t-i} + \varepsilon_t. \tag{11}$$

In Equation (11), $\varnothing_i$, $\tau_i^n$, $\delta_i^n$ denote the constant value, regression coefficient, and represents autoregression, parameters.

## 3. Results

### 3.1. Descriptive statistics of variables

The overall results of descriptive statistics in natural logarithms of the variables are exhibited in Table 1. And on top of that, the scatter plot, histogram, and correlation matrix of underlying variables were drawn and presented in Fig. 1. From Tables 1 and it can be seen that the highest volatility is in the air transportation variable, while the lowest is in the globalization variable. Meanwhile, from Fig. 1, the positive correlation are confirmed between all variables.

### 3.2. Cross-sectional dependence (CD) tests

The results of LM and CD tests are reported in Table 2. Based on the P-values, the null hypothesis is rejected for both the LM and CD tests at 1% level of significance. In another word, the cross-sectional dependence is strongly confirmed in this study due to the evidence of the P-value is below 0.01. Thus, it implies that such an increase in one country affected the rest of other sample countries.

### 3.3. Panel unit root tests

After confirming the occurring of CD in this study, the second-generation panel until root tests (CIPS and CADF tests) are used to check the stationary condition of the underlying variables. Referring to the P-value, the results of CIPS and CIPS tests in Table 3 indicate that the null hypothesis is rejected in all variables. It is, thus, implying that the data is stationary at their 1st difference.

### 3.4. Panel cointegration test

After the CD and stationary issues are confirmed, the identification of cointegration is further required in the panel data analysis. The results of the Westerlund cointegration test provides both the group and probability statistics, and those results are tabulated in Table 4. According to the P-values, the Gt and Pt are confirmed to reject the null hypothesis in the Model 1 (EF), while the null hypothesis in the Model 2 ($CO_2$) is rejected only in the Ga at the 5% level of significance. The results imply that a cointegration relationship is found between the underlying variables.

### 3.5. Long-run estimation

The next step of the analysis is continued to investigate the long-run relationship between the variables. The Driscoll-Kraay standard errors estimator results are described in Table 5 and the details of findings are explained below:

First, the study confirms the EKC approach (an inverse U-shaped relationship) in the APEC countries for both Model 1 and Model 2. The GDP has a significant positive relationship with the EF and $CO_2$, while the $GDP^2$ has a significant negative relationship with the EF and $CO_2$ in the APEC countries at a significance level of 1%. The explanation for this finding is that the majority of APEC countries are from developed countries and higher middle-income countries. These countries have high income per capita, for example, Australia, Canada, Japan, New Zealand, Singapore, and the United States, etc. Therefore, their economic development exceeded some certain level of economic growth which have capability to improve their environmental quality. Also, these countries are the leading players in promoting the global environmental protection as the main bodies in the Paris agreement, and in the UN Sustainable Development Goals, etc. Furthermore, the economic structure in these countries focuses on the service economy that implementing the advanced technology. Those technologies increase the efficient and decrease the external effects at the same time. This result is consistent with the finding of the inverse U-shaped EKC relationship in G7 countries [51,64] and BRICS countries [65]. It is in contrast with the finding in OECD countries [66], BRICST countries [67].

Second, the long-run relationship between energy consumption and environmental degradation (the EF and $CO_2$) is positive and significant at the 1% significance level. The plausible reason is that these countries heavily consumed conventional energy especially fossil fuel, coal, and natural gas. Among the top 5 in the world, the US, China, India, Russia, and Japan are the top oil consumptions

**Table 1**
Descriptive statistics of underlying variables.

| Variables | lnEF | $lnCO_2$ | lnGDP | $lnGDP^2$ | lnENU | lnAIR | lnGLO |
|---|---|---|---|---|---|---|---|
| Mean | 1.283 | 1.613 | 9.193 | 86.135 | 7.667 | 17.033 | 4.208 |
| Median | 1.368 | 1.919 | 9.144 | 83.620 | 7.759 | 16.877 | 4.236 |
| Maximum | 2.349 | 3.004 | 10.916 | 119.177 | 9.040 | 20.497 | 4.448 |
| Minimum | −0.318 | −1.197 | 6.167 | 38.032 | 5.582 | 12.226 | 3.436 |
| Std. Dev. | 0.674 | 1.013 | 1.271 | 22.987 | 0.970 | 1.340 | 0.175 |
| Skewness | −0.335 | −0.563 | −0.272 | −0.097 | −0.366 | 0.418 | −1.182 |
| Kurtosis | 2.013 | 2.284 | 1.939 | 1.741 | 1.850 | 3.773 | 4.763 |
| Jarque-Bera | 24.223 | 30.311 | 24.157 | 27.585 | 31.569 | 22.086 | 147.891 |
| Probability | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Observation | 408 | 408 | 408 | 408 | 408 | 408 | 408 |

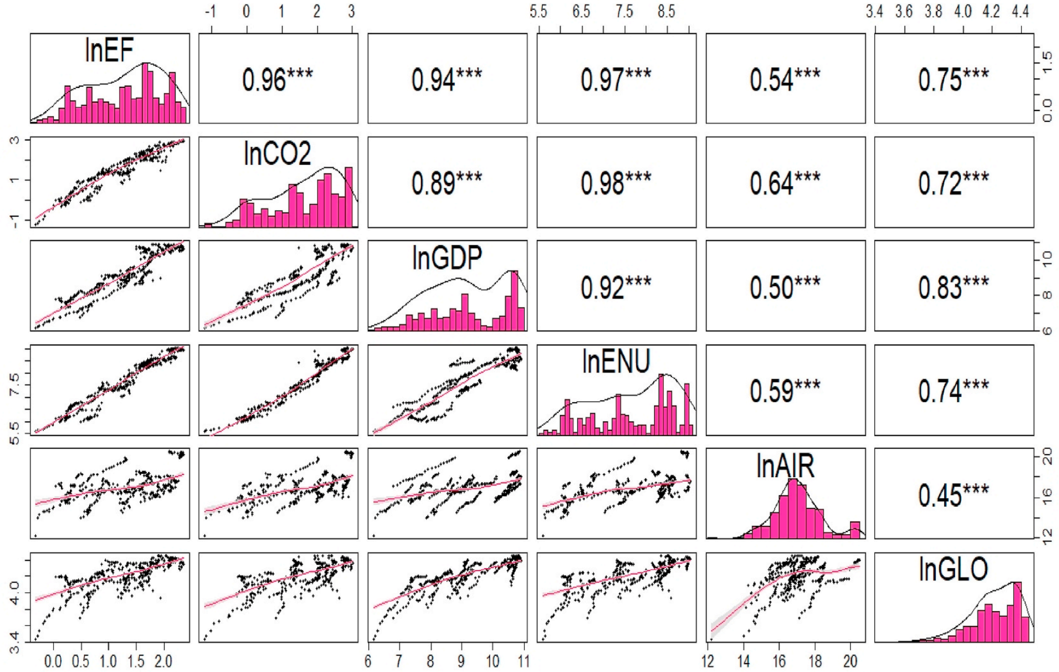

**Fig. 1.** Scatter plot, histogram, and correlation matrix of underlying variables.

**Table 2**
Results of cross-sectional dependence test.

| Variable | LM test | | CD test | |
|---|---|---|---|---|
| | Statistic | p-value | Statistic | p-value |
| lnEF | 182.3*** | 0.004 | 6.824*** | 0.000 |
| lnCO$_2$ | 255.6*** | 0.000 | 10.56*** | 0.000 |
| lnGDP | 320.6*** | 0.000 | 53.414*** | 0.000 |
| lnGDP$^2$ | 333.8*** | 0.000 | 53.412*** | 0.000 |
| lnENU | 182.9*** | 0.004 | 12.377*** | 0.000 |
| lnAIR | 263.5*** | 0.000 | 46.223*** | 0.000 |
| lnGLO | 236.4*** | 0.000 | 54.401*** | 0.000 |

Note: (***) indicates significance at the 1% level which affirms the the existence of CD.

**Table 3**
Results of panel unit root tests.

| Variable | CIPS test statistic | | CADF test statistic | | Order of integration |
|---|---|---|---|---|---|
| | Level | First difference | Level | First difference | |
| lnEF | −1.442 | −4.442*** | −2.267 | −3.280*** | I(1) |
| lnCO$_2$ | −2.187 | −2.912*** | −2.041 | −3.951*** | I(1) |
| lnGDP | −0.842 | −3.194*** | −1.932 | −2.730** | I(1) |
| lnGDP$^2$ | −0.703 | −3.146*** | −1.958 | −2.688* | I(1) |
| lnENU | −0.938 | −3.606*** | −2.232 | −2.917*** | I(1) |
| lnAIR | −1.723 | −4.826*** | −2.195 | −3.262*** | I(1) |
| lnGLO | −1.340 | −4.481*** | −2.063 | −3.307*** | I(1) |

Note: (***), (**), and (*) indicate significance at the 1%, 5% and 10% levels, respectively which affirm the existence of stationary.

[68]. Indeed, some APEC economies are also large producers and exporters of oil. The US, Russia, China, and Canada are ranked in the world's top 5 oil producers [68]. For example of the energy and CO$_2$ linkage in the US, the utilization of petroleum fuels, natural gas, and coal extremely contribute to CO$_2$ emissions at 46%, 33%, and 21%, respectively in 2019 [69]. Our finding supports the result of Saud et al. [32] for One-Belt-One-Road initiative countries, Kongbuamai et al. [70] for ASEAN countries, Wang et al. [51] for G7 countries, and Destek and Sinha [66] for OECD countries. In contrast, our finding differs from the finding of Ozturk et al. [71] for the

**Table 4**
Results of Westerlund cointegration test.

| Statistic | | Value | Z value | p-value | Robust p-value |
|---|---|---|---|---|---|
| Model 1 | Gt | −3.507** | −2.205 | 0.014 | 0.015 |
| | Ga | −7.468 | 5.277 | 1.000 | 0.455 |
| | Pt | −13.261** | −1.782 | 0.037 | 0.035 |
| | Pa | −9.068 | 3.023 | 0.999 | 0.085 |
| Model 2 | Gt | −2.306 | 1.474 | 0.930 | 0.425 |
| | Ga | −8.292** | 3.343 | 1.000 | 0.035 |
| | Pt | −7.044 | 2.535 | 0.994 | 0.695 |
| | Pa | −4.912 | 3.168 | 0.999 | 0.705 |

Note: (**) indicates significance at the 5% level which affirms the the existence of cointegration.

upper-middle, and high-income countries, Alola et al. [39] and Altıntaş and Kassouri [72] for EU countries.

Further, air transportation has a significantly negative relationship with the ecological footprint. Conversely, air transportation has a significantly positive relationship with $CO_2$ Nonetheless, the coefficient of $CO_2$ is smaller compare to the coefficient of the EF. It implies that air transportation mitigates the environmental degradation (the ecological footprint) as the ecological footprint is inclusive indicators, while $CO_2$ is one of the determinants in the ecological footprint. A possible reason is that aircraft in the current decade is highly efficient technology. Due to the increasing number of air passengers, air transportation releases higher $CO_2$, in adverse, those advanced technologies mitigate the aggregated environment (the ecological footprint). In addition, administration in the airline business is more efficient due to the use of technology in administrative works and passenger reservations. On top of that, the technology also increases the rate of seat occupation due to airline business cooperation which makes each route more efficient.

Lastly, there is the negative effect of globalization on the EF and $CO_2$ in the APEC countries. This is because the APEC countries facilitate trade liberalization, thus human and resources mobility as aiming globalization's and economic integration's achievement. For trade liberalization, it enhances the import of advanced technology and innovation to the APEC countries. Also, the human capital and knowledge can be transferred which improve product and service standards. Thus, their inclusive policy and regulations lead the global environmental agenda, and they stick to those environmental issues. Therefore, these actions help to increase the countries' competitiveness of the APEC countries in response to environmental protection.

Moving forward, the FMOLS, DOLS, and FGLS estimations are applied in this study in order to robust the long-run relationship results. Table 6 demonstrates the results of Model 1 and Model 2 which reveal these three estimation methods. Overall, the results of FMOLS, DOLS, and FGLS are concordant with the finding from the Driscoll-Kraay standard errors estimation for both models (EF and $CO_2$).

### 3.6. Dumitrescu-Hurlin panel causality test

Concerning the causality relationship, the Dumitrescu-Hurlin panel causality test is employed as the advantages of cross-sectional dependence eradication. The empirical result of this test is tabulated in Table 7. Interestingly, there is a bidirectional relationship between the ecological footprint and air transportation, while a one-way relationship is running from air transportation to $CO_2$ in the case of APEC countries. The result suggests that the ecological footprint Granger-causes air transportation and, in turn, air transportation also Granger-causes the ecological footprint in this region. Meanwhile, air transportation is Granger caused by $CO_2$ in a one-way path. Furthermore, a bidirectional relationship is found between economic growth and both the EF and $CO_2$. In addition, energy consumption is found to have a bidirectional relationship with both the EF and $CO_2$, reflecting that energy consumption is Granger-caused by both EF and $CO_2$ in the Granger sense.

## 4. Conclusions

The primary goal of this research was to examine the environmental impact of air transportation and globalization while taking into account the ecological footprint in APEC countries. By applying estimation approaches that are resilient for cross-sectional dependency, the study provides new findings on the influences of air transportation and globalization on the environment in the study region. Specifically, air transportation is found to increase $CO_2$ emissions, but it contributes a negative effect on the ecological footprint of APEC countries. Besides, globalization is confirmed to have a negative relationship with the ecological footprint and $CO_2$ emissions. We also found the evidence of bidirectional causality and unidirectional causality between air transportation and ecological footprint and $CO_2$, respectively. In addition, the empirical results also disclose the one-way causality relation running from globalization to EF and $CO_2$.

Empirical results of this study gives us a few policy recommendations. It is interesting to highlight that air transportation has a positive contribution to environmental quality improvement. Therefore, along with the impacts on economic growth, air transportation can be considered as a driver of sustainable development in APEC countries and policies to encourage air transport should be proposed and adopted in these countries. However, these policies also need to pay attention to concerns about increasing $CO_2$ emissions of this type of transport. Using alternative fuels or more fuel-efficient technology, developing hybrid electric aircraft and electric aircraft, and encouraging carbon offset actions can be considered solutions to this problem. In addition, globalization is indicated to help reduce both ecological footprint and $CO_2$ emission in APEC countries. Therefore, strengthening the interconnection

**Table 5**

Results of regression with Driscoll-Kraay standard errors.

| Variable | Model 1: EF = f(GDP, GDP$^2$, ENU, AIR, GLO) | | | | Model 2: $CO_2$ = f(GDP, GDP$^2$, ENU, AIR, GLO) | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (1) | (2) | (3) | (4) |
| lnGDP | 0.842*** (2.345) | 0.339*** (4.72) | 0.313*** (4.15) | 0.483*** (4.50) | 1.912*** (18.62) | 0.775*** (7.71) | 0.890*** (10.39) | 1.133*** (15.93) |
| lnGDP$^2$ | −0.019** (2.345) | −0.009*** (−2.42) | −0.008*** (−2.01) | −0.015*** (−2.78) | −0.066*** (−10.83) | −0.044*** (−7.79) | −0.050*** (−9.97) | −0.060*** (−14.36) |
| lnENU | – | 0.472*** (30.50) | 0.492*** (27.03) | 0.477*** (32.09) | – | 1.065*** (61.75) | 0.974*** (48.56) | 0.954*** (37.83) |
| lnAIR | – | – | −0.017*** (−4.57) | −0.012*** (−3.12) | – | – | 0.076*** (12.12) | 0.008*** (12.65) |
| lnGLO | – | – | – | −0.282*** (−4.39) | – | – | – | −0.400*** (−4.11) |
| Constant | −4.822*** (−28.35) | −4.639*** (−15.19) | −4.364*** (−12.90) | −4.085*** (−12.20) | −10.227*** (−23.98) | −9.814*** (−18.55) | −11.035*** (−25.02) | −10.638*** (−18.80) |
| F statistics | 6616.66 | 18031.25 | 11574.88 | 10025.53 | 11890.66 | 3535.71 | 18149.57 | 14304.33 |
| p-value | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| R$^2$ | 0.885 | 0.958 | 0.959 | 0.960 | 0.801 | 0.966 | 0.972 | 0.973 |
| Root MSE | 0.228 | 0.137 | 0.136 | 0.134 | 0.453 | 0.186 | 0.168 | 0.164 |

Note: t-statistics are shown in parentheses. (***) indicates significance at the 1% level.

**Table 6**
Results of FMOLS, DOLS, and FGLS estimation.

| Variable | Model 1: EF = f(GDP, $GDP^2$, ENU, AIR, GLO) | | | Model 2: $CO_2$ = f(GDP, $GDP^2$, ENU, AIR, GLO) | | |
|---|---|---|---|---|---|---|
| | FMOLS | DOLS | FGLS | FMOLS | DOLS | FGLS |
| lnGDP | 1.274*** (6.24) | 2.144*** (4.00) | 0.493*** (24.98) | 11.557*** (3.06) | 15.148** (2.10) | 1.121*** (68.10) |
| $lnGDP^2$ | −0.059*** (−5.78) | −0.101*** (−3.33) | −0.016*** (−16.10) | −0.646*** (−3.54) | −0.815** (−2.34) | −0.059*** (−68.96) |
| lnENU | 0.423*** (7.55) | 0.301*** (4.48) | 0.477*** (152.11) | 0.736*** (13.04) | 0.668*** (5.51) | 0.954*** (358.48) |
| lnAIR | −0.032 (−1.61) | −0.060*** (−2.99) | −0.012*** (−12.12) | 0.059** (2.06) | 0.039 (0.771) | 0.082*** (193.80) |
| lnGLO | −0.199*** (−1.95) | −0.273*** (−2.84) | −0.284*** (−19.63) | −0.279* (−1.72) | −0.708** (−2.25) | −0.392*** (−144.00) |

Note: t-statistics are shown in parentheses. (***), (**), and (*) indicate significance at the 1%, 5%, and 10% levels, respectively.

**Table 7**
Results of Dumitrescu-Hurlin panel causality test.

| Variables | lnEF | $lnCO_2$ | lnGDP | lnENU | lnAIR | lnGLO |
|---|---|---|---|---|---|---|
| lnEF | – | 2.873*** (0.000) | 5.396*** (0.000) | 2.273** (0.005) | 3.653*** (0.000) | 3.133*** (0.000) |
| $lnCO_2$ | 1.195 (0.839) | – | 3.736*** (0.000) | 2.040** (0.025) | 3.248*** (0.000) | 2.744*** (0.000) |
| lnGDP | 2.977*** (0.000) | 2.157** (0.011) | – | 1.830* (0.083) | 2.510*** (0.000) | 2.893*** (0.000) |
| lnENU | 1.969** (0.038) | 2.691*** (0.000) | 3.396*** (0.000) | – | 2.051** (0.023) | 3.720*** (0.000) |
| lnAIR | 3.926*** (0.000) | 1.613 (0.226) | 6.687*** (0.000) | 3.374*** (0.000) | – | 5.507*** (0.000) |
| lnGLO | 1.103 (0.985) | 0.932 (0.667) | 1.959** (0.041) | 1.505 (0.342) | 1.317 (0.619) | – |

Note: p-values are shown in parentheses. (***), (**), and (*) indicate significance at the 1%, 5%, and 10% levels, respectively.

between APEC countries in the socio-economic sectors (including air transport) should be further promoted.

In this study, we assess the environmental impact of air transportation in APEC countries by using ecological footprints and $CO_2$ emissions as proxies for environmental quality. The impact of air transportation to other environmental factors (such as noise, water pollution ….) or socio-economic aspects in this group countries also need to be more carefully evaluated. Besides, in further studies, this theme can also be conducted in other countries (such as developed or developing countries) to provide a more comprehensive view of the impacts of air transport and globalization process.

## Author contribution statement

Nattapan Kongbuamai: Analyzed and interpreted the data; Wrote the paper.
Ali Hashemizadeh: Analyzed and interpreted the data; Wrote the paper.
Virginia Cheung: Contributed reagents, materials, analysis tools or data; Wrote the paper.
Dang Hong Bui: Conceived and designed the experiments; Wrote the paper.

## Data availability statement

Data will be made available on request.

## Additional information

No additional information is available for this paper.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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