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Analyzing the nexus between tourism and CO_2 emissions: the role of renewable energy and R&D

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This study aims to investigate the relationship between tourism development, renewable energy consumption (REN), research and development (R&D) expenditure, and CO_2 emissions in 12 emerging markets and middle-income Europe spanning 1999–2020. We applied the panel autoregressive distributed lag and the Driscoll–Kraay estimator to determine the relationship between variables. According to both estimators' results, a U-shaped relationship exists between economic growth and CO_2 emissions. This result indicates that the environmental Kuznets curve hypothesis is invalid in these countries. Furthermore, REN and R&D contribute to decreasing CO_2 emissions and stimulating sustainable development. However, the impact of tourism development on CO_2 emissions is found to be negative in panel autoregressive distributed lag but positive in the Driscoll and Kraay estimator for fixed and random effects. Moreover, the Dumitrescu and Hurlin panel causality test reveals a two-way causal relationship between R&D and CO_2 emissions and a one-way causal linkage running from economic growth, the square of economic growth, and tourist arrival to CO_2 emissions. Overall, our results prove the existence of a relationship between international tourism and CO_2 emissions. Furthermore, our results suggest some policy recommendations for policymakers to reduce CO_2 emissions through REN, R&D, green economic development, and establishing an ecologically friendly tourism policy.

KEYWORDS

environmental degradation, CO_2 emissions, tourism, renewable energy, research and development, sustainable development

1 Introduction

There is great attention to environmental degradation and climate change as global problems, and combating climate change has become a crucial target for global society (Olejnik and Sobiecka, 2017; Fernandez et al., 2018; Bilgili et al., 2021). Due to economic activities, different types of greenhouse gas (GHG) emissions, including CO_2 emissions, are released into the atmosphere (Iqbal et al., 2022). Therefore, a consensus exists that CO_2 emissions are one of the driving forces of climate change (Adebayo, 2020; Mlaskawa, 2022). In line with this issue, recent data show that global energy-related CO_2 emissions were 31.5 Gt, approximately 50% higher than the industrial revolution in 2021. In addition, CO_2 emissions caused by oil exceeded 650 Mt CO_2 in 2021 (IEA, 2021). As the Intergovernmental Panel on Climate Change [IPCC] (2018) points out, global warming will reach 1.5°C during 2030–2052 if current global activities continue. Since the devastating impact of CO_2

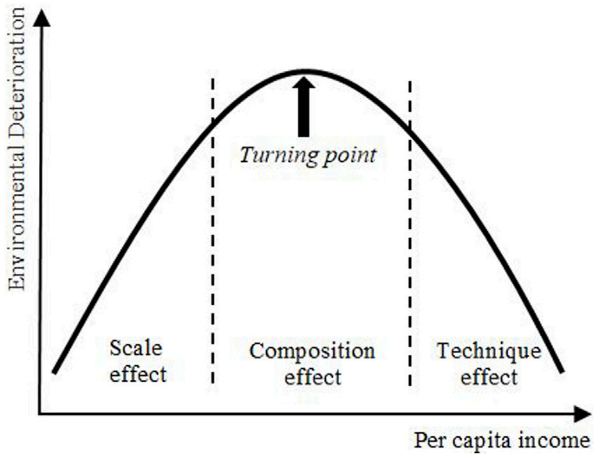

FIGURE 1
Graphical representation of the EKC hypothesis (Murshed and Dao, 2022).

emissions on climate change and environmental degradation has reached a dramatic level, many countries have strived to improve policies regarding reducing CO_2 emissions. As a result, global society has paid attention to overcoming this problem. For example, Kyoto Protocol and Paris Agreement initiatives have been adopted to achieve environmental quality and sustainable development by reducing dependency on non-renewable energy sources that cause environmental problems (Guo et al., 2023).

In the relevant literature, environmental degradation is investigated in the context of the environmental Kuznets curve (EKC) hypothesis, which represents that economic growth initially causes an increase in pollution and lately decreases environmental degradation. The EKC hypothesis originated in the work of Kuznets (1955). In his study, Kuznets focused on the relationship between income inequality and economic growth and provided that along with economic growth, as *per capita* income increases, income inequality increases in the early stages of development, but it declines after a certain threshold income level. This relationship is called the Kuznets (1955) hypothesis and indicates an inverted U-shaped relationship between economic development and income inequality. Furthermore, following the pioneer study of Grossman and Krueger (1991), the Kuznets (1955) hypothesis is adapted to the EKC hypothesis, and it is expected that as income level increases, environmental degradation increases in the early stages, but after the threshold level, environmental degradation decreases. As depicted in Figure 1, the EKC hypothesis displays an inverted U-shaped relationship between income level and environmental degradation (Shafik and Bandyopadhyay, 1992; Panayotou, 1993; Dinda, 2004; Yilanci and Pata, 2020; Onifade, 2022).

As depicted in Figure 1, the inverted U-shaped portrayal of the EKC hypothesis consists of scale, composition, and technical effects (Beyene, 2023; Uche et al., 2023). The scale effect means that in the early stage of income growth, the economy's production capacity increases, and primary energy consumption, including fossil fuels, increases. Hence, the environment is negatively affected by the increase in the scale of production (Pata, Kartal, Erdogan, and Sarkodie, 2023). The composition effect refers to the fact that during economic growth, the economy's structure shifts from agricultural to industrial, increasing environmental degradation. Furthermore, the pollution level decreases since the economic structure moves from industry to the service sector (Adeel-Farooq et al., 2020). Finally, the technical effect characterizes replacing traditional production methods with technology-intensive ones. So, green technologies are used in production, and economic productivity increases with technological improvement. Hence, environmental pollution decreases (Sarkodie, 2018; Adeel-Farooq et al., 2020; Pata et al., 2023a).

Therefore, after the seminal work of Grossman and Krueger (1991), a vast body of literature has emerged investigating the validity of the EKC hypothesis. Researchers have studied the nexus between income and environmental pollution in different sectors. For instance, agriculture (Mahmood et al., 2019; Liu et al., 2021; Selcuk et al., 2021; Atasel et al., 2022; Ntim-Amo et al., 2022; Selvanathan et al., 2023), industry (Mahmood et al., 2020; Jadoon et al., 2021; Luan et al., 2022; Ullah et al., 2022), and the service sector (Hashmi et al., 2020; Murshed et al., 2020; Yassin and Aralas, 2020; Karthikeyan and Murugesan, 2022; Ali et al., 2023) are considered crucial factors influencing environmental pollution. In this context, economic activities are closely linked to an environmental issue. As one of the vital sectors for economic growth, the role of the tourism sector is crucial for many countries. Tourism contributes remarkably to economies and is one of the driving forces of economic development (De Vita et al., 2015; Danish, 2018). According to the World Travel and Tourism Council (2022), travel and tourism activities' contribution to world economic growth was US$ 5.8 trillion in 2021, accounting for 6.1% of global GDP. Furthermore, the travel and tourism sector created 333 million jobs in 2019 worldwide. However, the employment effect of the travel and tourism sector declined to 271 million, resulting in a loss of 62 million jobs in 2020 due to the COVID-19 crisis. Nevertheless, the contribution to global employment increased to 289 million, representing 9% of global employment in 2021. As experienced in the post-COVID-19 pandemic period, the tourism sector should be handled within a new model prioritizing sustainability. Therefore, sustainability policies for tourism should be developed to reflect the objectives of all stakeholders, such as public authorities, the tourism sector, non-governmental organizations, regional and local unions, and international organizations.

The tourism sector profoundly influences economic growth by creating employment, increasing foreign exchange savings, accelerating the mobility of people, stimulating financial inflow, and expanding government revenue (Bekun et al., 2022; Hussain et al., 2022). Based on this background, there is a large body of empirical studies on the relationship between tourism and economic development (Ivanov and Webster, 2007; Manzoor et al., 2019; Brida et al., 2020; Fuinhas et al., 2020; Adedoyin et al., 2021; Rasool et al., 2021). While most countries realized economic growth due to development in the tourism sector (Khan et al., 2023), it is responsible for increasing environmental degradation by causing CO_2 emissions. The tourism industry is forecasted to cause 11% of worldwide greenhouse gas (GHG) emissions, and it is expected to increase two-fold by the year 2050 (Peeters and Papp, 2023). There are several ways the tourism industry affects environmental quality. For example, the tourism sector requires places to use and construct

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hotels that can deploy natural resources. In addition, the increasing population with tourist arrivals exaggerates environmental problems (Destek and Aydın, 2022). Apart from the negative impact of tourism on environmental quality, there is also a positive effect on the environment. Development in tourism may encourage people to protect destination countries' national heritages and legacies, increase social networks, and be aware of preserving the environment (Rahman et al., 2022a), and it also promotes infrastructure quality (Guan et al., 2022). Tourism allows for social and cultural exchange between different societies, which can lead to changes in the social network (Singgalen et al., 2023). This interaction enables local people to learn to become more environmentally conscious from tourists.

The United Nations' Sustainable Development Goals (SDGs) are core factors in enhancing sustainable development and promoting responsible and sustainable tourism. In the scope of the 2030 Agenda of the United Nations for SDGs, the World Tourism Organization emphasizes the importance of tourism as *"tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment and host communities"* (World Tourism Organization, 2023). Thus, it is evident that tourism has a substantial effect on 17 SDGs, directly or indirectly (Tian et al., 2021). Tourism and sustainable development have a complementary relationship.

Investigating the relationship between environmental degradation and the tourism sector has been crucial in studies over the last decade. This relationship is analyzed in the EKC hypothesis framework. Based on the seminal work of Grossman and Krueger (1991), the EKC hypothesis states an inverted U-shaped relationship between economic growth and environmental degradation, indicating that as economic development increases, environmental degradation rises to a point. After the threshold level, it starts to decline (Alola and Ozturk, 2021; He et al., 2022a). Hence, a plethora of literature is available to check the validity of the EKC hypothesis for different countries (Dogan and Inglesi-Lotz, 2020; Pata and Caglar, 2021; Murshed and Dao, 2022; Onifade, 2022; Pata and Samour, 2022; Massagony and Budiono, 2023). Furthermore, R&D as one of the crucial determinants of environmental quality is less explored in the literature. However, R&D is closely linked with environmental quality (Han et al., 2023). Expanding R&D activities triggers technological innovation in the energy sector and improves energy efficiency. Moreover, along with R&D, improvement in technological innovation promotes REN instead of non-renewable energy (Erdogan, 2021). Hence, it is expected that R&D will positively affect environmental quality. Moreover, REN plays a crucial role in decreasing CO_2 emissions (Awan et al., 2022). It offers an alternative to non-renewable energy sources, such as fossil fuels and coal, that cause environmental degradation (Akar, 2016; Yu et al., 2022). Therefore, the transition to renewable energy can improve environmental quality by reducing CO_2 emissions (Jena et al., 2022; Shah et al., 2022). In addition to the direct links between tourism development and environmental degradation, this association still needs investigation by controlling other factors affecting CO_2 emissions. In the research line, this work aims to analyze the impact of tourism development on CO_2 emissions by controlling the influence of REN and R&D, focusing on 12 emerging markets and middle-income European countries, including Azerbaijan, Belarus, Bulgaria, Croatia, Hungary, Kazakhstan, North Macedonia, Poland, Romania, Russia, Turkey, and Ukraine, using annual data covering 1999–2020. The countries were chosen for two significant reasons. First, they have shown considerable economic growth over the past few decades. In 1995, they produced over \$1.6 trillion in GDP, and their GDP level has since increased by approximately \$4 trillion in 2021 (World Bank, 2023). Furthermore, these countries had adopted policies to liberalize their economies and integrate with the world economy, resulting in vulnerable geopolitics and external shocks. Hence, to preserve the adverse effects of integration, they require sufficient international reserves. Therefore, tourism becomes a vital way to obtain international reserves. Second, the International Monetary Fund (IMF) classifies emerging markets and middle-income countries by region. We chose emerging markets and middle-income countries in Europe as a sample because these countries have significant international tourist arrivals from other regions. For example, these countries hosted approximately 350 million tourists in 2019, representing approximately 15% of world international tourist arrivals (World Bank, 2023). In addition, these countries have remarkable potential for tourism revenue. According to the World Bank (2023), they received over \$115 billion in 2019. Furthermore, these countries have tried to implement structural reform, but tourism is still a key sector in the development process. Thus, economic growth keeps its priority, and the environment is ignored on behalf of economic growth.

Figure 2 indicates the CO_2 emissions *per capita* in the panel sample of our analyses. It shows us that trends in CO_2 emissions *per capita* follow an identical and stable pattern in most countries. However, the trends in Kazakhstan, Russia, and Poland are different, and they released more CO_2 emissions compared to other countries. Moreover, from Figure 3, it can be seen that Poland, Croatia, Hungary, Turkey, and Russia had an upward trend in tourist arrivals in the last decade, except in 2020. The rest of the countries have a stable trend. Due to the COVID-19 pandemic, the tourism sector has been negatively affected worldwide, but it has recovered progressively to catch up to a pre-pandemic level (World Tourism Organization, 2023).

One of the most crucial tools to achieve sustainable development is innovation. Based on endogenous growth models, R&D activities contribute to economic growth by enhancing technological improvement and innovation (Fernandez et al., 2018). Figure 4 shows that R&D is remarkable in the panel sample countries. Remarkably, Hungary, Poland, Croatia, Russia, and Bulgaria have continuously increased their paths in R&D during 2000–2020. On the contrary, Azerbaijan and Kazakhstan have a relatively decreasing trend. Due to the global financial crisis, R&D has fluctuated in most countries. In addition to promoting economic growth, R&D also positively affects environmental quality by fostering technological advancement in the environmentally friendly energy sector (Kihombo et al., 2021). The increase in REN is essential to reducing CO_2 emissions. The energy transition from traditional sources to renewables is important in combating environmental degradation. As shown in Figure 5, per capita energy consumption from renewables in

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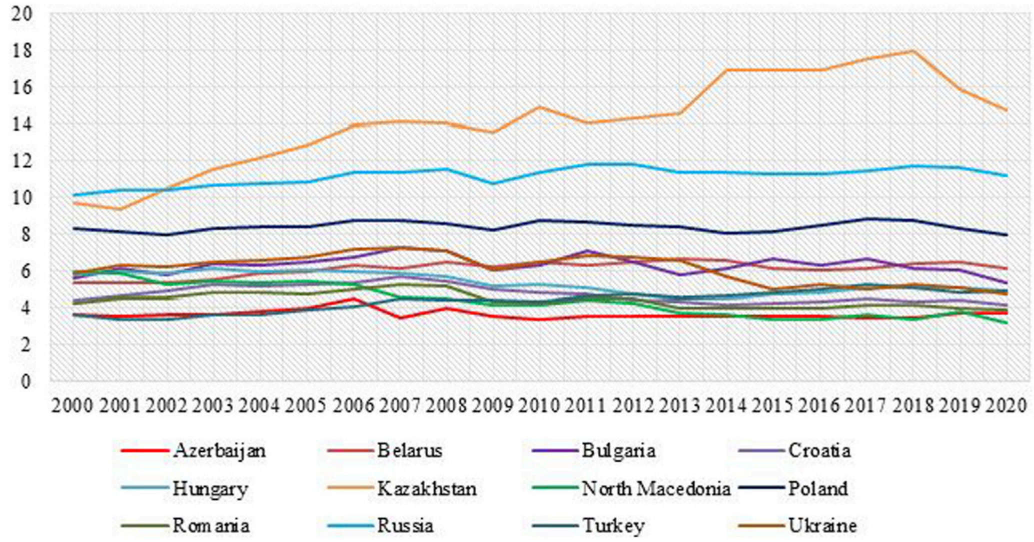

FIGURE 2
CO_2 emissions *per capita* by country (Our World in Data, 2023).

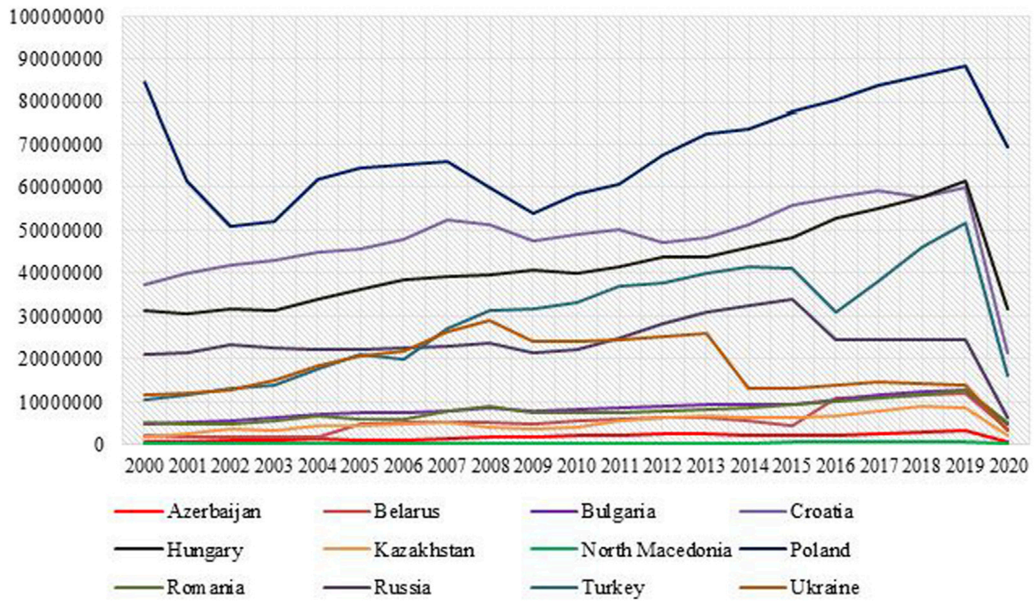

FIGURE 3
Number of international tourist arrivals (World Bank, 2023).

panel sample countries has an increasing trend, except in Azerbaijan and Belarus. The highest REN belongs to Croatia, followed by Russia, Turkey, Romania, Bulgaria, and Poland. Furthermore, Belarus has the lowest value among these countries.

Relying on these aforementioned features, the key issue is whether there is a connection between tourism growth, R&D, REN, and CO_2 emissions in emerging markets and middle-income Europe. One of the characteristic features of these countries is that they are shifting from low- to middle-income status by focusing on industrial activities. However, industrialization puts pressure on the environment in these nations (Hove and Tursoy, 2019). Hence, our study adds to the empirical literature in the following ways: 1) to the best of our knowledge, this is the first study that examines the relationship between tourism development and CO_2 emissions for a panel sample of 12 emerging markets and middle-income European countries; 2) we observe the role of REN and R&D on CO_2 emissions. The prior empirical studies that research the association between tourism development and environmental degradation ignore the potential role of R&D on CO_2 emissions;

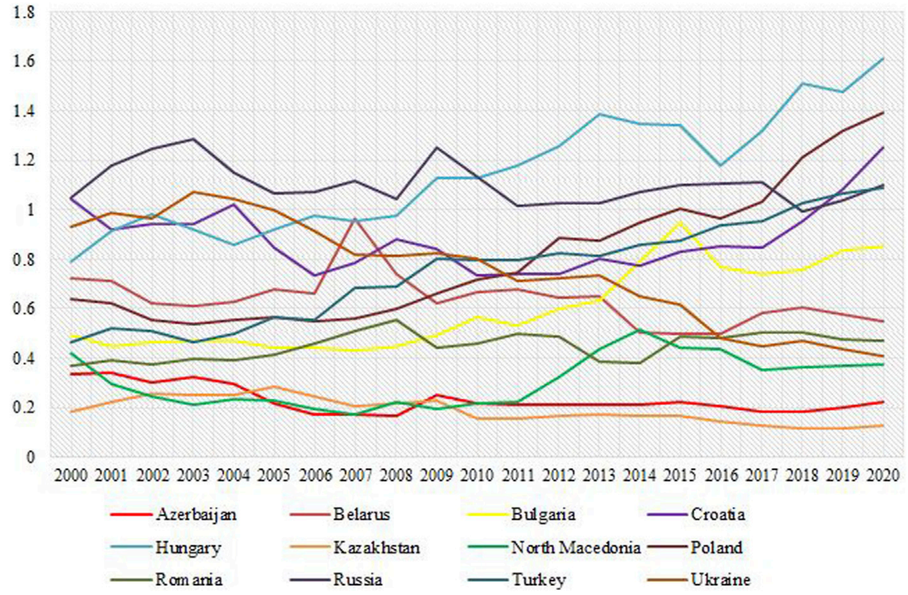

FIGURE 4
R&D expenditure (% of GDP) (World Bank, 2023).

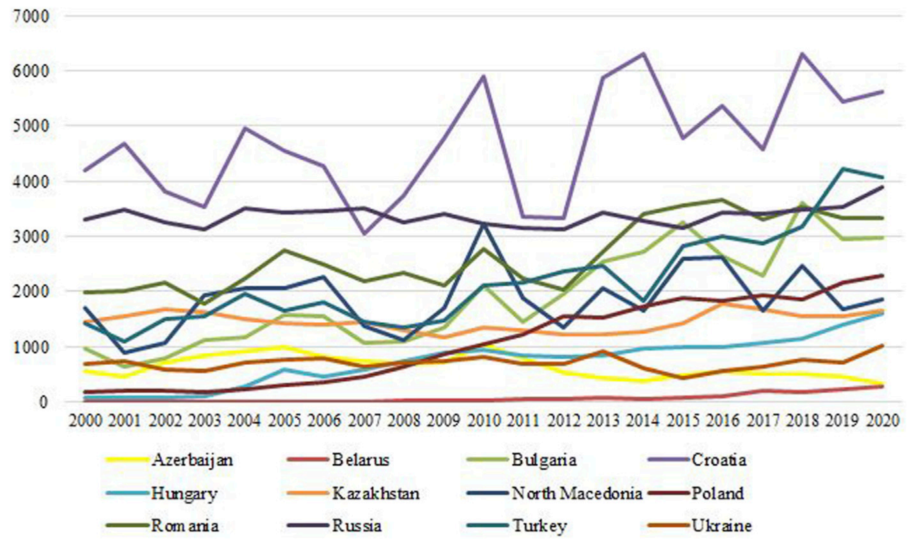

FIGURE 5
Per capita energy consumption from renewables (Our World in Data, 2023).

and 3) in addition to panel ARDL methodology, we performed the Driscoll–Kraay estimator, which is robust to autocorrelation, heteroscedasticity, and cross-sectional dependence.

The remainder of this study is organized as follows: Section 2 briefly reviews the empirical literature on the relationship between CO_2 emissions and independent variables. Section 3 offers data, model, and empirical methodology. Section 4 presents the empirical results and discussion, and Section 5 deals with the conclusion and policy recommendations.

2 Literature review

The relationship between economic growth and environmental degradation is complex. Thus, following the seminal work of Grossman and Kreuger (1991), environmental degradation has become a crucial topic, and a large body of literature has emerged that focuses on the determinants of environmental degradation by considering different indicators, samples, and methodology. Zeraibi et al. (2022) tested the EKC hypothesis using government expenditure and money supply in China from 1980 to 2018. The empirical results indicate that the EKC hypothesis does not hold and that an N-shaped relationship exists between economic growth and environmental degradation. Bandyopadhyay and Rej (2021) researched the validity of the EKC hypothesis in India with annual data for 1978–2019 by controlling the effect of FDI, nuclear energy consumption, and trade openness. The empirical results revealed an inverted N shape exists instead of an inverted U-shaped portrayal. Saqib et al. (2022) examined the validity of the EKC hypothesis for the panel sample of E–7 countries by considering the effect of human development, REN, and patents. They found that the EKC hypothesis exists in these countries. Al-Mulali et al. (2022) examined the EKC hypothesis for the panel group of 170 countries during 2010–2018 and concluded that the EKC hypothesis is valid. Pata and Kartal (2023) tested both the EKC and load capacity curve (LCC) hypotheses in South Korea by using data from 1977 to 2018 and investigating the role of renewable and nuclear energy consumption. They confirmed the validity of the EKC and LCC hypotheses. Another investigation conducted by Genç et al. (2022) studied the EKC hypothesis in Turkey over the period 1980–2015 and considered the effect of the volatility of economic growth and energy consumption. They demonstrated that the EKC hypothesis is valid, indicating an inverted U-shaped relationship between economic growth and environmental degradation. Aydin et al. (2023) analyzed the EKC hypothesis for the panel sample of G7 countries spanning 1990–2018 by considering the effects of nanotechnology and REN. The empirical outcomes pointed out that the EKC hypothesis holds only in the United States. In most studies, the validation of the EKC is confirmed for different countries/country groups (Ntim-Amo et al. (2022) for Ghana; Mahmood (2023) for Latin America; Voumik et al. (2023) for BRICS countries; Kostakis et al. (2023) for MENA countries; and Murshed et al. (2022) for South Asian countries).

In contrast, it must be noted that there is no consensus about the validity of the EKC hypothesis. For instance, Pata and Yurtkuran (2023) showed that the EKC hypothesis is valid only for Switzerland and Denmark but not for the Netherlands, Sweden, and Austria. In the case of the top 10 innovative economies, Gormus and Aydin (2020) documented that the EKC hypothesis exists only in Israel. Hossain et al. (2023) verified the N-shaped relationship for the case of CO_2 emissions but did not confirm it for the case of ecological footprint in India. Pata and Tanriover (2023) tested the EKC and LCC hypotheses for the top ten tourism destinations and concluded that both are invalid in these countries. It is seen that the EKC hypothesis is researched with different indicators. The previously summarized studies show that the validity of the EKC hypothesis differs by sample, method, and variable. Thus, first, we propose Hypothesis 1 in terms of the validity of the EKC.

Hypothesis 1: *The EKC hypothesis is valid in our panel sample countries.*

In order to examine the determining factors of environmental degradation, the tourism sector is nowadays one of the most crucial and controversial issues for countries. Hence, a large body of literature examines the validity of the EKC hypothesis and the impact of tourism development on environmental degradation. For instance, Villanthenkodath et al. (2022) reported that tourism development causes an increase in environmental degradation in India. Usman et al. (2022) documented that tourism development increases CO_2 emissions in South Asian economies. Destek and Aydın (2022) found that although tourism contributes to economic growth, it also damages environmental quality in the 10 top visited countries. Fethi and Senyucel (2021) investigated the impact of tourism on CO_2 emissions using panel data from the top 50 tourism destination nations. They concluded that tourism exaggerates environmental degradation. Kumail et al. (2020) studied the relationship between CO_2 emissions, tourism, technological improvement, and economic growth with time series data for Pakistan from 1990 to 2017. The empirical findings indicate that tourism harms environmental quality. Isik et al. (2020) tested the tourism-induced EKC hypothesis for G-7 countries from 1995 to 2015. The augmented mean group (AMG) estimator results show that the EKC hypothesis is valid in France. Furthermore, tourism positively affects CO_2 emissions in Italy and negatively in Canada. Alola et al. (2020) investigated the effect of energy imports by considering the role of international tourism development in coastline Mediterranean countries (CMCs) spanning 1995–2013. They reported that although tourism receipts are negatively associated with CO_2 emissions, international tourist arrivals are positively related to CO_2 emissions. Zha et al. (2020) experimented with the connection between tourism and environmental quality in Chinese provinces during 2005–2016 using a decomposition technique. They reported that the scale effect of tourism is the main contributing factor to CO_2 emissions. However, the technical effect has a remarkable impact on reducing CO_2 emissions. Similar outcomes are also documented by Rahman et al. (2022b) for Malaysia, Salahodjaev et al. (2022) for Europe and Central Asia, Cevik (2023) for 15 Caribbean countries, Guan et al. (2022) for G-10 countries, Balsalobre-Lorente et al. (2023) for 36 OECD countries, and Satrovic and Adedoyin (2023) for Southeastern Europe countries. The positive impact of tourism on environmental degradation verifies that as the tourism sector develops, usage of energy consumption, natural resources, and depletion of biocapacity increases (Guan et al., 2022). On the other hand, another perspective on the relationship between tourism development and environmental degradation points out that tourism contributes to developing environmental quality. In this framework, Ghosh et al. (2022) researched the effect of economic complexity and tourism development on environmental degradation in G7 countries and showed that tourism development decreases environmental degradation. Ohajionu et al. (2022) observed that tourism development is negatively associated with CO_2 emissions in Mediterranean countries. Wei and Lihua (2023) concluded that tourism arrivals reduce CO_2 emissions in ASEAN countries. Wei and Ullah (2022) demonstrated that tourism development has a negative impact on CO_2 emissions in Asian economies. Furthermore, Isaeva et al. (2022) assessed a one-way causal relationship running from tourism to CO_2 emissions in post-communist countries. Empirical studies show no consensus on the impact of tourism development on environmental degradation. Thus, we propose Hypothesis 2.

Hypothesis 2: *Tourism increases CO_2 emissions in our panel sample countries.*

REN is the primary aim of the SDGs. In order to achieve the increasing utilization of REN, most countries struggle to develop new policies. Furthermore, the relevant literature clearly defines and verifies that REN is negatively associated with environmental degradation. In this context, Magazzino et al. (2022) studied the relationship between REN, CO_2 emissions, and GDP in Scandinavian countries and revealed that REN has a negative impact on CO_2 emissions. Dagar et al. (2022) investigated the determinants of the ecological footprint in 38 OECD countries and concluded that REN negatively affects the ecological footprint. Suki et al. (2022) scrutinized the effect of REN and technological innovation on environmental degradation in Malaysia. The authors' results show that both variables have a negative impact on environmental degradation. Another study conducted by Miao et al. (2022) examined the effect of REN and globalization on the ecological footprint in newly industrialized countries and approved that REN reduces the ecological footprint. In a recent study, Shah et al. (2023) researched the determinants of pollution in Japan with quarterly data covering the period 1970Q1–2019Q4. They found that the impact of FDI, economic growth, REN, economic complexity, and trade differs by quantiles. Economic complexity, economic growth, FDI, and trade positively affect CO_2 emissions. REN has a negative effect on CO_2 emissions in the 0.60–0.90 quantiles and a positive impact in the 0.95 quantile. In addition, some studies [Chien (2022) for N-11 economies; He et al. (2022b) for China; Shang et al. (2022) for ASEAN countries; Wang et al. (2022) for G-7; Awosusi et al. (2022) for Colombia; and Raihan et al. (2023) for Indonesia] explored the negative impact of REN on environmental degradation. In line with empirical approaches, we expected the negative effect of REN on CO_2 emissions and proposed Hypothesis 3.

Hypothesis 3: *REN decreases CO_2 emissions in our panel sample countries.*

As previously discussed, R&D is an essential component of economic growth and technological improvement and is closely associated with REN. Since R&D activities develop in the economy, specifically in the energy-related sector, energy efficiency and opportunities for REN sources also increase. Hence, R&D does not only promote economic growth but also contributes to environmental quality. Several studies have reported that R&D positively impacts environmental quality. Mehmood et al. (2022) examined the association between renewable and non-renewable energy, R&D, economic growth, and environmental degradation in ASEAN countries spanning 1990–2016. The FMOLS and DOLS results indicate that R&D contributes to a decreased ecological footprint. Shahzadi et al. (2022) investigated the causal relationship between R&D, REN, forest area, and GHG emissions for 17 developed and 23 developing economies over 1995–2018. The causality test results verify the feedback causality between total patents and GHG emissions and one-way relationship between GHG emissions and R&D in developed countries. In addition, a one-way causal relationship exists between GHG emissions and total patents in developing countries. Kihombo et al. (2021) analyzed the effect of R&D, financial development, and environmental deterioration in West Asia and Middle East countries between 1990 and 2017. The empirical outcomes confirm that R&D lowers CO_2 emissions. Another study conducted by Koçak and Ulucak (2019) revealed that there is no meaningful relationship between energy-related R&D and CO_2 emissions in the 19 high-income economies of the OECD. Cheng et al. (2021) applied the panel quantile regression method to observe the role of technological innovation on CO_2 emissions for the panel sample of the 35 OECD member countries from 1996 to 2015. The authors used patent development as a proxy for technological innovation. The empirical findings show that overall technological innovation negatively affects CO_2 emissions, but the impacts differ across quantiles. Alam et al. (2019) examined the effects of corporate R&D investment on environmental deterioration in G-6 countries through firm-level data covering 2004–2016. The authors' empirical findings suggest that R&D investment positively affects environmental quality. Godil et al. (2021) utilized the QARDL method to analyze the effect of R&D, globalization, institutional governance, financial development, and energy consumption on energy utilization in the case of India. The quarterly data analysis is performed, and the results show that R&D negatively affects energy utilization. Sinha et al. (2020) used the technological progress index and R&D indicators as proxies for technological innovation to reveal the potential long-run relationship between technological innovation and environmental quality in N-11 countries. The empirical results indicate that technological development harms environmental quality by causing pollution. According to empirical analysis results studied by Ullah et al. (2021), patents and trademarks do not significantly affect CO_2 emissions in the long run, but negative shocks in patents cause a decrease in environmental quality in Pakistan. The important part of the empirical studies demonstrates that R&D has a negative impact on environmental degradation. Therefore, we propose Hypothesis 4 on the impact of R&D on CO_2 emissions.

Hypothesis 4: *R&D decreases CO2 emissions in our panel sample countries.*

The summary of the validity of the EKC hypothesis and how tourism development, R&D, and REN influence environmental degradation is provided in Table 1. As shown in Table 1, it is clear that the relationship between tourism development and environmental degradation is not clearly defined. Hence, it requires more empirical findings regarding the relationship between tourism development and environmental degradation. Moreover, tourism is a dynamic sector, and well-developed tourism destinations are needed for more energy consumption and technology usage. Based on these, to the best of our knowledge, the studies on the nexus between tourism development and environmental degradation ignore the role of R&D and REN simultaneously. Hence, to fill this gap, this study aims to investigate the relationship between tourism development and environmental degradation by controlling the role of R&D and REN in 12 emerging markets and middle-income Europe.

3 Data, model, and empirical methodology

This study focuses on the impact of tourism development on CO_2 emissions in 12 emerging markets and middle-income European countries, including Azerbaijan, Belarus, Bulgaria,

TABLE 1 Empirical literature review.

Nexus between tourism and CO_2 emissions			
Study	Sample	Period	Result
Razzaq et al. (2023)	Top 10 GDP countries	1995–2018	TD causes an increase in CO_2 emissions
Pata et al. (2023a)	ASEAN countries	1995–2018	TD causes an increase in pollution
Liu et al. (2022)	70 countries	2000–2017	TD increases the environmental quality
Pata and Balsalobre-Lorente (2022)	Turkey	1965–2017	TD decreases environmental load capacity
Musa et al. (2021)	EU-28 countries	2002–2014	TD harms the environmental quality
Jayasinghe and Selvanathan (2021)	India	1991–2018	TD causes a dirty environment
Gaoa and Zhang (2021)	Mediterranean countries	1995–2010	There is a two-way causality relationship between TD and air pollutants
Wei and Lihua (2023)	ASEAN countries	1995–2018	Effects of TD vary across quantiles
Haseeb and Azam (2021)	Low-, lower-middle-, upper-middle-and high-income countries	1995–2015	TD pollutes more in low-income countries compared to others
Sharif et al. (2020)	China	1978Q1–2017Q4	TD positively affects the environmental quality
Selvanathan et al. (2021)	South Asia	1990–2014	TD stimulates CO_2
Leitão and Lorente (2020)	European Union	1995–2014	TD promotes environmental quality by decreasing CO_2
Kongbuamai et al. (2020)	ASEAN countries	1995–2016	TD promotes the environmental quality
Zhang and Liu (2019)	10 Asian countries	1995–2014	TD worsens the environmental quality
Nexus between economic growth and CO_2 emissions			
Voumik et al. (2022)	34 countries in the EU	1990–2021	There is a U-shaped causality relationship between economic growth and CO_2
Manga and Cengiz (2020)	Turkic Republics	1991–2014	There is an N-shaped relationship between economic growth and CO_2
Raihan et al. (2022)	Argentina	1990–2019	Economic growth is positively associated with CO_2
Jahanger et al. (2022)	78 developing economies	1990–2016	EKC hypothesis is valid
Pata and Samour (2022)	France	1977–2017	EKC hypothesis is not valid
Massagony and Budiono (2022)	Indonesia	1965–2020	EKC hypothesis is not valid. Economic growth increases CO_2 in the long-run
Sun et al. (2021)	88 BRI countries	1995–2015	EKC hypothesis is valid
Murshed et al. (2021)	Bangladesh, India, Pakistan, Sri Lanka, Nepal, and Bhutan	1980–2016	EKC hypothesis is valid
Nosheen et al. (2021)	Asian Economies	1995–2017	EKC hypothesis is valid
Xiangyu et al. (2021)	United States	2000–2018	Economic growth positively affects CO_2 in lower quantiles but negatively in high quantiles
Abbasi et al. (2021)	Top 18 economic complexity index countries	1990–2019	Gross domestic products positively affect CO_2
Table 1 Summary of empirical works			
Jing et al. (2021)	18 Mediterranean countries	1995–2010	EKC hypothesis is valid
Pata and Caglar (2021)	China	1980–2016	There is a U-shaped relationship between economic growth and environmental degradation
Balsalobre-Lorente et al., (2020)	EU-28	1995–2014	GDP is positively related to CO_2
Adebayo (2020)	Mexico	1971–2016	EKC hypothesis is valid

(Continued on following page)

TABLE 1 (*Continued*) Empirical literature review.

Nexus between tourism and CO_2 emissions			
Study	Sample	Period	Result
Nexus between economic growth and CO_2 emissions			
Begum et al. (2015)	Malaysia	1980–2009	There is a U-shaped causality relationship between economic growth and CO_2
Manga et al. (2023)	Seven emerging Asian countries	1970–2014	EKC hypothesis is valid in China and Thailand
Nexus between renewable energy and CO_2 emissions			
Cengiz and Manga (2021)	OECD countries	1980–2014	REN ↔ CO_2 in Canada and Italy; REN → CO_2 in Greece and Ireland; CO_2 → REN in Austria, Switzerland, and United States
Mirziyoyeva and Salahodjaev (2022)	Top carbon-intense countries	2000–2015	REN negatively affects CO_2
Salahodjaev et al. (2022)	Europe and Central Asia	1990–2015	REP causes a decrease in CO_2
Khezri et al. (2022)	29 Asia–Pacific countries	2000–2018	REN negatively affects CO_2 in countries that have lower economic complexity
Chen et al. (2022)	97 countries	1995–2015	REN negatively affects CO_2 after a threshold level
Cengiz and Manga (2022)	12 Latin American and Asian countries	1990–2015	REN has a negative effect on CO_2
Kuldasheva and Salahodjaev (2022)	Rapidly urbanizing countries	2000–2015	REN has a negative effect on CO_2
Khan and Ahmad (2021)	Developed countries of Europe and developing countries of Asia–Pacific	2000–2020	REN positively impacts CO_2 in the Asia–Pacific countries, whereas it negatively affects CO_2 in European countries
Jamil et al. (2022)	G-20 countries	1990–2019	REN negatively affects CO_2
Radmehr et al. (2021)	European Union	1995–2014	REN is negatively related to CO_2 in Bulgaria, Czechia, France, Ireland, Netherlands, Slovakia, and Sweden
Aziz et al. (2020)	BRICS countries	1995–2018	REN has a negative impact on CO_2
Ben Jebli et al. (2019)	22 Central and South American countries	1995–2010	REN negatively affects CO_2
Cengiz and Manga (2023)	Central and Eastern European Countries	1995–2021	REN positively impacts CO_2; on the contrary, CO_2 negatively affects REN
Nexus between R&D and CO_2 emissions			
Pata et al. (2023b)	15 NATO countries	1991–2018	R&D has a positive effect on CO_2
Xu and Khan (2023)	G-7 Economies	1990–2020	R&D has a negative effect on CO_2
Zhuang et al. (2023)	China	2003–2018	Technological innovation has a negative effect on CO_2
Mamkhezri and Khezri (2023)	54 countries	2003–2017	R&D investment is negatively associated with CO_2
Nazneen et al. (2023)	64 BRI countries	1995–2019	Technological innovation is negatively associated with CO_2
Ni et al. (2022)	Selected developed countries	1990–2020	Renewable energy in the R&D sector reduces CO_2
Mentel et al. (2022)	26 countries	1995–2015	An increase in R&D reduces CO_2
Alam et al. (2020)	30 OECD	1996–2013	R&D is negatively associated with CO_2
Wang and Zhang (2020)	BRICS countries	1996–2014	An increase in R&D reduces CO_2
Petrovic and Lobanov (2020)	16 OECD countries	1981–2014	R&D investment has a negative effect on CO_2
Wang and Wang (2019)	United States	1997–2015	The intensity and efficiency of R&D mitigate decoupling economic growth from CO_2
Ganda (2019)	Selected OECD	2000–2014	R&D has a negative impact on CO_2
Fernandez et al. (2018)	European Union (15), United States, and China	1990–2013	R&D contributes to a decrease in CO_2 emissions

TD, REN, REP, and R&D denote tourism development, renewable energy consumption, renewable electricity production, and research and development, respectively.
Source: authors' compilation.

TABLE 2 Detailed description of variables.

Variable	Definition	Unit	Source
CO_2	CO_2 emissions	Metric tons *per capita*	Our World in Data (2023)
GDP	GDP *per capita*	Constant price 2015$	World Bank (2023)
TA	International tourist arrivals	Number of arrivals	World Bank (2023)
REN	Renewable energy consumption	Per capita energy consumption from renewables	Our World in Data (2023)
RD	Research and development expenditure	% of GDP	World Bank (2023)

Source: authors' compilation.

Croatia, Hungary, Kazakhstan, North Macedonia, Poland, Romania, Russia, Turkey, and Ukraine, using annual data covering 1999–2020. In order to find out the relationship between tourism arrival development and CO_2 emissions, gross domestic *per capita*, REN, and R&D are control variables influencing CO_2 emissions. Furthermore, we included the gross domestic *per capita* square to check the validity of the EKC hypothesis in these countries. Table 2 identifies the data, variables, unit of measurement, and their sources.

Following the study of Rahaman et al. (2022a) to examine the relationship between tourism development and CO_2 emissions, we construct an econometric model as follows:

$$\mathrm{CO}_{2\mathrm{it}} = \mathrm{f}\left(\mathrm{GDP}_{\mathrm{it}}, \mathrm{GDP}^2_{\mathrm{it}}, \mathrm{TA}_{\mathrm{it}}, \mathrm{REN}_{\mathrm{it}}, \mathrm{RD}_{\mathrm{it}}\right). \quad (1)$$

In Eq. 1, $\mathrm{CO}_{2\mathrm{it}}$, $\mathrm{GDP}_{\mathrm{it}}, \mathrm{GDP}^2_{\mathrm{it}}, \mathrm{TA}_{\mathrm{it}}, \mathrm{REN}_{\mathrm{it}}, \text{and } \mathrm{RD}_{\mathrm{it}}$ denote carbon dioxide emissions *per capita*, gross domestic products *per capita*, the square of gross domestic products *per capita*, international tourist arrivals, *per capita* energy consumption from renewables, and RD, respectively.

The logarithmic function of Eq. 1 can be rewritten as follows:

$$\begin{aligned}\mathrm{lnCO}_{2\mathrm{it}} &= \alpha_0 + \beta_1 \mathrm{lnGDP}_{\mathrm{it}} + \beta_2 \mathrm{lnGDP}^2_{\mathrm{it}} + \beta_3 \mathrm{lnTA}_{\mathrm{it}} + \beta_4 \mathrm{lnREN}_{\mathrm{it}} \\ &+ \beta_5 \mathrm{lnRD}_{\mathrm{it}} + \mathrm{u}_{\mathrm{it}}, \end{aligned} \quad (2)$$

where β's are slope coefficients, α is a constant term, and u_{it} is the error term.

3.1 Econometric methodology

This study employed different estimators and causality tests to obtain more reliable and consistent findings.

3.1.1 Cross-sectional dependence test

There are four crucial econometric steps in our study. In the first step, we check the possible cross-sectional dependency among variables. In doing so, Breusch and Pagan's (1980) LM test, Pesaran's (2004) scaled LM and CD tests, and Baltagi et al.'s (2012) bias-corrected scaled LM are performed as the cross-sectional dependence (CSD) tests. The results of the CSD tests determine which unit root tests should be used.

3.1.2 CIPS unit root test

After validating the CSD test, it requires a second-generation unit root. Therefore, we perform a cross-sectional augmented Im, Pesaran, and Shin (CIPS) panel unit root test proposed by Pesaran (2007). The CIPS statistics can be computed through the cross-sectional augmented Dickey–Fuller (CADF) test statistic. The CADF test statistics can be written as follows (Murshed and Dao, 2022):

$$\Delta y_{it} = \alpha_i + b_i y_{i,t-1} + c_i \bar{y}_{t-1} + \sum_{j=0}^{s} d_{ij} \Delta \bar{y}_{t-j} + \sum_{j=1}^{s} \delta_{ij} \Delta \bar{y}_{i,t-j} + \varepsilon_{it}. \quad (3)$$

The T-statistics obtained from the CADF statistics can be used in the CIPS statistics as follows:

$$CIPS = \frac{1}{N} \sum_{i=1}^{N} \mathrm{CADF}_i. \quad (4)$$

3.1.3 Panel ARDL estimation technique

In order to estimate the long-run relationship between CO_2 emissions, GDP, GDP^2, TA, REN, and RD, we utilize the panel ARDL estimation technique proposed by Pesaran et al. (2001). The panel ARDL approach has some advantages. First, the panel ARDL method offers an advantage in econometric analyses in that series are not required to be integrated in the same order. However, the series in the model should be I(0), I(1), or a combination of both (Darsono et al., 2022); second order cannot be used in the model (Massagony and Budiono, 2023). Hence, it can be performed in cases of no co-integration (Simionescu et al., 2021). Second, it provides reliable and robust results in small samples and simultaneously allows short- and long-run estimation (Wang and Huang, 2022). Third, it considers the cross-sectional heterogeneity in the model (Tenaw and Beyene, 2021; Pata et al., 2023b). The ARDL format of Eq. 1 can be expressed as follows:

$$\begin{aligned}\Delta lnCO2_{it} &= \alpha_0 + \sum_{j=1}^{m} \beta_{i,j} \Delta lnCO2_{i,t-j} + \sum_{j=1}^{m} \gamma_{i,j} \Delta lnGDP_{i,t-j} \\ &+ \sum_{j=1}^{m} \delta_{i,j} \Delta lnGDP^2_{i,t-j} + \sum_{j=1}^{m} \theta_{i,j} \Delta lnTA_{i,t-j} \\ &+ \sum_{j=1}^{m} \vartheta_{i,j} \Delta lnREN_{i,t-j} + \sum_{j=1}^{m} \varphi_{i,j} \Delta lnRD_{i,t-j} + \aleph lnCO2_{i,t-1} \\ &+ \omega_1 lnGDP_{i,t-1} + \omega_2 lnGDP^2_{i,t-1} + \omega_3 lnTA_{i,t-1} \\ &+ \omega_4 lnREN_{i,t-1} + \omega_5 lnRD_{i,t-1} + \varepsilon_{it}, \end{aligned} \quad (5)$$

where Δ is the first difference operator, β, γ, δ, θ, ϑ, and φ are short-run coefficients, ω_1, ω_2, ω_3, ω_4, and ω_5 are long-run coefficients, and $\aleph$ is the coefficient of the speed of adjustment (Demir, 2022).

TABLE 3 Descriptive statistics.

	$lnCO_2$	lnGDP	$lnGDP^2$	lnTA	lnREN	lnRD
Mean	1.786362	8.769003	77.21592	16.068	6.951655	−0.58941
Median	1.733948	8.872613	78.72327	16.267	7.292528	−0.47603
Maximum	2.884745	9.621302	92.56945	18.305	8.749543	0.47478
Minimum	1.147402	7.191103	51.71197	11.502	1.695663	−2.147035
Standard deviation	0.407894	0.567203	9.702665	1.580	1.382148	0.6161
Skewness	0.728558	−0.784066	−0.658072	−0.875	−1.760686	−0.619994
Kurtosis	2.835909	2.89835	2.661458	3.208818	6.299477	2.459624
Jarque–Bera	23.65125	27.16306	20.31528	34.16697	256.1526	20.12534
Observations	264	264	264	264	264	264

Source: authors' own calculations.

3.1.4 Fixed- and random-effects model

In order to obtain a clear association between variables, we also employ fixed- and random-effects estimators. In order to choose between fixed- and random-effects results, the Hausman test is considered. Hence, the Hausman test is used to decide the appropriate estimator, and the hypothesis is as follows (Sheytanova, 2014):

H0: Random effects are appropriate.

H1: Fixed effects are appropriate.

3.1.5 Dumitrescu–Hurlin causality test

Following the long-run estimation, the Dumitrescu–Hurlin (D–H) causality test is employed to reveal the causality relationship between CO_2 emissions, GDP, GDP^2, TA, REN, and RD for selected panel groups. Dumitrescu and Hurlin's (2012) test depends on Wald test statistics and can be formulated as follows (Razzaq et al., 2023):

$$y_{i,t} = \sum_{k=1}^{K} \delta_i^{(k)} Y_{i,t-k} + \sum_{k=1}^{K} \vartheta_i^{(k)} X_{i,t-k} + \varepsilon_{i,t}, \quad (6)$$

where K is the lag orders and $\delta_i^{(k)}$ and $\vartheta_i^{(k)}$ are slope parameters that vary between groups. One of the most important advantages of this method is that it considers CSD (Dumitrescu and Hurlin, 2012). Considering CSD provides robust and reliable results.

4 Empirical results and discussion

Before providing empirical analyses, descriptive statistics can show the general properties of the variables. All variables' descriptive statistics are summarized in Table 3.

Table 3 presents descriptive statistics of variables for the period 1999–2020. The variable set comprises CO_2, GDP, GDP^2, TA, REN, and RD for selected panel groups. GDP^2 has the highest standard deviation; it is followed by tourist arrivals (TAs), REN, R&D expenditure, gross domestic product (GDP), and CO_2 emissions.

In panel data econometrics, CSD is crucial. In the era of globalization, interdependency is high across countries, and any development in one country can quickly spread to others. According to the findings from Table 4, the null hypothesis of no CSD among countries for all variables is rejected. Thus, we obtained CSD, indicating that a shock in a country affects the rest of the world. Moreover, we performed Pesaran and Yamagata's (2008) delta (Δ) and delta (Δ)adj to test the slope homogeneity. The results show that the slope coefficients are heterogeneous. Therefore, after obtaining CSD, it is required to apply the second-generation panel unit root test, which concerns CSD. For this, we employ the CIPS unit root test, and the findings are documented in Table 5.

The CIPS unit root test results indicate that lnGDP and $lnGDP^2$ are stationary at the first level, while lnCO2, lnTA, lnREN, and lnRD are stationary at the first difference. In other words, lnGDP and $lnGDP^2$ are integrated at I(0), whereas lnCO2, lnREN, lnRD, and TO are integrated at I(1). The mixed order of integration allows employing the panel ARDL estimation technique to investigate the long-run relationship between variables. The panel ARDL technique includes two estimators: a mean group (MG) and a pooled mean group (PMG). The Hausman test results determine the choice of MG or PMG as an efficient estimator. The Hausman test results are documented in Table 6.

The Hausman test results indicate that PMG is more efficient than MG. Thus, we concentrate on the results of the PMG estimator. Therefore, the panel ARDL/PMG long-run results are offered in Table 7.

In addition to panel ARDL, the Driscoll and Kraay (1998) estimator (both for fixed and random effects) is employed to obtain further evidence in terms of the relationship between variables. The main advantage of the Driscoll–Kraay estimator is that it considers autocorrelation, heteroscedasticity, and CSD (Beylik et al., 2022; Haseeb et al., 2023). The fixed- and random-effects results based on the Driscoll–Kraay estimators are documented in Table 8.

The Hausman test results from Table 8 indicate that the null hypothesis of random effects is adequate and cannot be rejected at a 1% significance level. Hence, it represents that the random-effects results must be considered.

TABLE 4 CSD test results.

	$lnCO_2$	lnGDP	$lnGDP^2$	lnTA	lnREN	lnRD
Breusch–Pagan LM	407.4185*** [0.000]	1243.821*** [0.000]	1239.381*** [0.000]	677.0439*** [0.000]	360.7344*** [0.000]	458.3072*** [0.000]
Pesaran scaled LM	29.71667*** [0.000]	102.5162*** [0.000]	102.1297*** [0.000]	53.18454*** [0.000]	25.65334*** [0.000]	34.14596*** [0.000]
Bias-corrected scaled LM	29.43095*** [0.000]	102.2305*** [0.000]	101.844*** [0.000]	52.89883*** [0.000]	25.36762*** [0.000]	33.86024*** [0.000]
Pesaran CD	6.839918*** [0.000]	35.19073*** [0.000]	35.12315*** [0.000]	23.59073*** [0.000]	11.14794**** [0.000]	−1.796747* [0.0724]
Slope heterogeneity test						
		Statistics		*p*-value		
Delta (Δ) test		11.107		0.000		
Delta $(\Delta)_{adj}$ test		13.451		0.000		

Numbers in brackets are *p*-values. * and *** indicate the statistical significance at 10% and 1%, respectively.
Source: authors' own calculations.

TABLE 5 CIPS unit root test results.

Variable	Levels	1st difference	Order of integration
	Trend and constant	Trend and constant	
$lnCO_2$	2.6895	3.2064***	I(1)
lnGDP	−3.1177***	-	I(0)
$lnGDP^2$	−3.1190**	-	I(0)
lnTA	−2.6314	−3.7344***	I(1)
lnREN	−2.2332	−2.8903**	I(1)
lnRD	−2.4314	−2.832*	I(1)

Critical values for 10%, 5%, and 1% level are −2.71, −2.84, and −3.09, respectively. *, **, and *** indicate the statistical significance level at 10%, 5%, and 1%, respectively.
Source: authors' own calculations.

TABLE 6 Hausman test results.

Estimator	Chi-square	Probability
MG, PMG	1.1929	0.9456

Source: authors' own calculations.

The panel ARDL results indicate that economic growth has a long-term negative and substantial impact on CO_2 emissions *per capita*. An increase of 1% in economic growth causes a 0.691% decrease in CO_2 emissions. To check the validity of the EKC hypothesis, we included GDP^2 in the model. The result shows a positive and significant coefficient of GDP^2 on CO_2 emissions *per capita*. It implies that the EKC hypothesis is invalid in our panel sample and that there is a U-shaped relationship between economic growth and CO_2 emissions *per capita*. Our result for checking the validity of the EKC hypothesis is consistent with studies of Begum et al. (2015), Balsalobre-Lorente et al. (2023), Voumik et al. (2022), Abbasi et al. (2021), Pata and Caglar (2021), and Massagony and Budiono (2023). The U-shaped relationship between economic growth and CO_2 emissions can be caused by increasing green technologies at the beginning of the production process; however, in the later stage of economic growth, non-renewable energy sources are used, and environmental degradation increases (Voumik et al., 2022). In addition, tourist arrivals negatively affect CO_2 emissions *per capita* in the long run. For example, an increase of 1% in tourist arrivals causes a 0.037% decrease in CO_2 emissions *per capita*. The negative parameter of tourist arrivals on CO_2 emissions is in line with Leitão and Lorente (2020), Pata and Balsalobre-Lorente (2022), Sharif et al. (2020), and Kongbuamai et al. (2020).

REN also negatively affects CO_2 emissions *per capita* in the long run, as expected. An increase of 1% in REN reduces CO_2 emissions *per capita* by 0.031%. The negative result of REN on CO_2 emissions *per capita* is in line with Mirziyoyeva and Salahodjaev (2022), Aziz et al. (2020), Salahodjaev et al. (2022), Jamil et al. (2022), and Kuldasheva and Salahodjaev (2022). REN plays an important role in sustainable development, which is crucial for combating environmental degradation. Using REN such as hydro, wind, and solar sources instead of non-renewable energy preserves environmental quality. Hence, REN becomes a key factor in a cleaner environment (Aziz et al., 2020). Likewise, R&D has a decreasing effect on CO_2 emissions *per capita*. An increase of 1% in R&D corresponds to a decrease of 0.143% in CO_2 emissions. Our finding supports the results of Alam et al. (2020), Wang and Zhang

TABLE 7 Panel ARDL/PMG long-run results.

Dependent variable: CO_2 emissions *per capita*				
Variable	Coefficient	Standard error	t-statistic	Probability
lnGDP	−0.6917	0.3872	−1.7863	0.0767
$lnGDP^2$	0.0497	0.0220	2.2555	0.026
lnTA	−0.0374	0.0105	−3.5359	0.0006
lnREN	−0.0315	0.0176	−1.7891	0.0762
lnRD	−0.1437	0.0350	−4.1023	0.0001
ECT(-1)	−0.39675	0.1609	−2.4736	0.0148

The lag length is selected as 2 based on the Schwarz information criterion.
Source: authors' own calculations.

TABLE 8 Driscoll–Kraay estimator results for fixed and random effects.

Variables	Fixed effects		Random effects	
	Coefficient	Standard error	Coefficient	Standard error
lnGDP	−2.5409*** [0.000]	0.4019	−2.5286*** [0.000]	0.4381
$lnGDP^2$	0.1518*** [0.000]	0.0246	0.1511*** [0.000]	0.0260
lnTA	0.0872*** [0.000]	0.0206	0.0866*** [0.000]	0.0172
lnREN	−0.0413*** [0.005]	0.0132	−0.0408*** [0.002]	0.0118
lnRD	−0.1245*** [0.000]	0.0233	−0.1255*** [0.000]	0.0269
Constant	11.1560*** [0.000]	1.8327	11.1060*** [0.000]	1.7921
Hausman test	Prob > chi2 = 0.9456			
Robust Hausman test	Prob > chi2 = 1.0000			
	AC Wooldridge test: F-statistics (1, 11): 34.938 [0.000]			
	Heteroscedasticity test for random effects: Levene–Brown–Forsythe test			
	Test statistics		Probability	
	W0 = 15.001655		0.000	
	W50 = 10.788044		0.000	
	W10 = 14.041468		0.000	

The values in [] denote probability.
Source: authors' own calculations.

(2020), Mentel et al. (2022), Xu and Khan (2023), and Mamkhezri and Khezri (2023). The negative impact of R&D on CO_2 emissions is related to improving energy efficiency and energy-saving technologies, which require less energy consumption (Wang and Wang, 2019). Thus, R&D not only facilitates the installation and utilization of REN (Alam et al., 2020) but also provides technological innovation incentives to use environmentally friendly technology. Furthermore, the finding indicates that the coefficient of the error correction term (ECT) is negative and statistically significant. It proves a speed of adjustment from the short-run to the long-run equilibrium path among variables.

Furthermore, the Driscoll–Kraay estimators' results (for fixed and random effects) regarding parameters' signs are consistent with panel ARDL except TA. Since we have determined that random effects are appropriate for our model, the coefficients of the random effects should be interpreted. For this purpose, the random-effects model shows that an increase of 1% in GDP causes a 2.52% decrease in CO_2 emissions. However, the impact of the GDP^2 positively affects CO_2 emissions. An increase of 1% in the GDP^2 increases CO_2 emissions by 0.15%. When considered together with the signs of the lnGDP and $lnGDP^2$, it is approved that the EKC hypothesis is invalid in these countries, and a U-shaped association exists between economic growth and CO_2 emissions. Therefore, the U-shaped association between economic growth and CO_2 emissions rejects our first hypothesis that the EKC hypothesis is valid in our panel sample countries. Moreover, an increase of 1% in REN and RD

TABLE 9 D–H causality test results.

Null hypothesis	W-stat	Zbar-stat	Probability	Result
$lnGDP \nrightarrow lnCO_2$	4.49897	2.81684	0.0048	$lnGDP \rightarrow lnCO_2$
$lnCO_2 \nrightarrow lnGDP$	3.49418	1.5252	0.1272	No causality
$lnGDP^2 \nrightarrow lnCO_2$	4.39331	2.681	0.0073	$lnGDP^2 \rightarrow lnCO_2$
$lnCO_2 \nrightarrow lnGDP^2$	3.50365	1.53737	0.1242	No causality
$lnRD \nrightarrow lnCO_2$	3.67632	1.75934	0.0785	$lnRD \rightarrow lnCO_2$
$lnCO_2 \nrightarrow lnRD$	6.18456	4.98362	0.0000	$lnCO_2 \rightarrow lnRD$
$lnREN \nrightarrow lnCO_2$	2.08646	−0.28439	0.7761	No causality
$lnCO_2 \nrightarrow lnREN$	3.20375	1.15185	0.2494	No causality
$lnTA \nrightarrow lnCO_2$	4.98684	3.44397	0.0006	$lnTA \rightarrow lnCO_2$
$lnCO_2 \nrightarrow lnTA$	3.34908	1.33867	0.1807	No causality

Source: authors' own calculations.

reduces CO_2 emissions by 0.04% and 0.12%, respectively. Most importantly, the impact of TA is positive on CO_2 emissions. A 1% increase in international tourism arrivals causes a 0.086% increase in CO_2 emissions. Furthermore, the fixed-effects results support the random-effects results. Our result is consistent with the studies of Pata et al. (2023c), Salahodjaev et al. (2022), Sun et al. (2021), Musa et al. (2021), Fethi and Senyucel (2021), Kumail et al. (2020), Isik et al. (2020), Villanthenkodath et al. (2022), Usman et al. (2022), and Destek and Aydın (2022). Different results can cause the positive impact of international tourism on CO_2 emissions. For example, it indicates that these countries are not able to invest in eco-friendly tourism. Although the tourism receipts of these countries are remarkable, they cannot improve the tourism sector with well-developed technologies. In addition, as international tourism arrivals increase, energy consumption in hotels, restaurants, and cities also increases, thereby damaging the environment (Musa et al., 2021). Moreover, tourism infrastructure is closely linked to the environment. Modernizing transportation and roads is crucial to energy efficiency (Salahodjaev et al., 2022). Additionally, by estimating parameters, we research the causality paths between variables. The results from the Dumitrescu and Hurlin (2012) causality test are provided in Table 9.

It is evident that the causal linkages from Table 9 support the panel ARDL and the Driscoll and Kraay estimator's results. It is observed that there is a one-way causality running from lnGDP, $lnGDP^2$, and lnTA to CO_2 emissions. Furthermore, a bidirectional causality relationship exists between RD and CO_2 (see Figure 6).

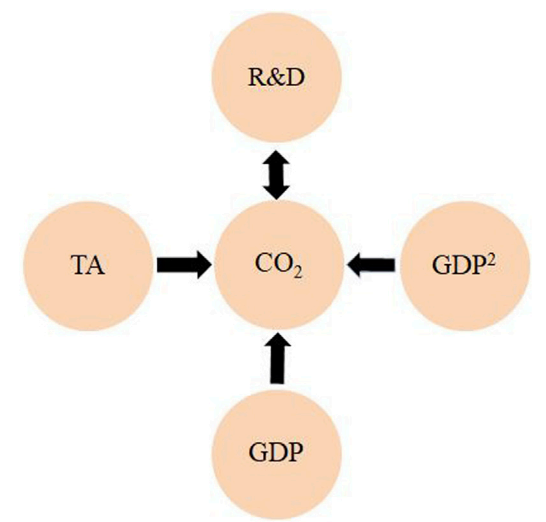

FIGURE 6
Causality relationship (authors' compilation).

5 Conclusion and policy recommendations

Our study works on the impact of tourism development on CO_2 emissions by investigating the roles of REN and R&D in 12 emerging markets and middle-income European countries, including Azerbaijan, Belarus, Bulgaria, Croatia, Hungary, Kazakhstan, North Macedonia, Poland, Romania, Russia, Turkey, and Ukraine, using annual data covering 1999–2020. We employ the panel ARDL and the Driscoll–Kraay estimator to determine the associations between variables. Moreover, we performed the D–H causality test to reveal potential causality linkages between variables. The findings from panel ARDL indicate that the EKC hypothesis is invalid in these countries and that there is a U-shaped relationship between economic growth and CO_2 emissions. In addition, international tourist arrivals, REN, and R&D negatively affect CO_2 emissions. Consequently, a 1% growth in TA, REN, and R&D led to a 0.037%, 0.031%, and 0.143% decrease in CO_2 emissions, respectively. Moreover, the Driscoll–Kraay estimator results confirm the panel ARDL results, except for the impact of tourism development. According to the Driscoll and Kraay estimator results, an increase of 1% in international tourist arrivals causes CO_2 emissions to reduce by 0.086%. These results indicate that international tourism has an inverse effect on environmental degradation. There can be several results in this regard. For instance, international tourist arrivals cause an increase in energy consumption. Furthermore, increasing transportation usage with international tourist arrivals contributes to CO_2 emissions. In addition, in the case of tourism, infrastructure is far from modern technological tools, causing more energy consumption and reducing energy efficiency. Finally, even if developing countries receive significant tourism revenue, they cannot use it to establish environmentally friendly technologies for the tourism sector.

In addition, REN decreases CO_2 emissions. An increase in REN mitigates the adverse effect of fossil fuels on CO_2 emissions. Furthermore, R&D expenditure increases environmental quality by decreasing CO_2 emissions. R&D is associated with renewable energy policies. R&D contributes to the installation of energy saving technologies, increasing energy efficiency, and the availability of REN sources. Moreover, the D–H panel causality test reveals a two-way causal relationship between R&D and CO_2 emissions and a one-way causal linkage running from economic growth, the square of economic growth, and tourist arrival to CO_2 emissions. Overall, our results prove the existence of a relationship between international tourism and CO_2 emissions.

The findings of our study have several significant policy implications: First, economic growth decreases CO_2 emissions. It indicates that as economic growth increases, the usage of pollutant energy sources also decreases. In other words, economic growth stimulates green energy sources. Hence, policymakers of these countries should consider improving green energy sources along with economic growth. However, economic growth has a negative impact on CO_2 emissions. The square of economic growth caused an increase in CO_2 emissions. This can be caused by increasing non-renewable energy consumption, which causes severe environmental deterioration in the later stages of economic development. These findings indicate that the scale + composition effect is bigger than the technological effect in the long term. Economic concerns are given priority over environmental quality by the people. Policymakers must urge firms to avoid using environmentally harmful energy sources like petrol, coal, and natural gas. Second, tourist arrivals cause CO_2 emissions. For this purpose, policymakers should promote the use of environmentally friendly vehicles for transportation in the tourism sector. In addition, they can offer adaptable incentives for foreign visitors regarding keeping their interest alive in a clean environment. Furthermore, tourist destinations incorporating smart city technologies can play a vital role in promoting sustainable development and protecting the environment because smart cities provide incentives and facilitate sustainable development goals. Using new and developed technologies can reduce waste and increase energy efficiency. Third, as REN negatively impacts CO_2 emissions, policymakers of these countries can adopt policies regarding the spread of REN. This can decrease the dependency on non-renewable energy consumption and increase environmental quality and sustainable development. To promote the use of REN, policymakers should incentivize companies to include it in employee benefits and subsidize the expenses of installing REN systems. Finally, R&D stimulates environmental quality. Policymakers should provide incentives for firms to develop R&D activities. For example, cheap and selective credit can be a viable option to disseminate innovation and technology facilities. Improvements in innovation and technology also facilitate the installation of REN sources. Fourth, firms play a crucial role in reducing CO_2 emissions and protecting the environment. They can accomplish some policies in terms of a sustainable environment. For example, using REN sources, adopting eco-friendly production processes, and investing in new technologies and R&D are crucial measures. It is essential to prioritize environmentally conscious business and management models. Additionally, increasing employee awareness is an important way to challenge environmental destruction. Green human resource practices may encourage employees to protect the environment.

This study has some limitations that can be investigated in future research. First, we used R&D as a proxy for technological innovation. Other technological innovation indicators, such as patent applications, can be considered together with R&D. Second, we focused on only 12 countries. Future studies can investigate the relationship between tourism and environmental degradation for a larger group of emerging and developing countries. Third, we were able to use the overall CO_2 emissions as a proxy for environmental degradation. Future studies can use tourism-induced CO_2 emissions as an indicator of environmental degradation.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

EB: writing–original draft, data curation, and methodology. OC: writing–original draft, conceptualization, formal analysis, and software. AK: data curation, resources, and writing–review and editing. BA: supervision and writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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