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ORIGINAL PAPER

Analysis of the relationship between tourism, green technological innovation and environmental quality in the top 15 most visited countries: evidence from method of moments quantile regression

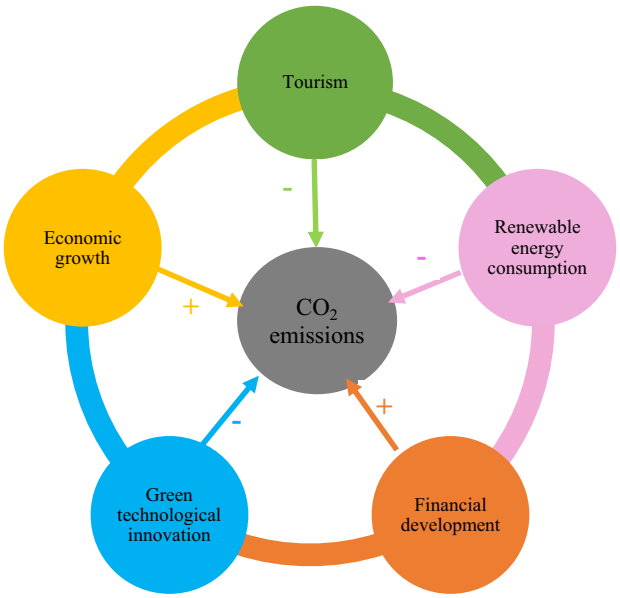
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Abstract

Global warming, climate change and environmental pollution are considered among the important developments that threaten all world economies. In this context, the transition to a zero-emission economy remains one of the environmental sustainability goals of policymakers. The literature investigating the tourism-environmental pollution relationship has limited emphasis on the role of green technological innovation. Therefore, this study explores the effect of tourism and green technological innovation on CO_2 emissions in top 15 most visited countries during the period of 1995–2019. Renewable energy consumption, financial development and economic growth are integrated into the CO_2 emissions equation as control variables. The cointegration tests verify the existence of a cointegration between variables. The long-run estimaters reveal that tourism, green technological innovation and renewable energy consumption serve to improve environmental quality by reducing CO_2 emissions. Contrary to these findings, financial development and economic growth play a role in the increase of CO_2 emissions implying a deterioration in environmental quality. The bootstrap causality analysis points to a bidirectional causality between tourism and CO_2 emissions and between green technological innovation and CO_2 emissions. The findings will make important contributions to policy makers in these countries in meeting their CO_2 emissions reduction targets.

Graphical Abstract



The long-run findings

Keywords Tourism · Green technological innovation · CO_2 emissions · MMQR · Driscoll–Kraay standart errors · Panel bootstrap causality

Extended author information available on the last page of the article

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Introduction

The recent increase in the frequency of extreme weather events due to the rapid increase in air pollution and greenhouse gas emissions brings with its climatic effects in different ways, such as changing precipitation patterns, increasing storm intensity and reversing ocean currents. These developments have important effects on environmental sustainability, the functioning of ecosystems, and the well-being of societies (Boutabba 2014; Shah et al. 2020; Erdogan et al. 2022; Sheraz et al. 2022; Jiang et al. 2022; Pata et al. 2022; Zhang et al. 2022a; Shah et al. 2023a; Yang et al. 2023a). Reducing CO_2 emissions has an important role in ensuring environmental sustainability (Bekun et al. 2019; Balsalobre-Lorente et al. 2023). Despite the Paris Agreement of 2015 and strong efforts by member states to reduce CO_2 emissions, British Petroleum (2022) statistics; It shows that global CO_2 emissions increased by about 19% over the period 2006–2021. This finding means that CO_2 emissions are on an upward trend and that research on the subject will still be on the agenda (Bekun et al. 2019). It is revealed by a large literature that the quality of the environment, which can be measured by CO_2 emissions, is influenced by many factors. These factors include; economic growth (Chen et al. 2019; Zhang et al. 2022b), renewable energy consumption (Bekun et al. 2019), non-renewable energy consumption (Nathaniel and Iheonu 2019), globalization (Wang et al. 2020), financial development (Shen et al. 2021; Shah et al. 2021), green technology (Meng et al. 2022), industrial value added (Jebli et al. 2020), and other notable variables (Lee and Brahmasrene 2013; Khan et al. 2020; Razzaq et al. 2021; Yu et al. 2023).

As one of the world's most important sectors, tourism creates jobs, encaurages exports, and has significant cultural and environmental effects (Kaya et al. 2022; Nepal et al. 2019; Onifade et al. 2022). Tourism can increase carbon emissions due to the fact that tourists prefer road, air and sea transportation and consume various goods and services and can therefore deteriorate environmental quality (Kumail et al. 2020). The potential effect of tourism on the environment is explored by many researchers (Lee and Brahmasrene 2013; Işik et al. 2017; Adedoyin et al. 2021; Ghosh et al. 2022; Liu et al. 2022). Tourism-led environmental recovery hypothesis is supported by Le and Nguyen (2021), Razzaq et al. (2021), Tian et al. (2021), Ghosh et al. (2022) and Kyara et al. (2022).

The most important feature of the study is that, unlike similar studies, it includes green technological innovation. When considered on a micro basis; such innovations offer the opportunity to improve the environmental performance of firms through environmental protection and firm development by integrating environmental objectives into business objectives (Opazo-Basáez et al. 2024). On a macro basis, green technological innovation has significant impacts on green economic growth (Li et al. 2023a), renewable energy use (Qamruzzaman and Karim 2023), natural resources (Tian and Fen 2023), and environmental sustainability. One of the factors that improves environmental quality by reducing CO_2 emissions is green technological innovation. It is observed that productive activities in the world do not consist only of profit and efficiency, and the demand for eco-technology in the fight against environmental pollution is increasing rapidly (Wu et al. 2021). It is seen that green technology reduces CO_2 emissions by providing growth with environmentally friendly technology in a way that causes the least damage to the environment (Nikzad and Sedigh 2017). In a similar way, Meng et al. (2022) and Razzaq et al. (2023) prove that environmentally friendly green technology improves environmental quality by reducing CO_2 emissions.

Undoubtedly, the most important variable that can affect environmental quality is economic growth (Işik et al. 2017). Economic growth has a stimulating effect on CO_2 emissions as it supports production activities and energy demand in all sectors of the country. However, in the long run, it can also show effects on improving environmental quality by reducing environmental pollution in the economy (Alaganthiran and Anaba 2022). This situation, known as the EKC hypothesis, is described by Adebayo (2020). It is also supported by Amin et al. (2020), Alsaedi et al. (2022), Shah et al. (2023b), and Naqvi et al. (2023a). On the other hand, according to Abbasi et al. (2023), the biggest concern of economies is to solve environmental problems without sacrificing economic growth targets. In this context, they argue that the energy demand required for growth should be met with renewable and nuclear energy sources instead of fossil fuels. As a matter of fact, renewable energy sources take their place in the energy and environmental policies of many countries with their features that are compatible with the environment, can be repeated continuously, and provide energy saving, efficiency and efficiency. Evidence from the empirical literature shows that the use of renewable energy improves environmental quality by reducing environmental pollution (CO_2 emissions) and can offer significant impacts for a sustainable environment (Patel and Singh 2023; Abdulwakil et al. 2023; Abbasi et al. (2023).

The effects of financial development on environmental pollution cause many empirical studies to focus on this issue. As a matter of fact, according to Shahbaz et al. (2018), the financial sector will be able to serve to improve both energy efficiency and environmental quality with its funds for renewable energy sector and technological innovation investments. In this context, Doğan and Seker (2016) and Xu et al. (2022) provide evidence that financial development improves environmental quality by preventing environmental

degradation, while Batala et al. (2023) find findings that financial development increases environmental pollution.

This study focuses on the impact of tourism and technological innovation on CO_2 emissions in the 15 most visited countries. There are important reasons why these countries constitute the case of the research. Considering the 1995–2019 period on which the study is based; According to World Bank data, global CO_2 emissions have increased from 21.6 million tons in 1995 to 32.9 million tons in 2019. This corresponds to a 52.3% increase in total CO_2 emissions over the period in question. Likewise, while CO_2 emissions per capita are 3.78 metric tons, this figure reaches 4.44 metric tons in 2019. CO_2 emissions per capita have increased by around 17%. On the other hand, the total number of incoming tourists on a global basis reaches 2.4 billion people in 2019 while it was 1.08 billion people in 1995. The world tourism sector sets the most important environmental target of reducing CO_2 emissions by 70% by 2050. In addition, while the number of patents on ecological technological innovation had a rate of 7.4% in the total number of patents in 1995, this rate reaches 9.9% in 2019.

Figure 1 shows the course of the number of incoming tourists and CO_2 emissions over the period 1995–2019 for the 15 most visited countries that make up the case of the study. According to World Bank data; When the values related to both indicators are examined, it is observed that when one indicator shows a decreasing trend, the other indicator experiences an increase. On the other hand, the trend of the share of patents on ecological innovation in total patents and CO_2 emissions in the said period are presented in Fig. 2. The general result in Fig. 1 applies to both of these variables. When both tables are taken into consideration, it is implied that there may be a negative link between these variables. This is the most important motivator for analyzing the empirical relationship between the number of incoming tourists, the number of patents on ecological innovation and CO_2 emissions.

In the light of the developments in the literature and the above information; Study seeks to answer the following research questions for 15 most visited countries: (1) Can developments in the tourism sector in these countries be an effective tool in combating CO_2 emissions? (2) Can technological innovation reduce CO_2 emissions? (3) Can the use of renewable energy sources provide an advantage in improving environmental quality? (4) How do economic growth and financial development affect CO_2 emissions? (5) From this point of view, what kind of effective policy steps should be taken to prevent environmental pollution?

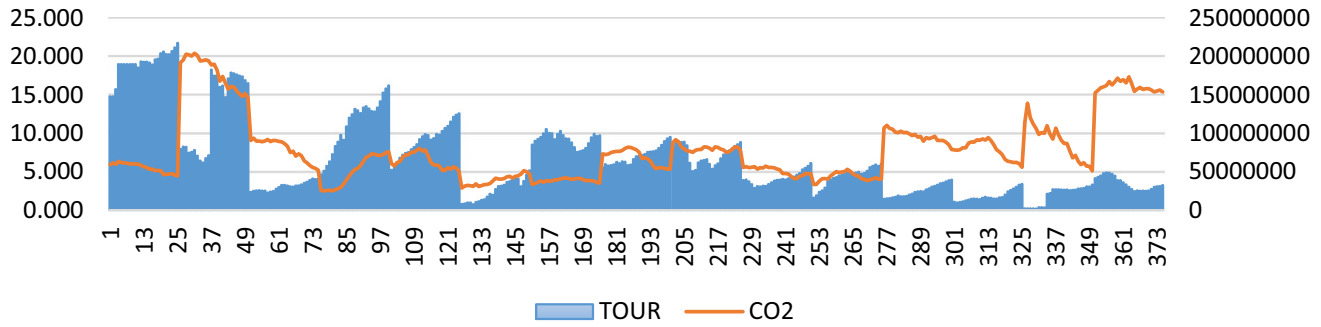


Fig. 1 Number of tourists and CO_2 emissions in the 15 most visited countries

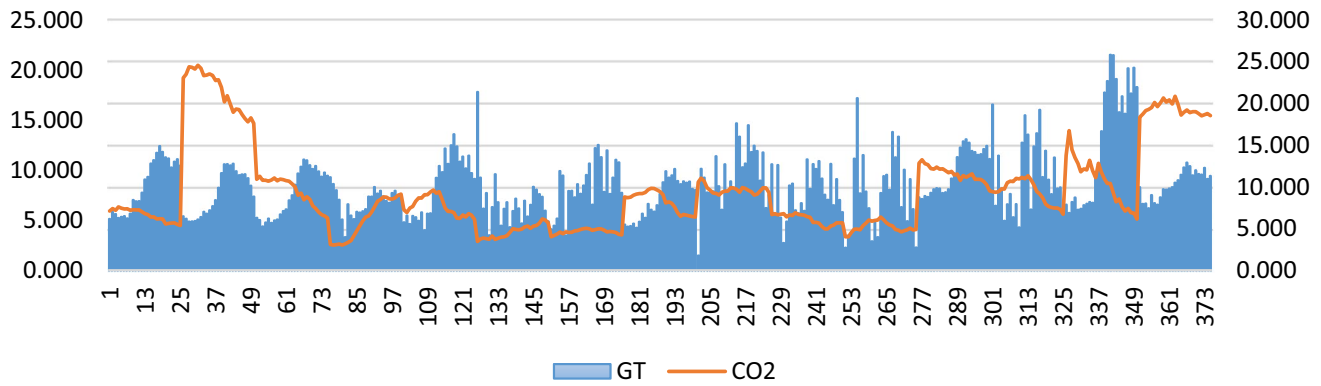


Fig. 2 Number of patents on ecological innovation and CO_2 emissions in the 15 most visited countries

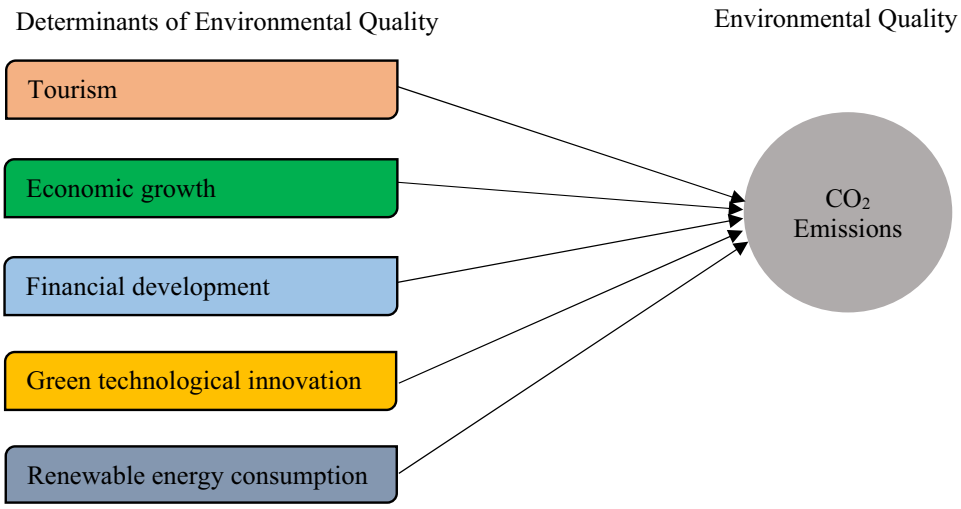


Fig. 3 The theoretical framework

The study aims to contribute to the literature from different aspects. First; Although it focuses on the relationship between tourism, green technological innovation, and CO_2 emissions, it models economic growth, financial development, and renewable energy use as controlling variables. Figure 3 summarizes the theoretical background of the study. Thus, by taking these variables into account together, it is thought to provide diversity in policy proposals in the fight against environmental pollution. Second; There is a methodological contribution. Long-term coefficient estimates are performed using several second-generation panel techniques such as Driscoll–Kraay, Panel-Corrected Standard Error (PCSE), Feasible Generalized Least Squares (FGLS), Fully Modified OLS (FMOLS) and Dynamic OLS (DOLS) estimators. In addition, we also use the Method of Moments Quantile Regression (MMQR) approach for robustness check. This method is based on estimating the relevant parameters in the mean of the conditional distribution of the dependent variable. This method addresses the potential shortcomings of the Instrumental Variables (IV) and Generalized Method of Moments (GMM) techniques. In this procedure, the effect of independent variables is examined at different quantile levels of the distribution function, while also taking into account the existence of fixed effects. In this study, the bootstrap version of the Dumitrescu-Hurlin causality test, which is not preferred by many studies, is applied for causality analysis instead of the classical version. Therefore, the findings of the study will be able to offer recommendations both for policymakers and for future studies.

The rest of the study is designed as follows. The second section summarizes the theoretical and empirical literature. The third section describes the model, data and methodology, while the fourth section focuses on the findings and their discussion. The final section focuses on conclusions and policy suggestions.

Literature review

Tourism and environmental degradation

According to one view, the tourism sector increases CO_2 emissions by supporting infrastructure facilities such as hotels, airports and roads, thus causing environmental pollution. Another view is that the tourism sector plays a role in improving environmental quality by reducing CO_2 emissions (Liu et al. 2022). These approaches lead to the hypothesis that "tourism supports or prevents environmental degradation". Ahmad et al. (2022), who conducted a panel data analysis on the G7 countries, apply FMOLS and DOLS forecasting techniques and determine that innovation and tourism serve to improve environmental quality by reducing environmental pollution. Tian et al. (2021) focuse on G20 economies. According to the findings obtained by the FMOLS technique, a 1% improvement in tourism causes a 0.05% reduction in CO_2 emissions. In addition, renewable energy consumption serves to reduce CO_2 emissions. However, Sun et al. (2021) for 88 BRI countries and Bano et al. (2021) for Pakistan reveal that tourism variables increase CO_2 emissions, causing environmental degradation. Similar to these findings, Shah et al. (2022) and Balsalobre-Lorente et al. (2023) reveal a positive relationship between tourism and CO_2 emissions for 36 OECD countries.

Liu et al. (2022) explore the link between tourism and the ecological footprint in Pakistan. Using the ARDL, Bayer and Hanck cointegration tests, the authors detect the existence of cointegration and reveal the inverse-U-shaped relationship between these variables. Ahmad et al. (2019) test the relationship between tourism and environmental degradation for Southeast Asian countries. The FMOLS forecast results provide evidence that tourism for Indonesia and the Philippines increases CO_2 emissions, while for Vietnam, tourism reduces CO_2 emissions. Similarly, Muhammad

et al. (2021), who examined 13 Muslim countries using the Driscoll–Kraay estimator, find that tourism ensures environmental sustainability by reducing CO_2 emissions. Nguyen and Su (2021) test the relationship among tourism, institutional quality and environmental degradation for 134 countries. The environmental sustainability index is used as the dependent variable, it is concluded that tourism expenditures reduce environmental sustainability. A separate finding is that this negative effect of tourism on the environmental polution is more severe in countries with good institutional quality.

Green technological innovation and environmental degradation

Green technology incorporates pollution control, ecological recovery and recycling related technologies. Green technological innovation is therefore seen as an important means of achieving low CO_2 emissions and sustainable development (Chen et al. 2023). This implies the hypothesis that "green technological innovation reduces environmental pollution". Xie and Jamaani (2022) explore the relationship between CO_2 emissions and environmental taxes, energy efficiency, green innovation, renewable energy consumption for G7 countries. In the study where the Dumitrescu-Hurlin panel causality test with the MMQR estimator was applied, green innovation reduces CO_2 emissions, while economic growth enhances CO_2 emissions. Ding et al. (2021) analyze G7 countries. According to the results of the CS-ARDL model, foreign trade and economic growth increase CO_2 emissions, while eco-innovation and energy efficiency reduce CO_2 emissions.

Yikun et al. (2022) study the link among green technological innovation, green growth, and environmental sustainability for G7 economies. The study supports environmental sustainability as green technological innovation and green growth reduce environmental pollution. Chen et al. (2023) test the green technological innovation-CO_2 emissions relationship for 30 Chinese cities. The results of empirical analysis carried out through the nonlinear spatial Durbin model reveal an inverse-U-shaped link between green technological innovation and CO_2 emissions. Hao et al. (2021) analyze the green growth-sustainable environment relationship. Using the CS-ARDL approach for the G7 countries, all other variables other than economic growth, such as green technological innovation, play a role in reducing CO_2 emissions. Xie and Jamaani (2022), who analyzed the G7 economies, find that green technological innovation reduces CO_2 emissions and points to a bidirectional causality between the two variables. The existence of a negative relationship between the two variables is also proven by Onifade and Alola (2022).

Economic growth and environmental degradation

Economic growth can be effective in increasing CO_2 emissions by supporting energy consumption in almost all sectors, thus deteriorating environmental sustainability (Naqvi et al. 2023b). In this case, the hypothesis that "economic growth causes environmental degradation" can be presented. Empirical literature investigates the effect of economic growth on environmental degradation. Some researchers (Doğan and Seker 2016; Abid 2017; Adams and Klobodu 2018; Alaganthiran and Anaba 2022; Jahanger et al. 2023a) have found that economic growth increases environmental degradation, while some (Liu et al. 2021; Mujtaba et al. 2022; Zeraibi et al. 2023) finds that it has decreased. Doğan and Şeker (2016) analyze the energy-growth-environment relationship using FMOLS and DOLS estimators. The findings show that economic growth promotes CO_2 emissions. Intensifying on 58 MENA and 41 EU countries, Abid (2017) concludes that economic growth for increases environmental degradation. Similarly, Adams and Klobodu (2018), who applied the GMM method for 26 African countries, indicate that economic growth is positively correlated with CO_2 emissions.

Alaganthiran and Anaba (2022) examine the economic growth-CO_2 emissions relationship in 20 SSA countries by incorporating energy consumption, the tourism sector and population into the empirical model. According to the first-generation panel estimation techniques; economic growth increases CO_2 emissions, causing environmental degradation. This outcome is proved by Zhang et al. (2022b), Jahanger et al. (2022a) and Yang et al. (2023b). In contrast to this study, Mujtaba et al. (2022), who analyzed OECD countries using panel data techniques, find that economic growth reduces CO_2 emissions.

Financial development and environmental degradation

Financial development can play a crucial role in determining environmental degradation. The development of the financial sector leads to lower financing costs, promotes opportunities for enterprises to invest more, purchase new machinery and equipment. In addition, financial development can encourage consumers to buy homes, cars and durable goods with cheap credit rates, which increases production, energy consumption and gas emissions. However, financial development can reduce energy use and CO_2 emissions, as it can promote the efficiency of business performance along with energy efficiency (Sadorsky 2010, 2011; Doğan and Türkekul 2016; Shahbaz et al. 2018). Thus, “financial development leads to both environmental degradation and environmental recovery” hypothesis can be developed.

Pata (2018) determines that financial development in Turkey has increased CO_2 emissions. Ibrahim and Vo (2021) find that financial development decreases CO_2 emissions in 27 industrialized countries and Khezri et al. (2021) for 31 Asia–Pacific countries. Ibrahim et al. (2022) conclude that renewable energy, nuclear energy, and green innovation reduce CO_2 emissions, which are indicators of environmental sustainability in BRICS economies, but that financial development increases CO_2 emissions. Ali et al. (2023) present evidence that financial development in the E7 countries is causing environmental degradation. Jahanger et al. (2022b) identify similar evidence for 69 developing countries. Doğan and Seker (2016) for countries with developed renewable energy sector reveal a negative link between financial development and CO_2 emissions. A similar finding is made by Shah et al. (2021).

Renewable energy and environmental degradation

Fossil energy sources are both expensive to use and in limited quantity worldwide. For this reason, the world's economies are rapidly moving towards the use of clean, cheap and abundant renewable energy sources rather than fossil energy sources. The main feature of these energy sources is that they are environmentally friendly and perform important functions in reducing environmental pollution (Uz Zaman et al. 2021). These explanations bring up the hypothesis that "the use of renewable energy sources prevents environmental degradation".

Applying the dynamic ARDL model to the Thai economy, Abbasi et al. (2021) show that renewable energy consumption inhibits CO_2 emissions, while non-renewable energy consumption serves as an increase in CO_2 emissions. Saidi and Omri (2020) investigate the relationship between renewable and nuclear energy consumption and CO_2 emissions in a sample of 15 OECD countries. The FMOLS estimates conclude in the context of the panel that investments in nuclear power and renewable energy reduce CO_2 emissions. The study reveals that these two energy sources are complementary to each other.

Uz Zaman et al. (2021) empirically investigate the link among renewable energy, education expenditures and CO_2 emissions in China. By applying ARDL and FMOLS techniques, it is concluded that education expenditures and renewable energy consumption are negatively related to CO_2 emissions. Using the AMG estimator, Danish et al. (2019) prove that in Russia, natural resources reduce CO_2 emissions, while in South Africa they increase CO_2 emissions. Dong et al. (2018) reveal that nuclear power and renewable energy reduce CO_2 emissions, while fossil fuel consumption also serves as an incentive for CO_2 emissions. Jahanger et al. (2023b) find that renewable energy consumption reduces CO_2 emissions. In addition, Shah et al. (2020), who investigated biomass energy as a fundamental dynamic of economic development and the environment, conclude that biomass energy increases CO_2 emissions.

Research gap

When the empirical literature is examined in detail; Based on this, it is possible to draw some important conclusions and see what research gap the study can fill. First of all; Some studies, such as Zaman et al. (2016), Shakouri et al. (2017), Ahmad et al. (2019), Tian et al. (2021), Meng et al. (2022), Ghosh et al. (2022), Kyara et al. (2022), and Razzaq et al. (2023), focus only on the relationship between tourism and environmental pollution (CO_2 emissions). Unlike this literature, our study also focuses on green technological innovation, which is considered as one of the important variables in reducing environmental pollution, and integrates it into the empirical model. Secondly; Some studies, such as Meng et al. (2022) and Razzaq et al. (2023), only investigate the green technological innovation-CO_2 emissions link. Our study models tourism as a main focus and reveals its different aspect from these studies. Thirdly; Unlike both these studies and other studies, our study adds economic growth, financial development and renewable energy consumption to the environmental pollution regression equation as other explanatory variables. Fourthly; When we look at some empirical literature such as Kumail et al. (2020), Shakouri et al. (2017), Wang et al. (2022), Xie and Jamaani (2022), Xu et al. (2022), Razzaq et al. (2023), Irandoust (2016), and Hao (2022), it is revealed that they do not prefer the panel bootstrap causality technique. The inclusion of this technique means that our study can fill another gap in the literature. Fifthly; The fact that 15 most visited countries are the subject of analysis expresses another different aspect of the study. Finally; It can also be emphasized that there is no study that uses the estimators used in the study together. Thus, it will be possible to offer healthier results and policy proposals.

Model setting, data and methodology

In this study, the evaluations mentioned in the literature section and the models of Ahmad et al. (2019), Khan et al. (2019), Tian et al. (2021), Waheed et al. (2020), and Ali et al. (2021) are utilized in the creation of our empirical model. The most important feature of these studies is that they use financial development, technological innovation, economic growth and renewable energy consumption as well as tourism variable as determinants of environmental pollution. In addition to these variables, we integrate green technological innovation, which is not addressed in studies

on the link between tourism and environmental degradation, into the CO_2 emissions model. Thus, an augmented linear regression specification is utilized to test the relations between the variables as follows:

$$lnCO_{2it} = \alpha + \theta_1 lnTOUR_{it} + \theta_2 lnGDP_{it} + \theta_3 lnFIN_{it} + \theta_4 lnGT_{it} + \theta_5 lnREN_{it} + \varepsilon_{it} \quad (1)$$

where CO_2 refers to CO_2 emissions, which are affected by tourism (TOUR), economic growth (GDP), financial development (FIN), green technological innovation (GI) and renewable energy consumption (REN), respectively. i is the country, t is the year, ε is the error terms, and ln is the logarithmic forms of the series. All variables are modeled by taking their logarithms. θ_1, θ_2, θ_3, θ_4, and θ_5 are the elasticities of TOUR, GDP, FIN, GI and REN, respectively. This study uses annual data from 1995 to 2019 in the 15 most visited countries, namely; France, United States, United Kingdom, China, Spain, Turkiye, Mexico, Italy, Poland, Hungary, Croatia, Germany, Greece, Denmark and Canada. According

Table 1 Variable descriptions

Variables	Symbol	Measure	Source	Expected sign
Environmental quality	CO_2	CO_2 emissions (metric tons per capita) (Chien et al. 2021)	WDI	–
Tourism	TOUR	International tourism, number of arrivals (Shakouri et al. 2017)	WDI	Negative
Economic growth	GDP	GDP per capita (current US$) (Dingru et al. 2023)	WDI	Positive
Financial development	FIN	Financial development index (Habiba and Xinbang 2023)	IMF	Positive
Green technology	GT	Patents on environment technologies, Total, Percentage (Chen et al. 2022)	OECD	Negative
Renewable energy	REC	Renewable energy consumption (% of total final energy consumption) (Zhang et al. 2022c)	WDI	Negative

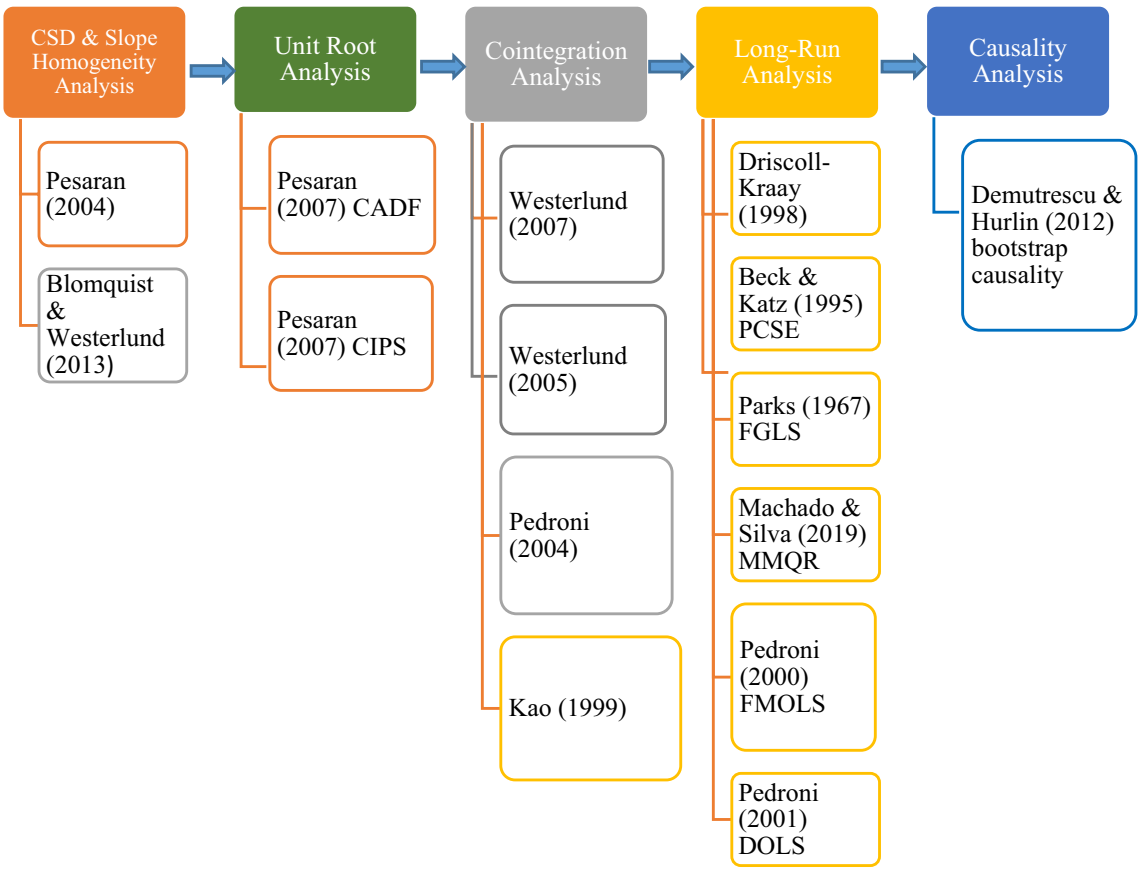


Fig. 4 Methodological framework

to the data availability, these countries and time period are selected. The beginning of tourism data in 1994 and the end of green technological innovation data and renewable energy consumption data in 2019 are effective in determining the period in question. In addition, it is important that the tourism data is complete in this time period. Table 1 identifies each variable used in the study with its symbols, criteria, sources, and expected signs.

This study follows a five-step empirical strategy to test the relationship between the variables. Summary information about the methodology is shown in Fig. 4. Firstly, it scrutinizes the cross-sectional dependence (CSD) and slope homogeneity. The analysis of CSD is very important to obtain reliable and unbiased results (Wang et al. 2021). To this end, we employ the CSD test offered by Pesaran (2004) following the studies of Habiba and Xinbang (2023) and Qalati et al. (2023). This test considers the null hypothesis of no dependency between cross-sectional units. In the first step, we also scrutinize the existence of slope homogeneity applying Blomquist and Westerlund (2013)'s Δ test. This procedure is an advanced version of Δ tests presented by Pesaran and Yamagato (2008).

The second step contains the unit root analysis for variables. For this purpose, we use the cross-sectionally augmented ADF (CADF) test. The CIPS test, another second-generation test suggested by Pesaran (2007) and used in the study, is calculated using CADF statistic. In the third step of the methodology, the cointegration analysis is performed through the approches offered by Kao (1999); Pedroni (2004); Westerlund (2005, 2007). Among these tests, the most developed one is the Westerlund (2007) test, which develops four statistics that are quite simple to implement.

The fourth step includes the examination of the long-run coefficients, is started. This is carried out with the help of Driscoll–Kraay (1998) standart errors approach. There are important reasons for choosing this estimator. First, it provides suitable results for both balanced and unbalanced panels. Second, it can overcome the problems of heteroscedasticity, autocorrelation and CSD (Wang et al. 2021). PCSE, FGLS, DOLS, FMOLS and MMQR estimation techniques are also used in the study. In the MMQR approach, effective coefficients are found by taking low, medium and high quantile changes into account with the panel quantile approach and an empirical contribution is made to the literature.

The final step dwells upon the causal linkages between the variables by using Demutrescu and Hurlin (2012) bootstrap causality technique. This process has important features: (i) this procedure has a flexible nature for balanced and unbalanced panels, (ii) it can be used both with and without bootstrap. Here, we prefer the causality procedure with bootstrap because of the presence of CSD. $\overline{W}$ and $\overline{Z}$ statistics are suggested by Dumitrescu and Hurlin (2012). Here, the causality conclusion is reached by comparing the test statistics with the bootstrap critical values.

Findings

Table 2 summarizes the descriptive statistics for all variables. CO_2 emissions range from 2.517 to 20.469, with an average of 7.831 and a standard deviation of 4.196. Canada

Table 2 Summary statistics

	CO_2	TOUR	GDP	FIN	GT	REC
Mean	7.831	66,460,842	9.780	0.616	10.236	13.215
Median	6.890	49,969,000	10.013	0.627	9.660	11.400
Std. dev	4.196	51,396,378	0.934	0.199	3.922	7.761
Min	2.517	2,020,000	6.412	0.232	1.760	0.850
Max	20.469	218,000,000	11.083	0.947	25.830	37.520
Skewness	1.337	1.211	−1.018	−0.050	1.098	0.897
Kurtosis	4.093	3.678	3.926	1.684	4.999	3.274
Obs	375	375	375	375	375	375

Table 3 Correlation matrix

	CO_2	TOUR	GDP	FIN	GT	REC
CO2	1.000					
TOUR	−0.025	1.000				
GDP	0.536	0.053	1.000			
FIN	0.596	0.195	0.810	1.000		
GT	−0.032	−0.034	0.317	0.142	1.000	
REC	−0.226	−0.114	−0.199	−0.216	0.269	1.000

Table 4 CSD analysis

Variables	$lnCO_2$	lnTOUR	lnGDP	lnFIN	lnGT	lnREC
Pesaran CD	13.837*** (0.000)	21.248*** (0.000)	46.325*** (0.000)	36.054*** (0.000)	23.350*** (0.000)	14.907*** (0.000)

The *p*-values are presented in parenthesis

*** shows significance at %1 level

Table 5 Slope homogeneity analysis

Test statistics	t-statistics	*p*-Value
$\tilde{\Delta}$	0.670	0.503
$\tilde{\Delta}_{adjusted}$	0.857	0.391

has the highest CO_2 emissions in 2019, while Mexica has the lowest CO_2 emissions. The number of tourists arriving in the relevant period has 66,460,842 average, 51,396,378 standard deviation. The minimum and maximum values of ecological patent applications with an average of 10.236 are 1.760 and 25.830, respectively. The financial development index is the variable with the lowest value in all descriptive statistics. The fact that the skewness coefficients of the variables other than GDP per capita and financial development index are positive indicates that these variables have a left-skewed distribution. Finally, the fact that all of the variables in the study has a positive coefficient of kurtosis suggests that the distribution of the variables is sharp.

The correlation matrix is reported in Table 3. The results point to a negative correlation between tourism and CO_2 emissions. Similarly, green technological innovation and renewable energy consumption are positively correlated with CO_2 emissions. The other independent variables have a similar correlation with CO_2 emissions.

Empirical analysis begins with the determination of the CSD of the analyzed variables by applying Pesaran's CD test. According to the results presented in Table 4, at the 1% significance level, the null hypothesis stating that there is no CSD between the cross-sectional units is rejected. This indicates the presence of CSD, that is, any shock to be experienced in one of the fifteen countries with the highest number of tourists may spread to other countries (Koçak et al. 2020). Blomquist and Westerlund (2013) slope homogeneity test results provided in Table 5 reveal the presence of slope homogeneity.

After CSD and slope homogeneity analyzes, stationarity analysis is carried out. In the presence of CSD, the findings of the first-generation unit root tests will not be strong and healthy (Erdoğan et al. 2022). Therefore, CADF and CIPS tests are used. Table 6 shows these tests findings. According to the results, the null hypothesis that all variables in the study do not contain unit roots cannot be rejected and it is stated that the variables are not stationary at the level. However, it is determined that the variables become stationary by taking their first differences. Therefore, these findings prove that the levels of integration of the variables are 1.

Table 6 Unit root tests

Variables	CADF		CIPS	
	Constant	Constant and trend	Constant	Constant and trend
Level				
$lnCO_2$	−1.024	−1.954	2.977	1.525
lnTOUR	−1.854	−2.240	−1.910	0.334**
lnGDP	−2.043	−2.757**	−3.922***	−1.818**
lnFIN	−2.037	−3.018***	−0.065	−0.726
lnGT	−2.074	−2.785**	−1.213	−2.124**
lnREC	−1.313	−1.864	1.825	1.900
First difference				
$lnCO_2$	−3.230***	−3.261***	−5.828***	−3.921***
lnTOUR	−2.321**	−2.836**	−3.561***	−2.148**
lnGDP	−2.368**	−2.660***	−4.892***	−2.687***
lnFIN	−2.163*	−3.522***	−1.568*	1.129
lnGT	−3.175***	−2.660***	−5.612***	−3.383***
lnREC	−3.107***	−3.474***	−5.338***	−4.806***

***, ** and * show significance at 1%, 5% and 10% level, respectively

Table 7 Cointegration tests results

Westerlund (2007) Statistics	Value	*Z*-value	*p*-Value
Gt	−2.418	0.926	0.210
Ga	−8.829**	2.888	0.020
Pt	−8.230	0.889	0.250
Pa	−7.453	1.795	0.180
Pedroni (2004)		Test statistic	*p*-Value
Modified PP t		6.731***	0.000
PP t		−21.309***	0.000
Augmented DF t		− 1.731**	0.041
Kao (1999)			
Modified DF t		2.0497**	0.020
DF t		1.945**	0.025
Augmented DF t		2.587***	0.004
Unadjusted modified DF t		1.247	0.106
Unadjusted DF t		0.996	0.159
Westerlund (2005)			
Variance ratio		2.115**	0.017

*** and ** indicate significance at %1 and %5 level, respectively

Empirical findings from unit root tests suggest that we need to perform cointegration analysis. In addition to the Westerlund (2007) cointegration test due to the presence of CSD, several classical cointegration techniques are also used. The findings are reported in Table 7. The results suggest a cointegration, that is, a long-term link among variables.

After the cointegration analysis, the estimation of long-term coefficients is started with the Driscoll–Kraay estimator, which can give strong results in the presence of CSD and slope homogeneity. In addition to this estimator, FGLS, PCSE, FMOLS, DOLS and MMQR methods are also applied. Table 8 presents the findings of the Driscoll–Kraay estimator. According to the findings, the coefficient of tourism (−0.069) is negative and statistically significant. This can be expressed as a 1% improvement in the tourism sector will result in a 0.069% decrease in CO_2 emissions. This means that tourism diminishes CO_2 emissions in the long run.

Long-term findings show that the coefficient of economic growth (0.175) is positive and statistically significant. This refers that a1% increase in economic growth will result in a 0.175% increase in CO_2 emissions. Thus, economic growth positively affects CO_2 emissions. According to the findings in Table 8, the coefficient of financial development (0.481) is positive and statistically significant. The finding can be explained as a 1% increase in financial development will result in a 0.481% increase in CO_2 emissions. This means that financial development enhances CO_2 emissions.

The coefficient of green technological innovation (−0.106) is negative and statistically significant. The finding indicates that a 1% increase in green technological innovation will result in a 0.106% decrease in CO_2 emissions. This means that green technological innovation decreases CO_2 emissions. The long-run findings also show that the coefficient of renewable energy consumption (0.105) is positive and statistically significant. This means that a 1% increase in renewable energy consumption will result in a

Table 8 Long-run estimates

Variables	Coefficient	Standard error	*p*-Value
lnTOUR	-0.069^{***}	0.010	0.000
lnGDP	0.175^{***}	0.024	0.000
lnFIN	0.481^{***}	0.057	0.000
lnGT	-0.106^{***}	0.028	0.000
lnREC	-0.105^{***}	0.030	0.002
Constant	2.196^{***}	0.456	0.000
F-statistic	3942.95		
P-value	0.000		
R^2	0.494		
Observation	375		
Number of countries	15		

*** and ** show significance at 1% and 5% level, respectively

Table 9 Robustness check

Variables	FGLS		PCSE		FMOLS		DOLS	
	Coefficient	*p*-Value	Coefficient	*p*-Value	Coefficient	*p*-Value	Coefficient	*p*-Value
lnTOUR	−0.068***	0.000	−0.069***	0.000	−0.007***	0.000	−0.085***	0.000
lnGDP	0.175***	0.000	0.175***	0.000	0.274***	0.000	0.439***	0.000
lnFIN	0.470***	0.000	0.481***	0.000	0.246***	0.000	0.098	0.332
lnGT	−0.079***	0.000	−0.106***	0.010	−0.116***	0.000	−0.237***	0.002
lnREC	−0.107***	0.000	−0.105***	0.000	−0.099***	0.000	−0.149***	0.000
Constant	2.126***		0.000		2.196***		0.000	
R^2	–		0.494		0.468		0.890	
Adj. R^2	–		–		0.462		0.640	
Wald χ^2	15,485.78		2324.25		–		–	
Prob	0.000		0.000		–		–	
Observation	375		375		375		375	
Number of countries	15		15		15		15	

*** and ** show significance at 1% and 5% level, respectively

Table 10 Panel quantile estimation results (MMQR), dep. var.: CO_2 emissions

Variables	Low		Medium		High
lnTOUR	−0.109***	−0.083***	−0.128***	−0.063***	−0.058***
lnGDP	0.222***	0.253***	0.173***	0.273***	0.132***
lnFIN	0.003***	−0.037	0.361***	0.021	0.495***
lnGT	−0.120***	−0.103**	−0.030***	−0.093	0.019**
lnREC	−0.164***	−0.167***	−0.135***	−0.129***	−0.199***

*** and ** show significance at 1% and 5% level, respectively

Table 11 Panel bootstrapt causality analysis

Hypothesis	W-stat	Zbar-stat	Bootstrapped *p*-value	Results
$lnTOUR \neq^{>} lnCO_2$	4.285	8.997**	0.026	$lnTOUR \leftrightarrow lnCO_2$
$lnCO_2 \neq^{>} lnTOUR$	3.528	6.932**	0.036	
$lnGDP \neq^{>} lnCO_2$	6.354	14.663***	0.002	$lnGDP \leftrightarrow lnCO_2$
$lnCO_2 \neq^{>} lnGDP$	4.282	8.990*	0.056	
$lnFIN \neq^{>} lnCO_2$	3.167	5.936**	0.042	$lnFID \rightarrow lnCO_2$
$lnCO_2 \neq^{>} lnFIN$	1.998	2.734	0.416	
$lnGT \neq^{>} lnCO_2$	4.274	8.966***	0.004	$lnGT \leftrightarrow lnCO_2$
$lnCO_2 \neq^{>} lnGT$	3.062	5.648*	0.058	
$lnREC \neq^{>} lnCO_2$	4.362	9.109*	0.056	$lnREC \rightarrow lnCO_2$
$lnCO_2 \neq^{>} lnREC$	3.091	5.726	0.104	

p-Values are estimated applying 500 bootstrap replications

***, ** and * denote significance at 1%, 5% and 10% level, respectively

0.105% decrease in CO_2 emissions. It is concluded that the consumption of renewable energy reduces CO_2 emissions.

The findings that tourism, green technological innovation and renewable energy consumption lower CO_2 emissions, and that economic growth and financial development support CO_2 emissions, are confirmed by findings from FGSL, PCSE, FMOLS and DOLS estimators applied to achieve stronger long-term results. Table 9 presents these additional evidences in detail.

Although the reliability of the coefficients in the study is ensured by Driscoll–Kraay, FGLS, PCSE, FMOLS and DOLS with Tables 8 and 9, the MMQR approach is also used both in order to see the variation of the coefficients between the quantiles and by ignoring the data distribution in the previous methods by Table 10. The results are consistent with previous findings.

The most important reason for using causality analysis in panel studies is that it helps to provide policy recommendations. In this context, the results of panel bootstrap causality approach are presented in Table 11. The results reveal a bidirectional causality between is identified between tourism, economic growth, green technological innovation and CO_2 emissions while financial development and renewable energy consumption cause CO_2 emissions.

Discussion

The long-run estimates indicate the existence of a negative relationship between tourism and CO_2 emissions meaning that CO_2 emissions are decreasing as the tourism sector develops. This result reveals that tourism has an important role in reducing environmental pollution and has the potential to reduce CO_2 emissions. Based on this finding, the fifteen most visited countries should follow more than one policy together to combat environmental degradation and that one of these policies may be the development of the tourism sector (Tian et al. 2021). This result also reveals that the countries in question are using less energy-intensive approaches for the tourism sector and are concentrating more on renewable energy (Ghosh et al. 2022). Our finding is similar to that of Nguyen and Su (2021), which tested the link among tourism, institutional quality and environmental sustainability for 134 countries. This negative finding is also confirmed by the findings of Le and Nguyen (2021) for 95 countries, Razzaq et al. (2021) for China, Tian et al. (2021) for G20 countries, Ghosh et al. (2022) for G7 countries, and Kyara et al. (2022) for Tanzania. In contrast to these studies, Zaman et al. (2016) for 34 developing countries, Kumail et al. (2020) for Pakistan, Adedoyin et al. (2021) for 26 EU countries, Onifade and Haouas (2023) for Middle Eastern region; Liu et al. (2022) for 70 countries, and Irfan et al. (2023) for China find that tourism increases CO_2 emissions and ecological footprint, i.e. causes environmental degradation.

The long-run estimates also indicate that environmental degradation will increase as economic growth increases in these countries. Therefore, it can be said that these countries are sacrificing ecological sustainability for the sake of economic expansion (Akadiri and Adebayo 2022). This result also shows that as income increases, individuals and institutions will buy more goods and services and energy consumption will accelerate, thus contributing to greater CO_2 emissions (Paramati et al. 2021). In this case, some authors state that green economic growth should be prioritized (Hao et al. 2021; Yikun et al. 2022). Our finding is consistent with the results of Paramati et al. (2021) for 25 OECD countries and Tang et al. (2022) for the Chinese economy. This positive finding between the two variables is confirmed by many studies (Boutabba 2014; Kumail et al. 2020; Alaganthiran and Anaba 2022; Batala et al. 2023; Li et al. 2023b; Gyamfi et al. 2023). On the other hand, Naqvi et al. (2023a), Shah et al. (2022), Jahanger et al. (2023c), Naqvi et al. (2023a), Shah et al. (2022) and Jahanger et al. (2023c) point to the existence of an inverse-U-shaped relationship between the two variables.

According to the findings, environmental degradation will increase as the financial sector of these countries develops. This finding can be attributed to different causes. First; The improvement in the financial system reduces information asymmetry, allowing capital to lend at a lower cost, expanding the financing channel. This leads to an expansion of the volume of production. Second; The development of the financial system increases the consumption of goods and services by consumers. Thus, energy demand increases and CO_2 emissions increase (Jiang and Ma 2019). This finding is confirmed by Shen et al. (2021), who applied the CS-ARDL approach for China. In addition, the results of Işık et al. (2017), Katircioğlu and Taşpinar (2017), Shah et al. (2022), and Habiba et al. (2022) are similar to the findings of our study. On the contrary, Xu et al. (2022) conclude that financial sector development in the G7 countries is hindering CO_2 emissions.

We have found that green technological innovation has a function of preventing CO_2 emissions. This conclusion is coalescing with the view that individuals and firms in these economies can reduce global CO_2 emissions by providing greater access to green technologies (Habiba et al. 2022). At the same time, the development of environmentally friendly technology alleviates the burden on the environment by introducing devices based on clean energy sources and the application of green technology facilitates the transition from non-renewable energy to green and clean energy sources and maximizes the benefits of renewable energy (Xie and Jamaani 2022). This finding is evidenced by the findings of some studies examining the green technological innovation-CO_2 emissions relationship, such as Habiba et al. (2022) and Meng et al. (2022). Cho and Sohn (2018), Xie and Jamaani (2022), Meng et al. (2022), and Razzaq et al. (2023) show similar results with these findings.

In addition, the use of renewable energy has a reducing effect on CO_2 emissions. The main reason for this is that renewable and green technologies are effective in reducing environmental pollution by using them in production sectors in these countries (Akadiri and Adebayo 2022). It reflects the fact that countries are deploying and funding green technologies to rise the use of green energy for a sustainable environment (Sheraz et al. 2022). This finding is similar to that of Khan and Ahmad (2021), which examined developed European countries and developing Asia Pacific countries. The results of Tian et al. (2021) and Xu et al. (2022) also support this result.

Finally, the impact of all the explanatory variables on CO_2 emissions is obtained for low (0.30–0.40), medium (0.50) and high (0.60–0.70) quantile levels. MMQR analysis results illustrate that while tourism in these countries decreases CO_2 emissions at all quantile levels, economic growth in these countries increases CO_2 emissions. In addition, the negative relationship between renewable energy consumption and CO_2 emissions clearly demonstrates that

renewable energy is environmentally friendly, especially in these tourism-oriented countries. Another striking finding is the power of financial development to increase CO_2 emissions in this tourism-oriented country group. In other words, the polluting role of investments supported by financial progress in this country group is undeniable.

According to the causal findings, a bidirectional causality is identified between tourism and CO_2 emissions. Our finding is confirmed by the finding of Kumail et al. (2020), which focused on 12 Asia Pacific countries. However, Shakouri et al. (2017) find that there is a one-way causality extending from CO_2 emissions to tourism. The causality findings detect that economic growth and CO_2 emissions cause each other. This finding is compatible with the results of Wang et al. (2022) for 11 countries and Xie and Jamaani (2022) for the G7 countries. The results identify a causality extending from financial sector development to CO_2 emissions. This finding is also compatible with the result of Xu et al. (2022) for the G7 countries.

Causality analysis points to a bidirectional causality between green technological innovation and CO_2 emissions. This conclusion is proved by Xie and Jamaani (2022) for the G7 countries. On the contrary, Razzaq et al. (2023) note the existence of a one-way causality for 10 countries, extending from green technological innovation to CO_2 emissions. Finally, the causality findings prove that renewable energy consumption causes CO_2 emissions. This finding of the study is in line with the findings of Irandoust (2016), which studied Nordic countries, and Hao (2022), which analyzed China.

Conclusion and policy suggestions

Conclusion

Although this study focuses on the relationship between tourism, green technological innovation and CO_2 emissions, it considers economic growth, financial development and renewable energy consumption as control variables. Long-term estimations between variables are made by Driscoll–Kraay, FGLS, PCSE, FMOLS, DOLS and MMQR estimation methods, and the causality relationship is made by Dunitrescu-Hurlin panel bootstrap causality technique.

Long-term estimates suggest that tourism inhibits CO_2 emissions and plays an important role in improving environmental quality. This finding actually proves that the tourism sector of these countries has a strong structure that is sensitive to the environment and that this structure needs to be developed. This conclusion is confirmed by Tian et al. (2021) and Ghosh et al. (2022). The findings indicate that green technological innovation is effective in preventing environmental pollution by reducing CO_2 emissions. In this case, green technological innovation reflects its feature of improving environmental quality in the findings of the study. Habiba et al. (2022) and Xie and Jamaani (2022) provide evidence proving this conclusion. Our study similarly presents the finding that renewable energy consumption is negatively related to CO_2 emissions. This result reveals the fact that these countries invest more in renewable energy sources and make more use of these resources. In addition, economic growth and financial development have the effect of increasing CO_2 emissions. Therefore, economic growth and financial development should incorporate environmentally-oriented practices. Panel bootstrap causality analysis points to a bidirectional causality between tourism, economic growth and green technological innovation and CO_2 emissions. The findings suggest that financial development and renewable energy consumption cause CO_2 emissions.

Policy implications

In the study, the emergence of tourism as a variable that reduces environmental pollution should be one of the important policy objectives to prioritize and encourage tourist entry to the country for environmental quality and environmental sustainability. As Tian et al. (2021) notes; By giving priority to the development of the sector of green tourism, CO_2 emissions can be reduced and at the same time resources can be provided to the development of economies. It is also possible for policymakers to ensure green growth with low CO_2 emissions. Policymakers should also focus on developing innovation and technical progress that will generate revenue through ecotourism as well as reduce emissions, and accelerate visa easing policy along with the attractiveness of the tourist destination.

It is also understood from the findings that green technological innovation is an important tool in the fight against environmental pollution. In this context, governments should allocate significant financial resources to green energy and green technological innovation projects that can enable a structural transformation from fossil fuels to renewable energy sources. In addition, as Shao et al. (2021) suggest, a pricing or taxation can be introduced for technologies that are not environmentally compatible in CO_2-emitting sectors. In particular, taxation policies need to motivate individuals to use green technological innovations, adapt to a clean consumption process.

The empirical finding that renewable energy consumption can be used to reduce CO_2 emissions suggests that these countries take a number of initiatives to increase renewable energy use and reduce fossil fuel consumption. It is imperative to rapidly increase the share of renewable energy in total energy production and consumption. In this context, the financial sector should be provided with priority funding for renewable energy sector investments. As Shao et al. (2021)

suggest, policymakers can use new techniques and academic training curricula to raise individuals' awareness to ensure the persistence of high demand for renewable energy.

To lessen the negative environmental effect of economic growth, policymakers should prioritize green economic growth and its targets in growth policies, as in the case of OECD countries. In this context, investments and incentives for green innovation, green financing and environmentally friendly energy sources should be accelerated. As Atsu et al. (2021) suggests; The level of financial depth in financial markets can be increased to reduce the environmental quality deterioration effects of financial development by increasing CO_2 emissions. In addition, projects for technology and innovative products to increase energy efficiency can be supported by loans.

Limitations and suggestions for future studies

This study does not even include other groups of countries because it analyzes the 15 most visited countries. However, in a significant part of the panel studies, different and comparative findings can be reached by taking country groups with different income or development status. In recent years, studies on environmental pollution prefer carbon footprint or load capacity factor because it covers a wide range of environmental dynamics instead of CO_2 emissions. In addition, various economic, social and environmental variables such as corporate quality, green economic growth, green finance, economic complexity, political stability and environmental taxes that may have an impact on environmental sustainability (or environmental pollution) can be modeled as control variables. Thus, it will be possible to diversify policy proposals to improve environmental quality. Finally; CS-ARDL, CS-ADL and DCCE, which do not find application in this study, may also be preferred by future studies, which help to obtain healthier empirical findings by taking into account CSD and slope heterogeneity. Thus, it will be possible to present both long-term and short-term findings.

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Declarations

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