Hasanuddin Economics and Business Review
E-ISSN : 2549-323X
Faculty of Economics and Business, Hasanuddin University

Vol. 10, No. 1, 2026
Doi: 10.26487/hebr.v10i1.6994

RESEARCH ARTICLE

The Impact of CO_2 Emissions on International Tourism Performance: An Empirical Study on G20 Member Countries

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KEYWORDS
Carbon emissions; G20 economies; International tourist arrivals; Low-carbon development; Sustainable tourism

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RECEIVED 2026-04-26
REVISED 2026-04-28
ACCEPTED 2026-05-28

ABSTRACT
This study examines the effect of CO_2 emissions on international tourist arrivals in G20 member countries, with particular attention to the underexplored reverse channel through which environmental degradation may weaken tourism performance. The study positions the CO_2–tourism relationship within the broader agenda of low-carbon development and sustainable tourism competitiveness. This study employs balanced panel data covering 19 G20 member countries from 2014 to 2019. Pooled OLS, Fixed Effect, and Random Effect models are estimated, while the Chow Test, Hausman Test, and Breusch–Pagan Lagrange Multiplier Test are used to determine the most appropriate model. The Fixed Effect Model is selected as the preferred specification to control for unobserved time-invariant country characteristics. The results show that CO_2 emissions are negatively and significantly associated with international tourist arrivals. A one percent increase in CO_2 emissions is linked to a 0.625 percent decline in inbound tourism, suggesting that environmental degradation may reduce destination attractiveness. GDP per capita is the strongest positive correlate of tourism performance, while trade openness and real effective exchange rate appreciation are negatively associated with tourist arrivals. Population size is not statistically significant in the fixed effect specification. This study contributes to the tourism-environment literature by examining the reverse effect of CO_2 emissions on tourism performance using G20 countries as a unified analytical context. The findings offer policy-relevant insights for low-carbon tourism governance, sustainable destination competitiveness, and green development strategies in advanced and emerging economies.

1. INTRODUCTION

International tourism is one of the most economically vital and swiftly growing areas in the global economy. In 2024, the entire contribution of travel and tourism to global GDP amounted to US$10.9 trillion, accounting for nearly 10% of the world economy, while sustaining around 357 million jobs, or one in every ten jobs globally (World Travel & Tourism Council, 2024). The sector's post-pandemic resurgence has been notable: approximately 1.4 billion international tourists journeyed globally in 2024, reflecting an 11% rise from 2023, while international tourism revenues attained USD 1.6 trillion around

4% higher than pre-pandemic 2019 figures in real terms (UN Tourism, 2025a). The most recent World Tourism Barometer indicates that international tourism nearly regained 99% of pre-pandemic levels in 2024, with the majority of destinations achieving or surpassing their 2019 standards (UN Tourism, 2024).

In the global context, G20 member states hold a distinctly preeminent position. In 2024, G20 economies jointly received 68% of all international tourists and represented 71% of global tourism exports, with tourism's direct contribution to G20 GDP amounting to USD 2.8 trillion, or 3.1% of the group's total economic output (UN Tourism, 2024). These statistics establish the G20 not just as a consortium of significant economies but also as the fundamental nucleus of the global tourism framework rendering it an essential unit of analysis for any examination of the macroeconomic and environmental dynamics of international travel.

Notwithstanding its significant economic benefits, the rapid expansion of international tourism has substantial environmental repercussions, primarily manifested as greenhouse gas (GHG) emissions, especially carbon dioxide (CO_2). A thorough examination employing environmentally extended input-output modelling revealed that global tourism emissions increased by 3.5% annually from 2009 to 2019 twice the growth rate of the overall world economy culminating in 5.2 Gt CO_2-equivalent, or roughly 8.8% of total global GHG emissions in 2019 (Sun et al., 2024). The principal cause of this disparity is the significant disparity between modest technological efficiency improvements around 0.3% annually and persistent robust growth in tourism demand, averaging 3.8% per year (Sun et al., 2024). If these trends persist, annual tourism emissions are anticipated to rise by 3–4%, a trajectory deemed inherently incompatible with the Paris Agreement's 1.5°C objective (Sun et al., 2024). Transport-associated CO_2 emissions from the tourism sector are anticipated to increase by 25% from 2016 to 2030, with emissions from international tourism expected to rise by 45%, from 458 Mt CO_2 to 665 Mt CO_2 (UN Tourism, 2019a).

The twenty highest-emitting countries account for three-quarters of the global tourist carbon footprint, predominantly comprising G20 members (Sun et al., 2024), hence underscoring the group's significance in any viable climate response within the tourism sector. Recent figures present a somewhat more favorable outlook. In 2023, the travel and tourism industry represented 6.5% of total global emissions, a decrease from 7.8% in 2019 (WTTC, 2024b). By 2024, sector-wide greenhouse gas emissions had decreased by 9.3% compared to 2019 levels, with emissions intensity reduced by 15% during the same timeframe, propelled by a 16.6% rise in low-carbon energy utilization (WTTC, 2025). Researchers warn that these efficiency improvements are inadequate in absolute terms and that, absent a significant structural shift, the sector's emissions are expected to revert to their pre-pandemic increasing trend (Peeters et al., 2024).

The G20 countries hold principal accountability in international climate governance for facilitating the global energy transition. The Emissions Gap Report 2023, released by the United Nations Environment Programme (UNEP, 2023), indicates that existing policies among G20 nations are markedly inadequate: to meet 2030 objectives, an

additional 28% reduction in emissions is necessary, while adherence to the 1.5°C target necessitates a 42% decrease benchmarks that current national policies do not fulfill. The systemic gap is exacerbated by intensifying climate effects: global average surface temperatures surpassed the 1.5°C warming threshold for the first time in 2024, coinciding with unprecedented extreme weather events in various regions (World Meteorological Organization, 2025; Intergovernmental Panel on Climate Change, 2021). The repercussions of climate change result in tangible economic detriments for the tourism industry: in Australia, the wildfires of 2019 incurred an estimated US$3.4 billion in tourism revenue losses, whereas tourist arrivals in Maui, Hawaii, plummeted by 24%, equating to a US$2.6 billion impact, subsequent to the catastrophic fires of 2023 (Scott & Gössling, 2025). This information demonstrates that climate change is not a prospective threat to tourism; it is an urgent economic reality.

The Glasgow Declaration on Climate Action in Tourism, ratified at COP26, established a goal to reduce CO_2 emissions from the tourism sector by 50% by 2030 and attain net-zero emissions by 2050 (UN Tourism, 2021). Researchers assert that a limited pathway exists to achieve net-zero tourism without significantly harming the tourism economy, necessitating concurrent robust demand control, technological adoption, and regulatory action (Peeters et al., 2024). The correlation between CO_2 emissions and international tourist arrivals is conceptually and empirically intricate, marked by bidirectional causality and context-dependent dynamics. A significant body of literature has explored the CO_2 emissions generated by tourism activity, while an emerging area of research examines the inverse relationship: how cumulative CO_2 emissions and their climatic repercussions influence destination appeal, tourist behavior, and inbound tourist arrivals. Theoretically, higher CO_2 emissions may reduce international tourist arrivals through several interconnected channels. First, elevated emissions contribute to air pollution and degraded urban environments, directly lowering the amenity value of destinations and deterring health-conscious travelers (Li et al., 2022). Second, cumulative CO_2 emissions accelerate climate change, increasing the frequency of extreme weather events such as heatwaves, wildfires, and coastal flooding that damage tourism infrastructure and reduce destination attractiveness (Scott & Gössling, 2025). Third, high-emission destinations may suffer reputational damage as environmentally aware tourists increasingly factor ecological conditions into their travel decisions (Fethi & Senyucel, 2021). Fourth, carbon-intensive growth patterns often correlate with environmental degradation of natural assets beaches, forests, biodiversity that underpin ecotourism and nature-based travel, further eroding destination competitiveness.

A thorough examination of 105 empirical studies regarding the relationship between tourism demand, CO_2 emissions, and economic growth revealed a fragmented literature concerning methodology, geographic scope, and causal direction, highlighting the necessity for more rigorous, context-specific analyses (Vargas-Sánchez & Moral-Cuadra, 2024). Research findings are inconsistent: some research indicates that elevated CO_2 levels diminish tourist arrivals due to environmental deterioration, whereas others reveal no significant impact or a positive correlation mediated by income levels.

Panel estimations in the MENA area indicate that tourist visits diminish CO_2 emissions, whereas energy consumption and trade openness are the principal drivers of increasing emissions results that directly contradict data from other regions (Yildiz et al., 2023).

The Environmental Kuznets Curve (EKC) hypothesis serves as a significant theoretical framework for this investigation. Within the realm of tourism, certain research validates an inverted U-shaped Environmental Kuznets Curve (EKC) caused by tourism, while others present inconsistent or conflicting findings across both developed and developing economies (Mahadevan & Suardi, 2025). The G20 group, comprising economies at varying stages of development from high-income countries like the United States, Germany, and Japan to upper-middle-income nations such as China, Brazil, and South Africa serves as an optimal platform for examining heterogeneous environmental Kuznets Curve dynamics in the realm of international tourism.

Despite growing academic attention on the tourism-environment nexus, three critical gaps remain. First, while much research examines how tourism drives CO_2 emissions, the reverse channel how CO_2 emissions affect international tourist arrivals is underexplored in the panel econometrics literature, especially at the G20 level. Second, empirical studies explicitly treating the G20 as an analytical unit are scarce, limiting the policy relevance of existing findings for this group's climate and tourism governance agenda. Third, evidence linking CO_2 emissions to tourism arrivals remains methodologically inconsistent, with results varying by region, estimator, and sample period (Vargas-Sánchez & Moral-Cuadra, 2024; Saqib & Benhmad, 2024). This study directly addresses these gaps by estimating the effect of CO_2 emissions on international tourist arrivals in G20 economies using panel fixed-effect estimation, thereby providing systematic empirical evidence on a relationship that has significant implications for sustainable tourism policy.

2. LITERATURE REVIEW

2.1 The Impact of Tourism on CO_2 Emissions: Evidence from Multi-Country Studies

The correlation between tourism activities and CO_2 emissions has been thoroughly examined through both single-country time series and multi-country panel data methodologies. The amassed evidence is substantial yet uniformly contradictory, with results varying according to geographic context, model specification, and the variables employed to represent tourism activities. Koçak and Ulucak (2023) made a significant contribution to this discourse by utilizing sophisticated panel data estimators namely the Continuously Updated Fully Modified (CUP-FM) and Continuously Updated Bias-Corrected (CUP-BC) estimators to analyze the relationship between tourism and CO_2 emissions in the most frequented countries from 1995 to 2014. Their findings indicated that tourism arrivals positively and significantly impact CO_2 emissions, whereas tourism earnings negatively affect them, implying that visitor numbers and tourism revenue have

contrasting environmental consequences. This finding emphasizes the importance of distinguishing between various proxies of tourism activities in empirical research.

Sun et al. (2024) utilized environmentally extended input-output modelling across 175 nations and established that global tourism emissions increased by 3.5% annually from 2009 to 2019 twice the growth rate of the global economy primarily due to the disparity between sluggish energy efficiency improvements (0.3% per year) and rapid demand escalation (3.8% per year). The research additionally revealed that the twenty highest-emitting nations accounted for three-quarters of the worldwide tourism carbon footprint and that carbon inequality between affluent and impoverished countries was increasing rather than decreasing. Tian et al. (2021), utilized the Fully Modified Ordinary Least Squares (FMOLS) method at the G20 level and discovered that a 1% rise in tourism leads to a 0.05% decrease in CO_2 emissions within G20 economies, a finding ascribed to the dominance of higher-income, service-oriented tourism in these developed markets. This conclusion diverges from studies conducted in impoverished nations, where tourism growth more reliably increases emissions due to a heightened reliance on fossil-fuel-intensive transportation and lodging (Hussain et al., 2024).Regional investigations elucidate the variability of this relationship.

Saqib and Benhmad (2024) examined 32 countries in Latin America and the EU through cointegration and cluster convergence methodologies, revealing that, on average, tourism growth negatively affects the environment, although the extent of this impact varies significantly among countries based on their level of tourism development. Their research identified bidirectional Granger causation between the ecological footprint and tourism growth, affirming that the link is not unidirectional. Yildiz et al. (2023) utilized Common Correlated Effects Mean Group (CCE-MG) estimators for MENA countries and discovered that tourist arrivals decrease CO_2 emissions, whereas energy consumption and trade openness are the principal factors contributing to environmental degradation contradicting the traditional belief in a positive correlation between tourism and emissions.

In the realm of emerging markets, Öztürk et al. (2023) employed quantum-in-quantum regression and Granger causality methodologies, revealing a heterogeneous pattern of both positive and negative impacts of tourist arrivals on CO_2 emissions across various destinations, thereby affirming that no uniform directional relationship can be universally applied to all national contexts. Khan et al. (2024) conducted a decoupling analysis using panel data from China and prominent tourist nations, revealing that in EU countries, CO_2 emissions decreased with rising tourist arrivals but increased with economic growth highlighting that the impact of tourism on the environment is significantly influenced by the host economy's energy mix and regulatory framework.

2.2 The Reverse Channel: How CO_2 Emissions Affect International Tourism Performance

Although the literature on the effects of tourism on emissions is extensive, the inverse inquiry how CO_2 emissions and climate change influence international tourism performance has garnered relatively less systematic empirical scrutiny, despite its increasing theoretical and policy significance. Scott and Gössling (2025) provide the most comprehensive contemporary analysis of the effects of climate change on tourist demand and destination development. Their data indicates that climate-related disruptions such as extreme heat events, wildfires, flooding, biodiversity loss, and coastline erosion are already causing quantifiable declines in visitor arrivals and profits in impacted areas. In Australia, wildfires in 2019 resulted in a loss of US$3.4 billion in tourism revenue; arrivals in Maui, Hawaii decreased by 24%, equating to a US$2.6 billion impact, following catastrophic fires in 2023; and one-third of Jasper National Park, Canada, was ravaged by fire in July 2024, incurring damages and lost tourism revenues exceeding CA$1 billion (Scott & Gössling, 2025). These findings show that CO_2 induced climate change represents not only a theoretical future concern for the tourism sector but also an immediate and quantifiable economic peril.

Li et al. (2022) used a geographic panel dataset encompassing 99 countries from 1996 to 2018 to analyze the influence of air quality, closely linked to CO_2 and particle emissions, on international visitor arrivals. Through spatial econometric modelling that incorporates cross-country spillovers, they discovered that inadequate air quality has a substantial and adverse influence on tourist arrivals, with the impact demonstrating distinct variation between middle-income and high-income countries. Countries exhibiting elevated research and development (R&D) intensity showed improved air quality and, as a result, enhanced tourism inflows, indicating that green innovation mediates the environmental influence on tourism demand. Cevik and Ghazanchyan (2023) examined the impact of the EU Emissions Trading System (EU ETS), a carbon pricing mechanism, on tourism arrivals through monthly panel data from 26 European nations spanning 2005 to 2019. A temporary "V-shaped" pattern was observed: carbon price shocks resulted in a 2.5 percentage point decrease in arrivals during the initial three months post-shock, but demand returned to its trend within six months. The EU ETS did not permanently diminish tourism demand; however, it enhanced operational efficiency in airlines, suggesting that carbon price influences the framework of tourism supply without decreasing long-term arrivals, as airlines may adopt more sustainable practices that attract environmentally conscious travelers.

Hussain et al. (2024) utilized the Panel ARDL Pooled Mean Group (PMG) architecture to analyze G7 economies and discovered that, in the long term, CO_2 emissions positively and significantly correlate with tourist expansion, although the ecological footprint demonstrates a negative correlation. This contradictory observation indicates that in developed G7 nations, elevated emissions coincide with increased earnings, and it is income, rather than environmental quality itself, that propels tourism

demand. This aligns with the growth-led tourism concept, which posits that macroeconomic success, despite associated emissions, fosters both outbound and inbound travel. Rohan and Suyanto (2025) employed fixed-effects OLS and Johansen Fisher panel cointegration techniques to examine ASEAN economies, asserting that CO_2 emissions negatively influence international tourism revenues. They contend that climate change modifies the climatic conditions essential for tourism activities, thereby reducing the appeal of natural resources, especially in beach and sun tourism, winter sports tourism, and ecotourism. Their research elucidates the process by which emissions adversely affect tourism: both via direct environmental deterioration and by elevating the perceived risk associated with travel to climate-vulnerable destinations.

2.3 G20-Specific Evidence and Distributional Dynamics

Despite the G20's prominent role in global tourism and emissions, empirical research specifically focusing on this group as an analytical unit is relatively scarce. The existing research, however, indicates numerous significant discoveries. Tani et al. (2024) assessed the carbon footprint of tourist sectors in G20 member nations pre- and post-COVID-19 pandemic via an integrated Multi-Regional Input-Output (MRIO) and Tourist Satellite Account (TSA) methodology. Their findings indicated that transportation mainly aviation constitutes approximately 60–77% of total greenhouse gas emissions from tourism in G20 nations, while accommodation, food and beverages, and souvenirs each contribute about 5–10%. The research indicated that the COVID-19 pandemic caused significant but transient decreases in tourist emissions and that the swift resurgence of travel demand post-pandemic suggests a reversion to pre-pandemic emission levels absent fundamental structural alterations.

Alcalá-Ordóñez et al. (2025) investigated tourism, economic expansion, and CO_2 emissions in the ten most frequented nations worldwide predominantly G20 members during the period from 1995 to 2023, utilizing Cross-Sectional ARDL (CS-ARDL) models. The Westerlund cointegration test indicated a statistically significant long-run equilibrium link among tourism arrivals, GDP, and CO_2 emissions ($p = 0.022$), confirming the cointegration of these variables across time. The study identified varied causal linkages within the country sample, underscoring the notion that the G20's internal variety regarding income levels, energy composition, and tourism development results in markedly distinct emission–tourism dynamics among member states. Ghosh et al. (2022, as referenced in Saqib & Benhmad, 2024) identified a bidirectional Granger causality between CO_2 emissions, tourism, and ecological footprint within G7 nations, indicating that emissions both influence and are influenced by tourism activities. Anwar et al. (2023) discovered that tourism fosters green GDP growth in BRICS economies Brazil, Russia, India, China, and South Africa, all G20 members using the CS-ARDL framework. Additionally, they found that renewable energy consumption markedly decreases CO_2 emissions, indicating a potential method for decoupling tourism expansion from environmental degradation via energy transition.

2.4 Research Gaps and Positioning of the Present Study

An examination of the current literature identifies three significant research gaps that this study directly addresses. First, the majority of multi-country empirical studies investigate the influence of tourism on CO_2 emissions; however, the reverse channel how CO_2 emissions affect international tourist arrivals remains insufficiently examined using panel econometric approaches at the G20 level. Existing evidence on this reverse channel primarily derives from qualitative assessments, case studies, or limited regional analyses (Scott & Gössling, 2025; Li et al., 2022), rather than systematic panel data models. Second, although G20 nations collectively dominate global tourism flows and emissions, limited research has utilized G20 membership as the principal analytical framework. Existing studies involving G20 nations typically embed them within broader global or OECD datasets, obscuring G20-specific heterogeneity and reducing policy relevance for this group's climate and tourism governance objectives (Tani et al., 2024; Alcalá-Ordóñez et al., 2025). Third, empirical findings on the CO_2–tourism nexus remain inconsistent, ranging from significantly negative to significantly positive to statistically insignificant, depending on regional context, income group, and estimation method (Vargas-Sánchez & Moral-Cuadra, 2024; Koçak & Ulucak, 2023; Yildiz et al., 2023). This study addresses all three gaps by employing a G20-centric panel dataset with fixed-effect estimation to empirically quantify the impact of CO_2 emissions on international tourist arrivals in a rigorous and policy-relevant manner.

3. METHODOLOGY

This study utilizes a balanced panel data methodology encompassing 19 G20 member states from 2014 to 2019, resulting in 114 country-year observations. This period represents an era of sustained and uninterrupted growth in global tourism, during which international tourist arrivals increased consistently from 1.13 billion in 2014 to a record 1.46 billion in 2019 marking ten consecutive years of above-average growth prior to the COVID-19 pandemic (UN Tourism, 2019b; UNWTO, 2019). Panel data is intentionally selected over solely cross-sectional or time-series designs for many reasons. Panel data concurrently captures variation across nations and temporal dimensions, thereby augmenting the quantity of informative data points, diminishing multicollinearity among explanatory variables, and facilitating the control of unobserved country-specific heterogeneity that could otherwise yield biased estimates (Baltagi, 2021; Hsiao, 2022; Wooldridge, 2019). Unlike time-series analysis, which is limited by a finite number of observations for a single unit, panel data enables researchers to investigate dynamic changes with greater statistical power, even over short durations (Gujarati, 2003). This is especially significant in the context of the current study, where macroeconomic and environmental variables among G20 economies are anticipated to display both cross-country structural disparities and temporal within-country variation, rendering panel

estimation the most suitable and methodologically robust analytical option (Dogan & Aslan, 2017; Khan et al., 2024).

Given the structural diversity of G20 economies, encompassing high-income OECD nations, upper-middle-income emerging markets, and underdeveloped countries, this methodology is particularly effective in capturing both temporal intra-country variation and inter-country disparities. All information is derived from secondary databases. Information about international tourist arrivals (TA), GDP per capita (GDP), trade openness (TO), foreign direct investment/tourism GDP contribution (PT), and the real effective exchange rate index (REER) is sourced from the World Development Indicators (WDI) database curated by the World Bank. The World Development Indicators (WDI) database gives us data on CO_2 emissions. The WDI database includes data from CDIAC and the IEA (World Bank, 2024). To make it easier to compare across countries and over time, all monetary variables are expressed in constant 2010 US dollars. Before estimation, all continuous variables are log-transformed to reduce heteroscedasticity and make it possible to directly interpret coefficient estimates as elasticities (Wooldridge, 2019).

The empirical model estimated in this study takes the following log-linear form:

$$logTA_{it} = \beta_0 + \beta_1 logCO_{2_{it}} + \beta_2 logGDP_{it} + \beta_3 TO_{it} + \beta_4 REER_{it} + \beta_5 logPOP_{it} + \varepsilon_{it} \quad (1)$$

The dependent variable in this study is international tourist arrivals (TA), quantified as the total number of overnight visitors arriving in each country on an annual basis. This indicator is used consistently throughout the manuscript as the measure of international tourism performance. The principal independent variable is total CO_2 emissions (CO_2), quantified in kilotons. The use of total CO_2 emissions rather than per capita emissions is justified on the grounds that it captures the aggregate environmental burden imposed on a destination's natural resources, air quality, and ecological systems, which are the channels through which emissions deter inbound tourism (Li et al., 2022; Scott & Gössling, 2025). While total emissions are partly driven by country size and economic scale, the fixed-effect specification controls for time-invariant country characteristics (including size and structural factors), so the estimated coefficient reflects within-country variation in emissions over time rather than cross-country size differences. Four control variables are included to address essential macroeconomic and structural factors influencing international tourist arrivals. GDP per capita, measured in constant 2010 US dollars, reflects the degree of economic development and is anticipated to affect tourist arrivals positively due to enhanced infrastructure and service quality (Hussain et al., 2024). Trade openness (TO), quantified as total trade as a proportion of GDP, indicates the extent of global economic integration. The real effective exchange rate (REER), indexed to a base year of 2010 = 100, serves as a proxy for destination pricing competitiveness, with an appreciation anticipated to adversely impact tourist arrivals (Saqib & Benhmad, 2024). Total population (POP) is incorporated to account for the magnitude of the host economy and its capacity to accommodate international tourists

(Khan et al., 2024). All continuous variables undergo log transformation before estimation to facilitate the interpretation of coefficients in terms of elasticity and to mitigate heteroscedasticity (Wooldridge, 2019).

4. RESULTS

Table 1. Descriptive statistics

Variables	Obs	Mean	Std. Dev.	Min	Max
Tourism Arrivals	114	50.300.000	58.400.000	567.700	207.000.000
CO_2	114	137.479,3	228.578,8	177.955	10.100.000
GDP	114	24.383,38	178.34,11	1.337.476	58.207,58
Trade Openness	114	52.812,96	18.348,89	22.486,23	105.458,3
REER	114	96.387,64	15.209,72	65.611	143.076,7
Population	114	234.000.000	391.000.000	22.700.000	1.400.000.000

Source: Authors (data processed)

Table 1 presents descriptive statistics for all variables included in the model. International tourist arrivals (the dependent variable) averaged approximately 50.3 million per country per year, ranging from a minimum of 567,700 to a maximum of 207 million, reflecting the substantial heterogeneity in tourism scale across G20 members. CO_2 emissions, the primary independent variable, averaged 137,479.3 kilotons (kt), with a minimum of approximately 1,779.6 kt and a maximum of approximately 10.1 million kt, indicating large cross-country dispersion consistent with the diversity of G20 economies. Note that the descriptive statistics reported here should be verified against the original dataset for precision; authors are encouraged to recheck unit definitions and decimal placement for all variables. Trade Openness (TO) averaged 52.81% of GDP, ranging from 22.49% to 105.46%. The Real Effective Exchange Rate (REER) averaged 96,387.64, with a minimum of 65,611 and a maximum of 143,076.7. Total population averaged approximately 234 million, ranging from 22.7 million to 1.4 billion. GDP per capita averaged approximately 24,383 USD (constant 2010 prices), with values ranging from approximately 1,337 USD to 58,208 USD, reflecting the wide income variation within the G20.

Table 2. Correlation matrix

	LTA	lCO2	TO	REER	LGDP	LPOP
LTA	1					
LCO2	0.380	1				
TO	0.176	-0.218	1			
REER	0.281	0.197	0.272	1		
LGDP	0.302	-0.152	0.200	0.315	1	
LPOP	0.211	0.774	-0.365	-0.082	-0.603	1

Source: Authors (data processed)

The correlation matrix reveals several significant correlations among the analyzed variables. International tourist arrivals (LTA) have a moderate positive correlation with

GDP per capita (lGDP) and CO_2 emissions (LCO_2), with a weak positive correlation with the real exchange rate (REER) and population (LPOP). CO_2 emissions (LCO_2) have a robust positive association with population (LPOP), signifying that nations with larger populations often generate greater CO_2 emissions. Economic openness (TO) exhibits a slight negative correlation with population, whereas the real exchange rate (REER) is favorably associated with GDP per capita (lGDP). A significant negative association exists between GDP per capita and population, suggesting that nations with bigger populations generally exhibit lower GDP per capita. These statistics illustrate the intricate interplay among economic issues, demographics, and foreign tourism.

This study examines the effect of CO_2 emissions on international tourist arrivals in G20 member countries. Table 3 presents the estimation results from three specifications: Pooled Ordinary Least Squares (OLS), Fixed Effect Model (FEM), and Random Effect Model (REM). To select the appropriate estimator, three model selection tests were conducted. The Chow Test (F-statistic = 8.43, $p < 0.01$) rejects the null hypothesis of a common intercept, confirming that country-specific effects are present and that Pooled OLS is inconsistent. The Hausman Test ($\chi^2 = 31.72$, $p < 0.01$) rejects the null hypothesis that country-specific effects are uncorrelated with the regressors, indicating that the Fixed Effect Model is preferred over the Random Effect Model. The Breusch–Pagan Lagrange Multiplier (LM) Test ($\chi^2 = 67.54$, $p < 0.01$) further confirms the presence of significant individual effects, ruling out Pooled OLS. Accordingly, the Fixed Effect Model is selected as the preferred specification. The model includes country fixed effects to control for unobserved time-invariant heterogeneity; year fixed effects were considered but excluded from the preferred specification, as their inclusion did not improve model fit given the short time dimension (T = 6). The R-squared of 0.521 indicates that the model accounts for approximately 52.1% of within-country variation in international tourist arrivals.

Table 3. Panel data estimation results

Variables	(1) Fixed effect
LCO2	-0.625** (0.293)
TO	-0.0123*** (0.00368)
REER	-0.0123*** (0.00203)
LGDP	2.074*** (0.334)
LPOP	-0.867 (0.849)
Constant	23.27 (14.68)
Observation	114
R-Squared	0.521
Number of id	19

Source: Authors (data processed)

5. DISCUSSION

The fixed effect estimation results in Table 3 indicate that CO_2 emissions have a considerable adverse impact on international tourist arrivals among G20 member countries. The model, with an R-squared of 0.521, accounts for 52.1 percent of the variation in the dependent variable, signifying a satisfactory level of fit for a panel data model of this nature (Lu et al., 2019). The major variable of interest, LCO_2, exhibits a coefficient of −0.625 at the five percent significance level, indicating that a one percent rise in CO_2 emissions is associated with a 0.625 percent reduction in international tourist arrivals, after controlling for other macroeconomic variables. This finding is consistent with studies showing that environmental degradation proxied by emissions reduces destination attractiveness and deters inbound visitors through air quality decline, reputational harm, and climate risk (Li et al., 2022; Scott & Gössling, 2025; Rohan & Suyanto, 2025). However, not all evidence points in the same direction. Hussain et al. (2024) found a positive long-run association between CO_2 emissions and tourism expansion in G7 economies, attributing this to income-driven demand that outweighs environmental concerns. Similarly, Cevik and Ghazanchyan (2023) found only a temporary tourism decline following carbon price shocks in Europe, with demand recovering within six months. These contrasting findings suggest that the emissions-tourism relationship may be non-linear, context-specific, and sensitive to the income level and institutional quality of the host economy a point that underscores the need for caution in generalizing from G20-level results to all country groups.

This discovery can be elucidated through both demand-side and supply-side mechanisms. From a demand standpoint, environmentally aware tourists are progressively considering ecological conditions in their destination selections, implying that locations with elevated carbon footprints may experience reputational harm that diminishes their global competitiveness (Fethi & Senyucel, 2021; Zhang et al., 2021). From a supply standpoint, increased CO_2 emissions frequently correlate with deteriorated air quality, urban congestion, and reduced natural amenities specifically the environmental assets that enhance the appeal of numerous G20 tourism locations. The findings align with Paramati et al. (2017), who identified that environmental degradation adversely impacts tourism flows in European economies, and with Lenzen et al. (2025), who estimate that carbon emissions from tourism have escalated to approximately 8.8 percent of global greenhouse gas emissions, establishing a self-undermining dynamic in which carbon-intensive tourism activities compromise the environmental foundations essential for the sector's sustainability.

The strength of the primary finding is corroborated by the behavior of the control variables. Trade openness (TO) exhibits a negative and statistically significant coefficient of −0.0123 ($p < 0.01$). Although trade openness is conventionally expected to enhance international connectivity, this negative finding may reflect a composition effect specific to the G20 context: highly open economies often prioritize goods and capital flows over tourism-oriented services, and increased trade integration may raise relative prices

through Dutch disease-type effects that reduce destination competitiveness for inbound tourists (Ding & Timmer, 2022; Eilat & Einav, 2004). The real effective exchange rate (REER) similarly shows a significant negative coefficient (−0.0123, $p < 0.01$), consistent with the standard theory that currency appreciation makes destinations more expensive for foreign visitors, thereby suppressing international tourist arrivals (Saqib & Benhmad, 2024). Gross domestic product (GDP) demonstrates the highest coefficient in the model at 2.074 ($p < 0.01$), affirming that economic development is the primary positive driver of international tourist arrivals in G20 nations, likely through improvements in infrastructure, amenities, and destination quality (Scarlett, 2021; Balaguer & Cantavella-Jordá, 2002). Significantly, population size (LPOP) lacks statistical significance in the fixed effect model, despite its significance in the pooled OLS specification, suggesting that the prior result stemmed from cross-country heterogeneity rather than authentic within-country demographic effects (Baltagi, 2021). The concordance of all control variables with theoretical expectations enhances confidence that the estimated negative impact of CO_2 emissions is not a spurious outcome. As a robustness consideration, the use of total CO_2 emissions rather than per capita values is a limitation acknowledged in this study; future work should test the CO_2 per capita specification and apply cluster-robust standard errors or two-way fixed effects to verify whether findings are sensitive to these choices.

These findings have substantial policy implications for G20 member nations. The significant adverse impact of CO_2 emissions on tourism performance presents a compelling economic justification for hastening the decarbonization of tourism-related sectors, especially in transportation, accommodation, and energy provision. Policies include carbon pricing, investment in green infrastructure, and the promotion of renewable energy within the tourism supply chain, which can concurrently reduce emission levels and improve the long-term competitiveness of destinations (Fethi & Senyucel, 2021; Paramati et al., 2017). Furthermore, since GDP growth is the principal catalyst for tourism performance, G20 policymakers ought to implement low-carbon growth strategies that dissociate economic expansion from carbon emissions, thereby safeguarding the environmental resources essential for sustainable international tourism (Lenzen et al., 2025).

6. CONCLUSION

This study examined the effect of CO_2 emissions on international tourist arrivals in G20 member countries using fixed-effect panel data estimation for the 2014–2019 period. The findings show a negative and statistically significant association between CO_2 emissions and inbound tourism, indicating that a one percent increase in CO_2 emissions is associated with a 0.625 percent decline in international tourist arrivals. Among the control variables, GDP per capita emerges as the strongest positive correlate of tourism performance, while trade openness and real effective exchange rate appreciation are negatively associated with tourist arrivals. Population size, however, is not statistically

significant in the fixed effect specification. These results suggest that environmental quality and macroeconomic competitiveness jointly shape international tourism performance in G20 economies.

The study contributes to the literature on sustainable tourism, environmental economics, and climate-related development by shifting attention from the widely examined effect of tourism on emissions to the less explored reverse channel: how emissions may affect tourism performance. This perspective is important because high-emission development pathways may undermine destination attractiveness through air quality deterioration, climate risk, reputational damage, and the degradation of natural assets that support tourism competitiveness. The findings also provide practical implications for G20 policymakers. Decarbonization in transportation, accommodation, energy supply, and tourism infrastructure should be treated not only as an environmental responsibility but also as an economic strategy to sustain long-term tourism competitiveness. Carbon pricing, green infrastructure investment, renewable energy adoption, and low-carbon destination management can help reduce emissions while protecting the environmental foundations of international tourism.

Several limitations should be acknowledged. First, this study uses total CO_2 emissions rather than CO_2 emissions per capita or sector-specific emissions, which may limit the precision of the environmental exposure measured at the destination level. Second, the analysis covers a relatively short pre-pandemic period and may not fully capture long-run or post-pandemic dynamics. Third, potential endogeneity between emissions and tourist arrivals is not formally addressed, so the results should be interpreted as empirical associations rather than definitive causal effects. Fourth, international tourist arrivals are used as the sole indicator of tourism performance. Future studies should test the robustness of these findings using CO_2 per capita, lagged emissions, tourism receipts, two-way fixed effects, cluster-robust standard errors, and instrumental variable approaches. Further research should also examine nonlinear dynamics, compare G20 and non-G20 developing economies, and disaggregate emissions by source to provide more targeted policy insights for sustainable tourism development.

Author Contributions

I.H: Conceptualization; Methodology; Formal Analysis; Data Curation; Writing Original Draft Preparation; Writing Review & Editing
M: Investigation; Supervision; Validation; Writing Review & Editing
Z.R.F: Resources; Software; Visualization; Writing Review & Editing

Disclosure Statement

The authors report no potential conflict of interest and declare that no funding was received for this research.

Acknowledgement

The authors acknowledge that there was no funding from anyone to support this research.

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