The role of clean energy in the development of sustainable tourism: does renewable energy use help mitigate environmental pollution? A panel data analysis

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Received: 18 November 2021 / Accepted: 26 March 2022 / Published online: 6 April 2022 © The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract
The tourism industry has long been accused of being the major driver of global warming as a result of the size of the industry and its subsequent high energy consumption, most of which comes from sources that emit carbon dioxide. However, in spite of the criticism directed towards tourism due to its negative effects on the environment, there is a scarcity of research that has aimed to ascertain its impact on the environment, thus revealing the existence of a gap in the literature. The current study uses a dynamic GMM model for 38 OECD countries from 2008 to 2019 for the purpose of filling the gap in the literature by investigating the effects of tourism development on the environment, as well as ascertaining the role of renewable energy in mitigating environmental impact. Unlike past studies that have alluded to the fact that tourism development exacerbates the emissions of carbon dioxide and hence global warming, the current research shows that in the OECD countries, tourism does not have any significant link with greenhouse gas emissions. This is because OECD nations have long started to shift from the use of fossil fuels to renewable sources of energy that do not exacerbate greenhouse gas emissions. The use of renewable energy sources instead of fossil fuels should continue to be encouraged in all nations for the purpose of achieving the carbon neutrality goal of the United Nations.

Keywords Tourism development · Greenhouse gas emission · Renewable energy · Energy

Introduction
The tourism industry is one of the world industries that is largely blamed for causing greenhouse gas emissions, which in turn causes global warming. The work of Tian et al. (2021) as well as Yue et al. (2021) reported that the tourism industry is blamed for having a strong negative impact on environmental degradation. However, it is shocking that despite these accusations of blame, very few researches have been undertaken to examine the nexus between the two (see, for instance, Yue et al. 2021; Tian et al. 2021). The strong negative impact of the tourism industry on environmental quality is a cause of concern for governments and policy makers. Although the tourism industry contributes a larger percentage of nations’ gross domestic product, it also negatively affects the environment, which presents a dilemma for policy makers in terms of whether the tourism industry be abolished or limited because of its negative impact on the environment or whether should it be encouraged since it increases nations’...
GDP. Economists, governments, and policy makers have sought to answer this question, and the current study addresses this issue by providing an alternative solution to the problem. The tourism industry is believed to negatively affect the environment because it uses more energy in its activities. Yue et al. (2021) also stated that existing studies on the implications of the tourism industry for the emissions of greenhouse gasses have presented contradictory results. For example, Zhang and Liu (2019) postulated that in the case of North and South East Asia (NSEA 10) countries, tourism has a strong influence on environmental degradation, while Tian et al. (2021) claimed that an increase in tourism development in the long run tends to reduce emissions.

The current research seeks to examine the role of clean energy on sustainable tourism development as well as the impact of renewable energy use on greenhouse gas emissions. The study also differs from past researches in that it examines the impact of tourism development on greenhouse gas emissions in the Organization of Economic and Corporation Development (OECD) member countries, which has not been examined before to the best of our knowledge. The study also seeks to examine the role of renewable energy in mitigating environmental pollution. To achieve the aim of the study, the dynamic generalized method of moments (GMM) model is employed, which is capable of providing robust results in the existence of endogeneity in the specified model.

Renewable energy has to this point been lauded as the best alternative source of energy that helps mitigate global warming, since the sources of energy are environmentally friendly (Chaoqun 2011; Salim and Rafiq 2012; Becker and Fischer 2013; Zhang and Liu 2019; Shabaz et al. (2020), (for review see also, Deka et al. 2022; Deka and Dube 2021). Of significant importance is the environmental Kuznets curve (EKC), founded through a series of studies by Selden and Song (1994), Shafik (1994), Grossman and Krueger (1995), and Stern et al. (1996) after the work of Kuznets (1955), who pioneered the existence of an inverted U-shaped association between income inequality and the growth of a nation’s economy. The EKC hypothesis also argues that an inverted U-shaped curve association also exists between the growth of a nation’s economy and environmental impacts. According to the study by Filippidis et al. (2021), the use of renewable sources and GDP growth rate exhibits a U-shaped curve, thus the EKC holds (see also, Ma et al. 2021; Dietz et al. 2012). All these findings clearly allude to the fact that renewable sources of energy reduce environmental degradation while simultaneously promoting economic growth. Therefore, instead of using fossil fuels in tourism development, nations should use clean sources of energy such as renewable energy which reduces greenhouse gasses emissions. Adopting the use of renewable energy in the tourism industry will help to solve this dilemma as the nation’s GDP will be increased without harming the environment.

As opposed to the claims that tourism development exacerbates the emissions of greenhouse gasses, the research results indicate that in the OECD nations, tourism development has no significant impact. The insignificant relationship between the two is due to the shift by countries from the use of fossil fuel sources of energy to renewable energy sources in the tourism industry. Thus, instead of using fossil fuel energy in the tourism industry, renewable energy has begun to be used. The results of the study also clarify the significance of renewable energy in curbing greenhouse emissions, since a negative significant effect has been ascertained. Therefore, this research concurs and adds to the EKC hypothesis suggesting that there is an inverted U-shaped relationship between environmental degradation and tourism development. An increase in tourism development while using fossil fuel as the source of energy results in environmental damage since fossil fuels emits greenhouse gasses, and this represents the upward sloping part of the EKC. The turning point of the EKC is achieved when nations shift from fossil fuel use to the use of clean energy. Any further increases in tourism development after the nation has shifted to renewable energy sources reduce environmental stress, and this is the downward sloping part of the EKC.

**Literature review**

**Environmental Kuznets curve**

Kuznets (1955) examined the association between income inequality and economic growth and came to the conclusion that there is an inverted U-shaped relationship between the two variables. According to the postulations of Kuznets (1955), as an economy grows from a low GDP per capita to a higher one, income inequality tends to increase until the turning point is reached. Further increases in economic growth beyond the turning point cause a decrease in income inequality in a nation. Almost 40 years after the work of Kuznets (1955), other researchers such as Selden and Song (1994), Shafik (1994), Grossman and Krueger (1995) Stern et al. (1996) postulated that Kuznets’ proposition is also applicable to environmental impacts, which led to the inception of the EKC proposition. Thus, the EKC hypothesis alludes that an increase in the economic growth of a nation will first encourage environmental degradation as the nation uses sources of energy and engages in activities that harm the environment up until the turning point is reached where environmental stress is relieved such that any further increases in economic growth tend to reduce environmental degradation. Dietz et al. (2012) argued that the turning point is achieved due to the nation’s shift from fossil fuel energy.
use to renewable energy among many other factors, which thus explains the reason behind the EKC curve.

The argument of Dietz et al. (2012) can be used to derive suitable policies for the tourism industry. Since the tourism industry is heavily dependent on energy to undertake its activities, if it uses fossil fuels then an improvement in the tourism industry will produce more degradation in the environment, which represents upward sloping part of the EKC curve. However, when nations realize the harm caused by non-renewable sources of energy and resort to the use of renewable energy, then an improvement in the tourism industry will bring about less stress on the environment, which is the downward sloping part of the EKC curve. Tourism is beneficial for nations since it contributes a greater percentage to the countries’ GDP and if its growth damages the environment, then a trade-off situation exists between the two. Thus, nations are encouraged to adopt the use of renewable energy which is environment friendly, see also Dietz et al. (2012).

Clean energy and green technology innovation

According to Shan et al. (2021), there are two essential factors that help nations achieve the goal of carbon neutrality as advocated by the United Nations, namely clean energy and green technology innovation. Clean energy refers to the sources of energy that do not emit greenhouse gases into the air such as solar energy, wind, tidal wave, among many other sources of energy. These sources of energy are also commonly known as renewable energy, because they can be used repeatedly without being depleted. Unlike renewable energy, non-renewable energy sources are harmful to the environment and are the major drivers of global warming.

Green technology innovations, according to Adams et al. (2016), Foster and Green (2000), and Seebode et al. (2012), take the form of new products, technologies, business models, or services that have positive effects on the society and environment. Wicki and Hansen (2019) stated that green technology innovation includes all modified ways of conducting business operations that fulfill customers’ needs with less harmful effects than the alternative methods. Thus, green technology innovation is aimed at solving societal problems as well as improving the sustainability of firms (Wicki and Hansen 2019). There are basically two green technology innovation models: the fireworks model, which studies innovation processes and the sequence of activities leading to innovation birth and the flow models, which are used to study processes of innovation (Wicki and Hansen 2019).

In addition to that, there are many other various factors that encourage future sustainable tourism. Aman et al. (2019) in their study undertaken in Pakistan alludes that the attitudes of religious respondents poses a positive impact towards sustainable tourism development in the future. The development of new sick road according to Mamirkulova et al. (2020) is observed improve residence quality of life, hence achieving the development of sustainable tourism since the infrastructure is enhanced. On the other hand, the Covid-19 outbreak together with lockdown measures that has been put in place to curb the spread of the disease have had negative impact on the tourism sector since traveling has been restricted (Mamirkulova and Mi 2022; Wang et al. 2021a; Zhou et al. 2022; Li et al. 2022; Liu et al. 2021a; Fu 2021).

Impact of tourism development on the environment

It is generally agreed that the tourism industry plays a crucial role in causing environmental degradation around the world. This is because the industry uses a significant amount of energy to carry out its activities. Most of this energy is obtained from non-renewable sources that pollute the air, thereby causing ozone depletion and hence global warming. The studies by Chaoqun (2011), Yue et al. (2021), Tian et al. (2021), and Zhang and Liu (2019) among many others concurred that tourism development significantly impacts the environment. The tourism industry is particularly crucial for the growth of the global economy as it contributes a greater percentage of GDP. At the same time, environmental degradation is not good for the world and future generations. As a result, we agree with Dietz et al. (2012) that this creates a trade-off situation between both tourism development and environmental stress, since factors that improve tourism and hence GDP have the tendency to negatively affect the environment. Therefore, nations should strive to devise measures that promote tourism development without harming the environment.

Empirical studies have thus far produced mixed results on the nexus between carbon dioxide emissions and tourism development. Tian et al. (2021) in their study observed that in the long run, increases in tourism development tend to reduce the emissions of carbon dioxide, indicating that tourism does not negatively affect the environment and rather helps to reduce pollution in the G20 countries. These findings are due to the fact that the G20 nations have started to shift from fossil fuel use to renewable energy use; hence, the tourism industry, which is more reliant on energy, is conducting its activities using renewable energy. However, these results contradict the findings of Yue et al. (2021), who postulated that tourism is a major driver of greenhouse gas emissions. Thus, nations are encouraged to shift from using non-renewable energy and use energy sources that are renewable as these sources will help mitigate environmental degradation.
Renewable energy and the environment

Various studies have been conducted on the nexus between renewable energy and greenhouse gas emissions (see for instance, Azam et al. 2021; Mohsin et al. 2021; Liu et al. 2021b; Xiaoan et al. 2021; Hdom 2019; Zhang et al. 2021; Saidi and Omri 2020; Wang et al. 2021b; Bhat 2018; Attiaoui et al. 2017; Kahia et al. 2019; Toumi and Toumi 2019; Khan et al. 2020; Abbasi et al. 2021a), and different results have been found. Some researchers have observed that the consumption of renewable energy has a negative and significant effect on greenhouse gas emissions, which means that if more renewable energy sources of energy are used in the economic activities of nations, the effects of greenhouse gas emissions will be lowered (Khan et al. 2020; Kahia et al. 2019; Bhat 2018; Zhang et al. 2021; Wang et al. 2021a; Hdom 2019; Xiaoan et al. 2021). These findings provide overwhelming evidence that if nations seek to curb the effects of greenhouse gasses, then renewable energy is the path to follow.

However, other studies, such as Mohsin et al. (2021), Liu et al. (2021a), and Zhang et al. (2021) have found a positive effect of renewable energy on greenhouse gas emissions. These are some of the few studies that have provided evidence that contradicts the majority of the literature, and this anomaly may have occurred due to the fact that the models employed that might not have been robust. Attiaoui et al. (2017) and Toumi and Toumi (2019) argued that the association between the two is neutral, while Saidi and Omri (2020) claimed that no association exists. Therefore, considering the overwhelming evidence provided by many previous studies, as mentioned in the paragraph above, we ascertain that renewable energy use is capable of reducing greenhouse gas emissions and should be used as a substitute for non-renewable sources.

Nexus between renewable energy and economic development

Recent studies on the nexus between the use of renewable energy and the growth of the economy have shown that renewable energy consumption asserts a positive effect on economic growth (Wang and Wang 2020; Smolović et al. 2020; Rahman and Velayutham 2020; Shahbaz et al. 2020; Ivanovski et al. 2021; Doğan et al. 2021; Chen et al. 2020). Thus, if world economies adopt the use of renewable sources, their gross domestic product will also be improved in addition to curbing the greenhouse effect (see, Deka et al. 2022; Deka and Dube 2021). Non-renewable energy has also been ascertained to have a significant positive effect on GDP even though it is harmful to the environment (Ivanovski et al. 2021; Rahman and Velayutham 2020), and this has left governments and policy makers facing a trade-off between the two. Both economic development and environmental quality are of paramount importance to nations. Therefore, since renewable energy can be used in place of fossil fuel and can also improve GDP, this should be the path to follow.

Various other researches have also ascertained that renewable energy has an effect on employment. For example, Ge and Zhi (2016) postulated that the green economy positively affects employment in both developing and developed nations. The study by Abbasi et al. (2021b) also examines the relationship between electricity consumption, price, and real GDP. The association of renewable energy consumption and rate of foreign exchange as well as inflation has been ascertained, and it has also been observed that renewable energy use impacts both inflation and rate of foreign exchange negatively, showing that renewable energy use causes the appreciation of the foreign exchange value and stabilizes the rate of inflation (Deka and Dube 2021; Deka et al. 2022). Therefore, in order for nations to achieve a clean environment in the future together with high economic growth, stable inflation rate and strong exchange value, renewable energy use should be encouraged.

Research design and method

Sample and data

To achieve the aim of this research study, our sample data comprised 38 Organization of Economic and Corporation Development (OECD) countries. The use of 38 countries in this research implies that our research makes use of panel data for the variables employed. The period of study is from 2008 to 2019, and yearly data is used. Therefore, since panel data is used, each variable will consist of 456 observations (12×38), and this data sample is sufficiently large to produce reliable results that are not biased. Moreover, secondary data is used and is retrieved from the OECD website.

Variables

In this current research, seven variables from 38 OECD member countries are used for the purpose of achieving the study’s aim. The seven variables employed are greenhouse gas emissions (GHG), tourism development (TOR), renewable energy (RE), population size (POP), inflation (INF), gross domestic product (GDP), and foreign direct investment (FDI).

Dependent variable

Greenhouse gas emissions (GHG) of the 38 OECD nations for the period 2008 to 2019 are expressed as the dependent variable in this research. According to www.data.oecd.org,
greenhouse gasses refer to a combination of seven gasses that impact global climate change. These gasses include methane (CH₄), carbon dioxide (CO₂), chlorofluorocarbons (CFCs), nitrous oxide (N₂O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), nitrogen trifluoride (NF₃), and sulfur hexafluoride (SF₆) (www.data.oecd.org). The measurement of greenhouse gas emissions is thousand tons and tons per capita, while carbon dioxide is measured in millions of tons and tons per capita (www.data.oecd.org).

Independent variables

Three variables are expressed as explanatory variables in this study, namely tourism development, renewable energy, and population size. The three variables have been chosen to be specified as explanatory variables of greenhouse gas emissions because they are known to directly impact it. The tourism development indicator in this research is represented by tourism receipts and spending. According to www.data.oecd.org, tourism receipts and spending is comprised of travel debits and credits and is the value of money spent by tourists on visits outside of their own country. It is measured in United States (US) dollars. The tourism industry has been accused of being the major driver of greenhouse gas emissions (Yue et al. 2021; Tian et al. 2021) and hence can be modeled to explain greenhouse gas emissions. Renewable energy sources, according to www.data.oecd.org, are sources of energy that contribute to total primary energy supply, which are environmentally friendly and can be used repeatedly. These sources of energy include hydro, wave, geothermal, tide, solar, and wind energy sources among many others. It is measured in thousand tons or as the percentage of the total primary energy supply. Renewable sources of energy have been promoted as alternatives to fossil fuels that emit greenhouse gasses. Moreover, population size is the number of people that are present in, or people that are temporarily out of the country, including aliens who have permanently settled in the country (www.data.oecd.org). As the population size grows, this means that more energy is required, since people use energy in their daily activities, and some of this energy is obtained from fossil fuels, which emits greenhouse gasses.

Control variables

To avoid missing out other explanatory variables, gross domestic product (GDP), inflation rate, and foreign direct investment (FDI) are specified as the control variables. GDP is the total value of goods and services that are produced within the borders of a country regardless of the citizenship status of the people involved in the production of those products. Thus, GDP includes all products and services that might have been produced by local and foreign firms, as long as those products are produced within the boundaries of a country and not outside. Inflation is the rate at which the prices of goods and services of a country change over time, such as in 1 year, and in this research, consumer price index (CPI) is taken to represent the rate of inflation (www.data.oecd.org). FDI flows is the value of cross border transactions that are related to direct investment, and these take the form of equity, intercompany debt, and earnings reinvestment transactions (www.data.oecd.org). It is measured in US dollars and as GDP share.

Method

As previously mentioned, this paper examines the impact of tourism development and renewable energy use of greenhouse gas emissions, and therefore, we follow the model below, as expressed in the form of a linear function:

\[ \text{GHG} = f(\text{TOR}, \text{RE}, \text{POP}, \text{INF}, \text{GDP}, \text{FDI}) \]  \hspace{1cm} (1)

where GHG represents greenhouse gasses emissions, TOR represents tourism development, RE represents renewable energy use, POP represents population size, INF represents rate of inflation, GDP represents gross domestic product, and FDI represents foreign direct investment.

Due to the nature of our data sample size and time period of the study, the best method that can be used for robust results is the dynamic generalized method of moments (GMM) model. This is because the number of countries included in our panel data (38) is more than the time period (12) under study. Therefore, when the number of countries or subjects under study is larger than the time period, the GMM model is the most suitable method to use. Anderson and Hsiao (1982), Holtz-Eakin et al. (1988), Arellano and Bond (1991), Arellano and Bover (1995), and Blundell and Bond (1998) in their series studies pioneered the dynamic GMM model. There are basically two types of GMM models, namely first-difference GMM (GMM-DIF), by Anderson and Hsiao (1982), Holtz-Eakin et al. (1988) and Arellano and Bond (1991), and the systems GMM model, by Arellano and Bover (1995), and Blundell and Bond (1998). The difference between the two is that first-difference GMM corrects endogeneity problems in the model through differencing the regressors and removing fixed effects (Arellano and Bond 1991) while systems GMM uses orthogonal deviations that subtract variables’ average of all future observations available (Arellano and Bover 1995; Blundell and Bond 1998). Systems GMM is generally preferred over first-difference GMM because it minimizes data loss and works well in both balanced and unbalanced panel data. In unbalanced data sets, first-difference GMM magnifies the gap because it subtracts previous data from contemporaneous data.
Generally speaking, the GMM model is preferred over ordinary least square methods because it overcomes the problems of heteroskedasticity, autocorrelation, and normality (Fraj et al. 2018). Heteroskedasticity, autocorrelation, and normality are very serious problems in time series data modeling since their presence will result in biased results being obtained. Therefore, any model that overcomes these problems is preferred. Additionally, the GMM model corrects endogeneity problems (see, Arellano and Bond 1991; Arellano and Bover 1995; Blundell and Bond 1998). Endogeneity emanates from various different channels and is a situation whereby one or more explanatory variables correlates with the error term, and these channels include, but not limited to, omitted variable(s) on the right-hand side of the regression, measurement errors of explanatory variables, and simultaneity, where both the explained and the explanatory variable simultaneously affect each other.

In this research study, we apply both systems and first-difference GMM for comparison purposes. The J-statistic and Arellano and Bond test of serial correlation are also employed as diagnostic tests. Before running the dynamic GMM model in this study, we start by checking the descriptive statistics of the variables, and check the unit root of the variables by employing the augmented Dickey Fuller (ADF) test developed by Dickey and Fuller (1979) and the Phillips Perron (PP) test, by Phillips and Perron (1988). The unit root test will help ascertain the integration order of the variables. The Pedroni test of cointegration will also be used to check if the variables have a long-run relationship. The equation below is the statistical representation of the GMM model employed:

\[ GHG_t = \beta_0 + \beta_1 \text{TOR}_t + \beta_2 \text{RE}_t + \beta_3 \text{POP}_t + \beta_4 \text{INF}_t + \beta_5 \text{GDP}_t + \beta_6 \text{FDI}_t + \epsilon_t \]  

(2)

The statistical representation in Eq. (2) above represents the GMM model specified in this study. In Eq. (2) above, GHG is the dependent variable, while TOR, RE, POP, INF, GDP, and FDI are explanatory variables. \( \beta_0 \) to \( \beta_6 \) are the coefficient parameters of the models, and \( \epsilon_t \) is the error term.

### Results and design

#### Descriptive statistics results

In Table 1 presented below, the results of the descriptive statistics of the indicators under study are presented. Greenhouse gas emissions of all the 38 OECD countries for the period of 12 years has a mean value of 7.64, maximum value of 21.76, minimum value of 1.27 and standard deviation of 3.94. Moreover, the mean, maximum, minimum, and standard deviation values of tourism spending are 21,495.56, 237,726, 0, and 35,147.96, respectively. In the case of renewable energy use, the average, maximum, minimum and standard deviation values are 18.57, 12.48, 90.14, 0, and 16.98, respectively. Population size in the OECD countries is observed to have mean, maximum, minimum, and standard deviation values of 34.67, 328.33, 0.32, and 56.68, respectively. In addition, inflation rate is observed to have a mean value of 2.21%, maximum value of 16.33%, minimum value of –4.48%, and standard deviation of 2.42%. The gross domestic product of the 38 OECD nations for the period under study has an average value of 38,974.64, while its maximum, minimum, and standard deviation values are 120,670.5, 10,324.88, and 16,969.43, respectively. Lastly, foreign direct investment has a mean value of 27,545.82, maximum value of 415,271, minimum value of –151,368.1 and standard deviation of 59,263.18. The total number of observations for each variable is 456 (see Table 1). The results of the sum of each variable and median value are also provided in Table 1.

#### PP and ADF results unit root test

This research uses ADF and PP unit root test to check the integration order of the variables under study, and the results are given in Table 2 below. The ADF and PP unit root test methods have been identified as the best and most reliable methods, see Granger (1986). According to Table 2 below, greenhouse gas emissions is not stationary at level and stationary at first difference as per the ADF unit root results. Both the ADF and PP unit root tests agree that greenhouse

| | GHG | TOR | RE | POP | INF | GDP | FDI |
|---|---|---|---|---|---|---|---|
| Mean | 7.461604 | 21.495.56 | 18.56897 | 34.67290 | 2.206102 | 38,974.64 | 27,545.82 |
| Median | 6.870000 | 10,887.50 | 12.48338 | 10.51072 | 1.776872 | 37,684.20 | 7233.000 |
| Maximum | 21.76000 | 237,726.0 | 90.13875 | 328.3300 | 16.33246 | 120,670.5 | 415,271.0 |
| Minimum | 1.270000 | 0.000000 | 0.000000 | 0.317404 | –4.478103 | 10,324.88 | –151,368.1 |
| Std. dev. | 3.940370 | 35,147.96 | 16.98201 | 56.67817 | 2.416702 | 16,960.43 | 59,263.18 |
| Sum | 3395.030 | 9,780.481 | 8448.879 | 15,776.17 | 1003.777 | 17,733,459 | 12,533,347 |
| Observations | 456 | 456 | 456 | 456 | 456 | 456 | 456 |
gas emissions are integrated of order 1. According to the PP test, tourism spending is stationary at first difference at 1% significant level; hence, it is integrated of order 1 and the ADF test also confirms the same results at 1% significant level. Renewable energy use, as per the findings in Table 1, is not stationary at level and is stationary at first difference according to the ADF test results, while the PP test also confirms that at first difference, it is indeed stationary. Moreover, population size, as per the PP test results, is not stationary at level but stationary at first difference at 1% significant level. The ADF test results also confirm that it is indeed stationary at first difference. Inflation rate, according to both ADF and PP test results, is stationary at both level and first difference at 1% significant level. The log of GDP (lnGDP) is not stationary at level and stationary at first difference as per both the ADF and PP tests. FDI at 1% significant level is not stationary at level but stationary at first difference as per the ADF test, while the PP test also confirms that it is indeed stationary at first difference, see Table 2 below.

### Pedroni cointegration test

The cointegration test is a crucial test in economic modeling that needs to be performed in order to ascertain the long-run relationship between variables (Granger 1986; Engle and Granger 1987). As shown in Table 3 below, in this research, the Pedroni cointegration test is used. The results of group ADF $t$-statistic, group PP $t$-statistic, panel PP $t$-statistic and weighted statistic, panel ADF $t$-statistic, and weighted statistic are significant at 1% level of significance, showing that the null hypothesis of no cointegration should be rejected, and it is accepted that the variables are cointegrated. The group rho-statistic, panel $v$-statistic, and panel rho-statistic results show that the null hypothesis of no cointegration should be accepted. However, this is overcome by the overwhelming evidence from group PP-statistic and ADF statistic, and panel PP-statistic and ADF-statistic, which shows that the variables are cointegrated. Therefore, there is a long-run equilibrium relationship between greenhouse gas emissions, tourism development, renewable energy, population size, inflation rate, GDP, and FDI of the OECD countries.

### Panel GMM results and discussion

The findings of the dynamic panel GMM model are given in Table 4 below. Both systems GMM and first-difference GMM model’s findings are presented. The dependent variable in this model is greenhouse gas emissions, while the other variables are explanatory variables. The first difference of greenhouse gas emissions is employed as an explanatory variable to cater for endogeneity problems that might exist. The second difference of greenhouse gas emissions is also automatically employed as the model’s instrument. Systems and first-difference GMM indicate that one lag

### Table 2 ADF and PP unit root results

|   | ADF   |         | PP   |         |
|---|-------|---------|------|---------|
|   | Level | 1stD    | Level | 1stD    |
| GHG| 88.73 | 141.74*** | 153.86*** | 338.43*** |
| TOR| 105.6** | 113.13*** | 61.90 | 113.19*** |
| RE | 63.19 | 124.57*** | 168.32*** | 368.16*** |
| POP| 111.6*** | 141.52*** | 50.45 | 126.67*** |
| INF| 114.1*** | 202.2*** | 181.39*** | 323.64*** |
| lnGDP| 6.84| 368.93*** | 8.975 | 426.44*** |
| FDI| 100.43** | 145.99*** | 265.46*** | 429.73*** |

***Significant at 1%
**Significant at 5%
*Significant at 10%

### Table 3 Pedroni results of cointegration

|       | $t$-Statistic | Weighted statistic |
|-------|---------------|--------------------|
| Panel $v$-statistic | -5.2744 | -6.3079 |
| Panel rho-statistic | 7.4942 | 7.2732 |
| Panel PP-statistic | -12.982*** | -12.624*** |
| Panel ADF-statistic | -7.2490*** | -2.8644*** |
| Group rho-statistic | 10.2506 | |
| Group PP-statistic | -18.2575*** | |
| Group ADF-statistic | -3.5639*** | |

***Significant at 1%
**Significant at 5%
*Significant at 10%

### Table 4 Results of panel GMM model

| Variable | GMM-SYS | GMM-DIF |
|----------|---------|---------|
|          | Coefficient | $t$-Statistic | Coefficient | $t$-Statistic |
| GHG(-1)  | -0.2855 | -6.0202*** | -0.2803 | -6.2461*** |
| TOR      | 1.6107 | 0.0267 | -3.7306 | -0.5211 |
| RE       | -0.1914 | -13.875*** | -0.1737 | -13.424*** |
| POP      | -0.0974 | -1.8742* | -0.1245 | -1.5839 |
| INF      | 0.1485 | 7.8762*** | 0.1449 | 11.936*** |
| lnGDP    | -2.8936 | -6.8497*** | -2.7529 | -5.5463*** |
| FDI      | -1.0207 | -0.1171 | -6.7908 | -0.1277 |
| $J$-statistic | 33.8002 | 33.7359 |
| AR(1)    | 0.9647 | 0.0447 |

***Significant at 1%
**Significant at 5%
*Significant at 10%

Greenhouse gasses emissions (GHG) is the dependent variable
The second lag of greenhouse gasses emissions (GHG(-2)) is the model’s instrument
value of greenhouse gas emissions significantly affects the current value of greenhouse gas emissions negatively. This shows that if greenhouse gas emissions were high in the past, it will drop in the future. This is a good sign since nations are working towards a low carbon environment in the future. The results of systems and first-difference GMM indicate that there is no significant association between tourism receipts and spending in the OECD nations with greenhouse gas emissions. This shows that tourism development does not significantly impact the emissions of greenhouse gasses. These findings oppose the findings of Zhang and Liu (2019) and Yue et al. (2021), who alluded that tourism development positively affects carbon dioxide emissions. The coefficient value of systems GMM is positive in this research (see Table 4), indicating that a rise in tourism development positively affects carbon dioxide emissions.

Renewable energy consumption has a very significant negative impact on greenhouse house gas emissions. The results for both systems and first-difference GMM are significant at 1% level. Therefore, there is a strong negative link between renewable energy use and greenhouse gas emissions. This shows that renewable energy use is the major driver towards reducing greenhouse gas emissions (Yue et al. 2021; Tian et al. 2021; Chaoqun 2011), and countries must be encouraged to adopt green technology to achieve low carbon in the future (Salim and Rafiq 2012; Becker and Fischer 2013; Deka et al. 2022; Deka and Dube 2021).

The results of systems GMM in Table 4 below indicate that the population size of the OECD nations negatively affects greenhouse gas emissions showing that an increase in population size significantly reduces greenhouse gasses emissions at 10% significant level. The coefficient of first-difference GMM is negative but not significant. The findings on the nexus between population size and greenhouse gas emissions differ from past studies such as Yue et al. (2021), who observed that population positively affects carbon dioxide emissions. The difference may be due to different population sizes and policies on population growth; for example, some countries have adopted a one child policy, which has led to a decrease in the population size in some parts of Europe, together with the adoption of renewable energy use which does not emit greenhouse gasses.

Inflation rate is observed to have a significant positive influence on greenhouse gas emissions. This shows that a high rate of inflation tends to cause an increase in the emissions of greenhouse gasses. Therefore, if inflation rate is stabilized together with the use of renewable energy sources, then a low carbon future accompanied with low rates of inflation will be achieved (Deka and Dube 2021; Deka et al. 2022). In addition, gross domestic product is observed to have a significant negative link with greenhouse gas emissions. An increase in the GDP of the OECD nations has the effect of reducing carbon dioxide emissions. These findings are favorable in that no trade-off situation is faced by policy makers as nations seek to improve GDP and at the same time reduce greenhouse gas emissions. All credit goes to green technology use as most of these OECD nations have resorted to the use of renewable energy and are hence enjoying its fruits. FDI is found to have no significant impact on greenhouse gas emissions. The coefficient is negative, indicating that an increase in FDI should reduce greenhouse gasses emissions, but its impact is not significant.

The J-statistic results, which are used for diagnostic testing of the GMM model to see if the model is correctly specified, show that its value is less than the critical value and its p-value is greater than the 10% significant level, indicating that we should accept the null hypothesis that the model is specified correctly. The Arellano and Bond test of serial correlation is also employed for first-difference GMM, and its value is less than the critical value, while its p-value is greater than 10% significant level. Therefore, we accept the null hypothesis that there is no serial correlation problem in the model. Thus, the findings provided in this model are robust, reliable, and valid.

Conclusion

The current study seeks to cover the existing gap in the literature on the association between tourism development and environmental degradation. The tourism industry has long been accused of being a major driver of global warming since it is one of the industries that uses more energy (Chaoqun 2011), most of which comes from sources that emit carbon dioxide. Unlike past studies that have found that tourism development exacerbates the emission of carbon dioxide and hence global warming (Tian et al. 2021; Yue et al. 2021), the current research shows that in the OECD countries, tourism does not have any significant link with greenhouse gas emissions. This is because OECD nations have long started to shift from fossil fuel use as a source of energy to renewable energy use which does not exacerbate greenhouse gas emissions. However, the current research concurs with the findings of past studies that the consumption of renewable energy significantly reduces greenhouse gas emissions (Hdom 2019; Mohsin et al. 2021; Xiaosan et al. 2021; Bhat 2018; Kahia et al. 2019; Khan et al., 2019). Renewable energy use should continue to be encouraged in all nations around the world for the purpose of achieving low carbon in the future (Salim and Rafiq 2012; Becker et al. 2013; Deka et al. 2022; Deka and Dube 2021).
and Fischer 2013; Deka and Dube 2021). Therefore, this research concurs and adds to the EKC hypothesis that there is an inverted U-shaped relationship between environmental degradation and tourism development. An increase in tourism development while using fossil fuel as the source of energy results in environmental damage since fossil fuels emit greenhouse gasses, and this is the upward sloping part of the EKC. The turning point of the EKC is achieved when nations shift from fossil fuel use to the use of clean energy. Any further increases in tourism development while the nation has shifted to renewable energy sources reduce environmental stress, and this is the downward sloping part of the EKC.

The limitations of the study are that it might have omitted other crucial explanatory variables that might have a significant impact on greenhouse gas emissions, such as urbanization and fossil fuels use among many others. However, the results are robust because the dynamic GMM model corrects for the endogeneity problem that might arise due to the omission of some regressors (Arellano and Bond 1995; Arellano and Bond 1991; and Blundell and Bond 1998). The GMM model also overcomes autocorrelation, heteroskedasticity, and normality problems (Fraj et al. 2018); hence, the robustness and reliability of the results is obtained. The study is also limited in that it only employs the GMM model, ignoring many other models that could be more effective in providing robust results. Thus, future studies should try to use other models such as the autoregressive distributive lag (ARDL) model, which examines the long-run and short-run relationships among variables, among many more. The findings of this research can be generalized to other developed nations with similar conditions to those of the OECD. Therefore, more work is required to examine the role of clean energy in tourism development as well as the role of renewable energy in mitigating environmental pollution in developing nations such as those in Africa.

Author contribution AD: conceptualization and methodology. CB: writing — original draft and software. HK: data curation and writing — review. HO: editing and supervision. AO: visualization and investigation.

Availability of data and materials
The data used in this paper are secondary data and were retrieved from the Organization for Economic Co-operation and Development (OECD) website www.oecd.org.

Declarations

Ethical approval Not applicable

Consent to participate Not applicable

Consent for publication The authors guarantee that this manuscript has not been previously published in other journals and is not under consideration by other journals. The authors also guarantee that this manuscript is original and is their own work.

Competing interests The authors declare no competing interests.

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