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ARTICLE

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Does trade openness mitigate environmental degradation in Organisation for Economic Co-operation and Development (OECD) countries? Implications for achieving sustainable development

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Abstract

The link between trade openness and CO_2 emissions is a key research focus in times of pressing global sustainability needs and ongoing climate change discussions. In this study, we address the critical issue of the impact of trade openness on CO_2 emissions in 20 OECD countries over a 150-year period using historical datasets. We investigate how trade openness affects environmental sustainability within this group of nations. To overcome the challenges related to heterogeneity and cross-sectional dependence, we applied robust cointegration techniques. Our analysis reveals direct and indirect impacts of trade openness on CO_2 emissions. The direct effect demonstrated a positive correlation between trade openness and CO_2 emissions, whereas the indirect effect, mediated by income growth, exerted a counteractive negative influence on this relationship. These divergent effects support the environmental Kuznets curve hypothesis. Our findings suggest that as income levels rise, the indirect effect gradually outweighs the direct effect, leading to a significant reduction in long-term CO_2 emissions in OECD countries.

KEYWORDS
CO_2 emissions, ecological footprint, economic growth, OECD countries, trade

1 | INTRODUCTION

In the contemporary global landscape, trade openness is a pivotal driver of economic growth, fostering international cooperation and economic development (Frankel & Romer, 1999; Grossman & Helpman, 1991). However, during these economic advances, the intricate relationship between trade and environmental sustainability, particularly in terms of carbon dioxide (CO_2) emissions, has come to the forefront of scholarly attention. In an era defined by the urgent need for global environmental sustainability and amid ongoing discussions surrounding climate change mitigation, the relationship between trade openness and CO_2 emissions has emerged as a paramount field of investigation. Understanding how trade affects CO_2 emissions is critical and complex, with far-reaching implications for addressing one of the most pressing challenges of our time: climate change. This dynamic relationship draws on a rich tapestry of economic and environmental theories and illuminates the multifaceted mechanisms through which trade influences CO_2 emissions. Trade is a driver of economic growth and globalization (Alsamara et al., 2019; Grossman & Helpman, 1991; Kim et al., 2019). It is undeniably intertwined with environmental considerations, presenting opportunities and challenges for the pursuit of a sustainable future.

At its core, the nexus between trade and CO_2 emissions reveals a dual nature, reflecting the intricate dynamics at play. Trade can serve as an engine of economic growth, leading to increase per capita income and the expansion of energy-intensive production processes. This phenomenon, known as the "*scale effect*," is often accompanied by a rise in energy consumption and a subsequent increase in CO_2 emissions (Copeland & Taylor, 2004). Further, trade can induce a "*composition effect*," as it alters the global patterns of production and consumption, leading to the production of emissions-intensive goods (M. I. Khan et al., 2020). Moreover, the "pollution haven hypothesis" adds another layer of complexity, suggesting that countries with lenient environmental regulations may specialize in pollution-intensive industries when facing differences in standards. Typically, such industries are capital-intensive in advanced countries with stringent environmental policies, and high capital endowments may offload pollution-intensive production to developing nations. This results in developing countries experiencing the environmental burdens of consumption in developed economies (Ansari & Khan, 2021; Dean, 2002).

Conversely, trade may open the doors to many possibilities for sustainable development. One of its key advantages is the exchange of technology and knowledge, which allows nations to adopt cleaner and more efficient production methods. This technological transfer aids in lowering emissions and boosts the global spread of environmentally friendly practices (Dean, 2002). Furthermore, the competitive nature of international trade can stimulate domestic innovation, encourage industries to devise energy-efficient processes, and reduce their carbon footprints. Trade also promotes better governance by aligning with international standards and regulations, resulting in strengthened environmental policies and regulations (Lopez-Cordova & Meissner, 2008). Additionally, the sharing of best practices and accessibility of cleaner technologies through trade can expedite the transition to more sustainable and eco-conscious economies.

These conflicting arguments regarding the actual effect of trade on environmental quality have been tested in several empirical studies; however, the results have been mixed. Some studies have found that trade openness increases environmental quality (Destek & Sinha, 2020; Kohler, 2013; Managi et al., 2009; Shahbaz et al., 2012), whereas others have found the opposite effect (Al-mulali, 2012; Baek & Kim, 2011; Jalil & Mahmud, 2009; Shahbaz et al., 2017; Udeagha & Ngepah, 2021). Sharma (2011) and Iwata et al. (2012) did not find a significant effect of trade openness on environmental quality.

The lack of consensus regarding the effects of trade on the environment motivated us to deepen our analysis of these two phenomena. We produce evidence using a new approach based on historical data covering almost a century and half of the economic, environmental, and trade activities of OECD countries. Consequently, our study focuses on several critical research questions: How has trade openness impacted the environment since the first wave of globalization? Is trade liberalization beneficial or detrimental to the environment? Does trade openness have a direct and/or indirect impact on carbon dioxide (CO_2) emissions, and what are the resulting short- and long-term implications? Further, we investigate whether economic growth in these nations contributes to or mitigates this problem.

This study focuses on OECD countries. The rationale for this selection was two-fold. First, these countries have played a pivotal role in historical carbon emissions, collectively accounting for 79% of the world's historical carbon emissions (CDG 2023). This historical responsibility underscores the importance of exploring the relationship between trade openness and carbon dioxide emissions within this specific group. Second, OECD countries have considerable influence on international trade. As collective entities, these nations hold a prominent position in global trade networks, making decisions and policies highly relevant to international trade dynamics. Therefore, by focusing on OECD countries, we aim to provide a nuanced understanding of how trade openness impacts CO_2 emissions and shed light on a critical aspect of the global sustainability discourse.

Moreover, our choice of the period 1870–2019 is meticulously reasoned. This extended historical timeframe enables us to analyze the long-term trends and evolution of the relationship between trade openness and CO_2 emissions, capturing critical developments and shifts in economic and environmental policies over the past century and a half. Furthermore, this historical perspective allows us to trace the roots of current environmental challenges and provides insights into how historical actions and policies have contributed to the current state of global carbon emissions. Considering this extensive historical context, we gain a comprehensive understanding of the intricate relationship among trade, development, and emissions, contributing novel insights into the existing literature.

Our study fills important gaps by enriching the literature in four ways. First, unlike previous studies on the effect of trade on CO_2 emissions that use panels with short or medium time series, we offer a long-time span, covering 150 years of economic, environmental, and financial activities. Our panel dataset comprises 20 OECD countries from 1870 to 2019, providing us with a total of 3000 observations.

Second, unlike previous studies, we thoroughly examined the impact of trade openness on CO_2 emissions within the EKC framework (Koc & Bulus, 2020). We identified and assessed the two channels through which trade may affect CO_2 emissions. The first channel is a direct effect, which represents the scale effect, in which any economic expansion due to increased trade will increase pollution because all other things being equal; more production means more pollution. The second is the indirect effect of economic growth. In other words, trade openness is likely to affect income (GDP per capita), which, in turn, affects CO_2 emissions through technical effects. By cumulating these effects, we quantify the total effect of trade on CO_2 emissions for 20 OECD countries from 1870 to 2019. To the best of our knowledge, this work is the first to measure direct and indirect effects of trade openness on air pollution for this group of countries.

Third, the study considers heterogeneity and dependency between countries. Thus, we employ a recent panel time-series technique robust to heterogeneity and cross-section dependence (CSD). Additionally, to capture the long- and short-term total effects, we employed the pooled mean group (PMG) technique as an additional estimator.

Finally, we used the ecological footprint as an alternative proxy for environmental quality instead of CO_2 emissions to check the robustness of our results.

The rest of the paper is organized as follows. Section 2 offers a summary of prior empirical research on the interconnection between CO_2 emissions, trade openness, and economic growth. Further, Section 3 provides an overview of the data used in the study and the descriptive statistics. Subsequently, Section 4 outlines the empirical model and methodology used in this study. Sections 5, 6, and 7 present the findings, discussion, and conclusions, respectively.

2 | LITERATURE REVIEW

Several scholars have explored the trade-CO_2 emissions nexus through two distinct approaches, both of which are discussed in this section. First, we discuss the studies that employ a panel of countries as their analytical frameworks. Subsequently, we shift our focus to research that delves into relationships at the individual country level.

2.1 | Multi-country studies

Several authors have referred to the flagship study by Grossman and Krueger (1995), which was the first to use the three mechanisms explained above. They aimed to assess the environmental impact of North American Free Trade Agreement (NAFTA) based on three air quality measures—sulfur dioxide (SO_2), particulate matter, and smoke concentrations—in different cities worldwide. They estimated these environmental indicators based on per capita income (scale and technical effects), specific variables for each observation site, and the commercial intensity variable (composition effect). They also addressed the relationship between pollution abatement costs and the patterns of trade and investment between Mexico and the United States. Using data for 32 countries from 1977 to 1988, their results indicate that trade opening may increase Mexico's specialization in sectors that cause less environmental damage. Additionally, they found a weakly significant link between high levels of trade openness and air pollution.

In the early 2000s, Antweiler et al. (2001) presented empirical research that explicitly focused on the scale, composition, and technique impacts of trade openness on the environment. They were the first to separate and econometrically test the magnitude of these effects. They concluded that by increasing the scale of economic activity by 1%, trade liberalization contributed to increasing SO_2 concentrations from 0.25% to 0.5% through the effect of scale. Nevertheless, its technical effect increased the concentrations from 1.25% to 1.5%, indicating that the total effect of trade is ultimately beneficial for the environment. This result was similar to that reported by Grossman and Krueger (1995) for SO_2.

Using panel data from 35 Asian countries between 1991 and 2016, Ansari and Khan (2021) found evidence that scale has a positive effect on the ecological footprint, while the technical effect has a negative impact. Therefore, the overall outcome is a decrease in environmental degradation in Asian countries. Their results also show that open trade policies have a positive impact on economic growth and environmental protection in high- and middle-income Asian countries.

An examination of the MENA region in terms of environmental sustainability literature provides valuable insights into the intersection of economic development, natural resource management, and environmental preservation. Omri et al. (2015) use panel data from 12 MENA countries between 1990 and 2011. Their findings indicated a positive correlation between GDP growth and trade. Similarly, Farhani, Chaibi, and Rault (2014) and Farhani, Shahbaz, et al. (2014) utilize Dynamic Ordinary Least Squares (DOLS) and fully modified OLS squares (FMOLS) estimations to examine a MENA panel and argue that the impact of trade openness on CO_2 emissions is positive.

In the context of Organisation for Economic Co-operation and Development (OECD) nations, Managi et al. (2009) conducted a study analyzing the causal impact of trade openness on emissions of SO_2, CO_2, and biochemical oxygen demand (BOD), utilizing a vast dataset spanning 1990–2011 for OECD and non-OECD countries. They discovered that trade openness led to a decrease in BOD emissions in OECD and non-OECD countries. Similarly, Destek and Sinha (2020) explore the validity of the EKC assumption in a sample of 24 OECD countries from 1980 to 2014. They demonstrated that trade and renewable energy consumption did not have an adverse impact on environmental quality in these countries. Can et al. (2021) explored how trading eco-friendly products contributes to environmental sustainability. Their research outcomes confirmed the Environmental Kuznets Curve (EKC) theory in 35 OECD countries. Moreover, they established that the green openness index, which encompasses conventional eco-friendly goods and environmentally preferred items, fosters environmental sustainability. F. Liu, Sim, et al. (2023) and H. Liu, Zafar, et al. (2023) examine how environmental tax, governance, and energy prices influence CO_2 emissions in OECD countries from 1996 to 2019. Using the cross-sectionally augmented autoregressive distributed lags model (CS-ARDL), Their findings suggest that environmental tax and governance have a positive impact on improving environmental quality in the long run.

Studies have also investigated how "green" trade openness can instead be used to counteract the negative effects of traditional trade in OECD countries. Their findings have significant relevance for practitioners and policymakers seeking sustainable development strategies. For instance, Can et al. (2022) introduced the green (trade) openness index to examine the potential of green trade in saving the environment in a sample study of 31 OECD countries. Their empirical analysis validated the EKC hypothesis and established that the inclusion of green products in a country's trade portfolio reduces the country's ecological footprint. This empirical analysis validates the EKC hypothesis and establishes that the inclusion of green products in a country's trade portfolio reduces its ecological footprint. This finding is significant for practitioners and policymakers who seek sustainable development strategies.

Nejati and Shah (2023) investigated the impact of ICT trade on environmental impacts in the northern (developed) and southern (developing) regions. Their results indicated that increasing ICT imports increased carbon emissions, energy consumption, and carbon intensity. They observed that when ICT flow occurred from south to south and south to north, these indicators exhibited a more intense impact compared with the north to other regions. They find that an increase in intra-regional imports has a negative composition effect, whereas improved inter-regional imports have a positive composition effect. Consequently, south–south and north–north trade increased the share of pollution-intensive sectors. Based on their study, the authors recommended prioritizing the trade of environmentally friendly ICT products that promote clean energy in both regions.

In another study of developed/advanced and developing countries, Kim et al. (2019) investigated the relationship between CO_2 emissions and trade using disaggregated trade data. They found that trade with the North increased CO_2 emissions, while that with the South mitigated CO2 emissions, particularly for less polluted host countries. In advanced countries, both Southern and Northern trade has reduced CO_2 emissions, especially in less polluted advanced countries. However, in developing countries, trade with the North worsened CO_2 emissions, while trade with the South helped mitigate CO_2 emissions, particularly in less-polluted developing countries. The study also examines the EKC hypothesis across quantiles for the full sample and for both developing and advanced countries. These findings suggest that trade benefits advanced countries but may harm developing countries in terms of CO_2 emissions, particularly when trading with high-income partners.

Other empirical studies have demonstrated that economic development, population dynamics, and energy utilization collectively contribute to increased global emissions at the national, urban, and household levels across countries and territories. Sarkodie et al. (2020) examined the global effects of urban sprawl, industrialization, trade, and economic development on CO_2 emissions. Their study revealed that industrialization and trade intensify global pollution levels, primarily driven by carbonized and energy-intensive economic structures in both developing and developed economies. Sarkodie et al. (2020) concluded that the triple effect of economic development (resource exploitation, production, and consumption) further exacerbates environmental pollution, necessitating a shift from a carbonized economy to a decarbonized economy. Moreover, urbanization, urban income growth, and energy consumption are closely intertwined, highlighting the need for urban-focused policy interventions to mitigate their combined impact on environmental sustainability.

To combat high environmental pollution, studies on BRICS economies have suggested implementing measures such as imposing high tariffs, changing tax structures, discouraging the import of polluted goods, and promoting green trade. Haseeb et al. (2023) examined the relationship between human capital, trade openness, and environmental sustainability in BRICS economies. Their Driscoll-Kraay standard error analysis revealed a negative relationship between human capital and CO_2 emissions. A one-point increase in human capital leads to a reduction in CO_2

emissions by 1.5279 and 0.1538 points, respectively. Conversely, 1% growth in trade corresponds to increases in CO_2 emissions of 0.3731% and 0.2384%, respectively. Furthermore, high long-term CO_2 emissions are associated with financial development and energy consumption. The findings also revealed a feedback effect of the human capital index on CO_2 emissions. Based on these findings, the governments of these nations and their relevant authorities are recommended to provide financial support and encourage investments in energy-efficient and sustainable green projects within the region.

Sun et al. (2020) examined the dynamic relationship between carbon emissions, trade, energy usage, urbanization, and economic growth from 1992 to 2015. The countries included in the analysis were divided into two subpanels: Belt and Road (B&R) countries and OECD countries, and the presence of the EKC was confirmed in all panels. The results obtained using the Common Correlated Effect Mean Group (CCE-MG) and Augmented Mean Group (AMG) methods consistently indicate that economic growth has a significant positive impact on environmental pollution. Additionally, the findings demonstrated that factors such as trade openness, urbanization, and energy usage contributed to the global increase in carbon emissions, although the estimated coefficients varied between the OECD and Belt and Road regions. Han et al. (2023) explored how improvements in export composition improvement affects carbon dioxide emissions in Belt-Road Initiative countries. Their findings demonstrated that export composition improvement is linked to carbon reduction and that industrial structure upgrading plays a crucial mediating role in this relationship. Intellectual property protection also moderates the relationship between improvements in export composition and industrial structure upgrades.

Researchers have also explored the impact of economic globalization on energy consumption and efficiency. Studies have often produced mixed findings, which, according to F. Liu, Sim, et al. (2023) and H. Liu, Zafar, et al. (2023), are due to the use of trade and foreign investment as indicators of economic globalization. To overcome these limitations, F. Liu, Sim, et al. (2023) and H. Liu, Zafar, et al. (2023) analyzed global data from 141 countries by employing refined measures of economic globalization and energy efficiency. These refinements include the consideration of infrequent temporal variations, business cycle effects, and heterogeneity bias. Their findings indicate that economic globalization has a positive impact on energy efficiency, although this effect is subject to an upward bias in the absence of controls. Economic globalization was found to improve energy efficiency in upper-middle- and lower-middle-income countries, but not in high- and lower-income countries.

Finally, Appiah-Twum and Long (2023) examine the convergence of environmental efficiency across Asia-Pacific countries. Although they find that human capital enhances environmental efficiency convergence, they also observe a mixed impact of trade competitiveness on environmental efficiency. The authors stressed that strengthening environmental regulations and the pursuit of green industrialization were required in the region.

2.2 | Individual country studies

Regarding individual country studies, Farhani, Chaibi, and Rault (2014) and Farhani, Shahbaz, et al. (2014) investigated the influence of energy consumption, economic growth, population growth, and trade on CO_2 emissions in Tunisia. Their results showed a positive relationship between trade and CO_2 emissions. Similarly, Udeagha and Ngepah (2021) used the ARDL estimator for South Africa and found that the scale effect of trade openness on CO_2 emissions is positive, whereas the technical effect is negative.

Dean (2002) developed a system of two simultaneous equations to estimate the effects of economic openness on income growth, and income growth on water pollution in Chinese provinces from 1987 to 1995. The authors found that trade openness directly worsened water pollution, but increased income indirectly mitigated this effect. The results also showed that trade reforms during the study period had a net beneficial impact on water pollution. According to Ren et al. (2014), who used the GMM method on a sample from China from 2000 to 2010, China's growing trade surplus was a significant reason for its rapidly rising CO_2 emissions.

The literature also shows that, in some cases, financial development can contribute to higher CO_2 emissions. This is found in the case of China for instance by Duan et al. (2022) who analyze the relationship between trade liberalization, financial development, and CO_2 emissions. However, they noted that trade liberalization did not have a significant impact on these emissions. Although its support for international trade is limited, China's trade liberalization has promoted its financial development. Their study revealed a two-way causal relationship between financial development and CO_2 emissions as well as between trade liberalization and financial development. Based on these results, researchers have proposed that trade openness influences carbon dioxide emissions, establishing a new functional pathway.

Kartal et al. (2022) investigated the impact of political stability on consumption-based carbon dioxide emissions (CCO_2) in Finland. Their empirical findings revealed that political stability has a significant impact on CCO_2 emissions. Positive changes in political stability had a statistically significant effect, whereas negative shocks did not. Economic growth positively affects CCO_2 emissions and positive shocks to renewable energy have a decreasing impact. Trade openness has a decreasing impact on positive shocks and an increasing impact on negative shocks to CCO_2 emissions. These results emphasize the importance of considering political stability in policy development and implementation to achieve Finland's carbon neutrality targets by 2035.

Other studies have emphasized the importance of addressing economic and governmental barriers to promote the productive use of greener production methods in the agricultural industry. Ali et al. (2023) investigated barriers to deploying biogas plants in Pakistan. Through a survey of 79 biogas plant adopters, this study found that all influencing factors were positively associated with successful biogas implementation, energy crisis mitigation, and cost-cutting goals. The authors added that offering technical assistance is crucial for the development of biogas facilities.

Despite the above findings, the effect of trade openness on CO_2 emissions remains uncertain and the debate among scholars is ongoing, reflecting the complexity of their relationship. Furthermore, most studies have used single equations to capture the various effects of trade on air pollution, which may lead to inconsistent results. To address these limitations, we collected comprehensive country samples containing data from 20 OECD countries over 150 years to examine the direct and indirect impacts of trade on carbon emissions, while paying attention to CSD and heterogeneity among countries, using a simultaneous equation approach.

3 | DATA

Our analysis utilizes extensive panel data spanning 20 OECD countries, covering 1870–2019 period. The data were sourced from various studies. Specifically, CO_2 emissions stemming from fossil fuels and industry were derived from Churchill et al. (2018),[1] with the primary data originating from the Carbon Dioxide Information Analysis Center (CDIAC). Population size and GDP per capita data also originated from Churchill et al. (2018), while trade openness, financial development, and investment data were acquired from Yao et al. (2020),[2] using Madsen's (2014) primary source. To ensure uniformity, all the data were updated to 2019 using the World Development Indicators databank. The following section provides a comprehensive description of our variables and elucidates the rationale behind our data selection.[3]

We used CO_2 emissions from fossil fuels and industry, specifically measuring carbon dioxide emissions in metric tons per capita, for two primary reasons. First, the environmental impact of CO_2 emissions has been extensively studied. The concentration of this form of pollution enabled us to draw comparisons with previous research. Second, historical data dating back to 1870 indicate a significant surge in CO_2 emissions in developed countries following World War II, making it one of the most concerning contributors to air pollution and the exacerbation of global warming.

Trade openness is our variable of interest and represents the sum of exports and imports as a percentage of GDP.

Income is represented by real GDP per capita (constant 1990 US$) and is widely used in the literature. We also include income in its quadratic form to test the EKC form in OECD countries. If per capita GDP is positive and significant, and GDP squared is significant with a negative sign, then the hypothesis is validated in the sample being studied, and an inverse U-shaped curve is observed.

Population size is associated with environmental degradation. Birdsall (1992) identified two channels through which population growth contributes to increasing CO_2 emissions. First, an increase in the population size could lead to greater energy consumption in different sectors, which could subsequently result in increased fossil fuel release. Population growth can impose additional strain on natural resources, which can contribute significantly to greenhouse gas emissions.

Financial development is represented by the private credit-to-GDP ratio. A growing number of studies have used financial development to investigate the determinants of CO_2 emissions (Boutabba, 2014; Salahuddin et al., 2015; Zhang, 2011). Some empirical studies have shown a positive effect of financial development on CO_2 emissions (Zhang, 2011), whereas others have found the opposite (Salahuddin et al., 2015).

4 | EMPIRICAL MODEL AND METHODOLOGY

4.1 | Empirical models

Our study emphasizes the direct and indirect effects of trade openness on CO_2 emissions. To capture these effects, our approach involves a joint estimation of the two equations. In the first equation, CO_2 emissions are regressed on income, trade openness, and other control variables. Therefore, the first equation allows us to capture the scale effect of trade on CO_2 emissions and check for the presence of a reverse U-shaped relationship between CO_2 emissions and income. In the second equation, per-capita income depends on trade and other factors. The first equation is as follows:

$$\text{LnCO}_{2it} = \alpha_0 + \alpha_1 \text{LnGDP}_{it} + \alpha_2 (\text{LnGDP}_{it})^2 + \alpha_3 \text{LnTra}_{it} + \alpha_4 \text{LnPOP}_{it} + \alpha_5 \text{LnFD}_{it} + \mu_{it} i = 1,2,3,\ldots N; t = 1,2,3,\ldots,T \quad (1)$$

where LnCO_{2it} is CO_2 emissions, LnGDP_{it} is per capita GDP, LnTra_{it} is our variable of interest and represents the share of the sum of exports and imports of goods and services in GDP, LnPOP_{it} is population size, and LnFD_{it} is financial development. All variables are expressed in log form so that they can be interpreted as elasticities to mitigate the problems of heteroscedasticity. Finally, α_0, μ_{it} and δ_i represent the constant and error terms, respectively.

Equation (2) focuses on the determinants of GDP per capita, in which income is regressed on trade openness and other control variables, including population (LnPOP_{it}), financial development (LnFD_{it}), and investment (LnINV_{it}) (Barro, 1991; Cole, 2007; Levine & Renelt, 1992). Equation (2) is defined as follows:

$$\text{LnGDP}_{it} = \alpha_0 + +\alpha_1 \text{LnTRA}_{it} + \alpha_2 \text{LnPOP}_{it} + \alpha_3 \text{LnINV}_{it} + \alpha_4 \text{LnFD}_{it} + \delta_i + \mu_{it} \quad (2)$$

where $i = 1,2,3,\ldots N; t = 1,2,3,\ldots,T$.

In our models, the impact of trade openness on CO_2 emissions was determined by adding the direct and indirect effects. The latter effect occurs through economic growth, where trade affects per capita income, which, in turn, affects CO_2 emissions. Thus, the total effect of trade is given by

$$\left(\frac{dCO_2}{dTrade}\right)_{\text{Total}} = \underbrace{\frac{\partial dCO_2}{\partial \text{Trade}}}_{\text{Direct effect}} + \underbrace{\left(\frac{\partial dCO_2}{\partial \text{GDP}}^{*} \frac{\partial \text{GDP}}{\partial \text{Trade}}\right)}_{\text{Indirect effect}} \quad (3)$$

where $\frac{\partial GDP}{\partial Trade}$ represents the effect of trade on income (Equation (2)), and $\frac{\partial dCO_2}{\partial GDP}$ refers to the effect of income on CO_2 emissions (Equation (1)). Hence, $\frac{\partial dCO_2}{\partial GDP} * \frac{\partial GDP}{\partial Trade}$ represents the indirect effect, while $\frac{\partial dCO_2}{\partial Trade}$ represents the direct effect illustrated in Equation (1).

4.2 | Estimation techniques

Our empirical analysis was conducted using balanced panel data encompassing 20 OECD countries from 1870 to 2019. To this end, we employed the CCE-MG and AMG estimators for three key reasons:

Firstly, these two techniques have been demonstrated to be highly relevant and robust when dealing with panel data involving large cross-sectional units and extended time periods (Sarkodie et al., 2020). This is especially pertinent to our own research, which spans 20 OECD countries for over a century and a half, resulting in a dataset comprising 3000 observations.

Secondly, these methods account for cross-sectional dependency (CSD) which may emerge from economic integration among countries and/or global shocks (Eberhardt & Teal, 2011). Unobserved common factors and CSD were present in our extensive panel data. Consequently, employing traditional panel procedures (such as OLS, FMLOS, ARDL, and GMM) that neglect CSD would not have been appropriate and would likely have led to inconsistent estimators and spurious results (Barkat et al., 2019; Barkat & Alsamara, 2019; Sadorsky, 2014; Sarafidis et al., 2009; Sarkodie et al., 2020).

Thirdly, the CCE-MG and AMG estimators exhibit robustness against slope heterogeneity, which is vital given the diversity in characteristics among our countries, resulting from their historical trajectories spanning over a century.

Additionally, to capture both long- and short-run total effects, we employed the PMG technique as an additional estimator. This approach accommodates long-run homogeneity and short-run heterogeneity within the panel model (Barkat et al., 2022).

5 | EMPIRICAL RESULTS

5.1 | CSD and unit root test results

Recent empirical work on panel data has shown that macropanel data are subject to strong cross-dependence. Therefore, it is important to investigate the residual CSD to select the appropriate unit root test and estimation methods that account for the CSD. The results of the CSD tests are presented in Table 1. The suggestion of cross-sectional independence is invalid at the 1% significance level for all seven datasets. Furthermore, the estimated exponent of the CSD was almost equal to one for all variables. These results imply that the second-generation unit root test and panel estimation methods allowing for CSD are more accurate and thus necessary for our study.

The results in Table 1 indicate the presence of a CSD in the data at the 1% significance level for the global panel. Therefore, we apply the second-generation test suggested by Pesaran (2007). Table 2 presents the test results. The results revealed that all the variables were stationary at the first difference, meaning that all series were I (1) in our sample.

The results of the second unit root test by Ditzen et al. (2021), which considered breaks in the series, showed that there were five potential breaks in our panel in 1893, 1922, 1947, 1981, and 1997 (Table 3). The first break coincided with a long depression that occurred in the late 19th century (Yao et al., 2020). The second (1922) and third (1947) breaks were associated with the post-World War I and II periods, and the fourth break (1981) coincided with the Volcker disinflation, which is considered by many to be the worst economic downturn in the United States since the Great Depression (Goodfriend & King, 2005). The final break (1997) may have been associated with the

TABLE 1 Estimation of cross-sectional exponent (alpha) and Pesaran (2015) test for weak cross-sectional dependence.

	Alpha	SE	CD	*p*-Value	*N*	*T*
LnCO_2	0.917	0.042	126.56	.000	20	150
LnGDP	0.917	0.106	117.27	.000	20	150
LnGDP^2	0.918	0.140	130.86	.000	20	150
LnTRA	0.918	0.324	158.65	.000	20	150
LnPOP	0.919	0.156	164.33	.000	20	150
LnFD	0.918	0.092	121.05	.000	20	150
LnINV	0.892	0.047	59.32	.000	20	150

Note: 0.5 ≤ alpha < 1 implies strong cross-sectional dependence. CSD, cross-sectional dependence; H0: Errors are weakly cross-sectional dependent.

TABLE 2 Unit root test (CIPS).

	Level		First difference	
	Level	Intercept and trend	Level	Intercept and trend
LnCO_2	−3.396***	−3.939***	−6.190***	−6.420***
LnGDP	−2.632***	−3.171***	−6.190***	−6.422***
LnGDP^2	−1.991*	−2.502***	−6.190***	−6.420***
LnTRA	−4.083***	−4.715***	−6.190***	−6.420***
LnPOP	−1.101	−1.182	−5.161***	−5.451***
LnFD	−2.051**	−2.509***	−6.190***	−6.420***
LnINV	−4.026***	−4.155***	−4.239***	−6.420***
LnEFP	−2.167**	−3.008***	−6.155***	−6.354***

Note: Critical values at 10%, 5% and 1% equals −1.99, −2.04 and −2.14 respectively. CIPS, Cross-sectionally agmunted Im, Pesaran and Shin (IPS).
****p* < .01; ***p* < .05; **p* < .1.

TABLE 3 Test for multiple breaks at unknown break dates (Ditzen et al., 2021).

	Test statistic	1% critical value	5% critical value	10% critical value
UD-Max (tau)	78.33	4.91	3.91	3.47

Note: H0: No break(s) versus H1: s = 5 break(s). Estimated break points: 1893, 1922, 1947, 1981, 1997 evaluated at a level of 0.95.

Asian financial crisis. Therefore, we consider these major events by including in our models (Equations (1) and (2)) five time-dummies for 1893 (DV1893), 1922 (DV1922), 1947 (DV 1947), 1981 (DV 1981) and 1997 (DV 1997) as explanatory variables.

5.2 | Results of slope heterogeneity and panel cointegration tests

After exploring the cross-dependency among the variables and the stationarity of our data, we used Westerlund's (2007) test to examine the cointegration relationships among the variables. The results are summarized in Table 4.

TABLE 4 Westerlund ECM panel cointegration tests.

	Bivariate model					Multivariate
	LnGDP	LnGDP2	LnTRA	LnPOP	LnFD	Full
G_t	−3.08***	−3.58***	−3.21***	−3.55***	−3.087***	−4.68***
G_a	−17.02***	−19.07***	−17.18***	−22.57***	−17.02**	−37.42***
P_t	−15.20***	−18.02***	−16.36***	−16.77***	−15.20**	−23.06***
P_a	−19.61***	−22.27***	−19.48***	−21.22***	−19.61***	−38.60***

Note: H0: No cointegration. The Panel tests (P_t and P_a) assess the overall cointegration of the panel, while the Group- mean tests (G_t and G_a) examine cointegration for at least one unit within the panel. Noting that, "a" denotes to the estimation of the error correction estimate, while "t" refers to the estimation for the standard error associated with "a".
Abbreviation: ECM, Error correction model.

TABLE 5 Testing for slope heterogeneity (Pesaran & Yamagata, 2008).

	Without CD		With CD	
	Coefficients	*p*-Value	Coefficients	*p*-Value
Detla	131.65	.000	55.06	.000
Delta adj	134.84	.000	56.64	.000

Note: H0: Slope coefficients are homogenous.
Abbreviation: CD, Cross-dependence.

Based on the outcomes in Table 4, Westerlund's (2007) test indicates that there is a long-run relationship between the explanatory variable (CO_2 emissions) and the independent variables (GDP, trade, population, and financial development), as well as the full model. In addition, a pre-estimation test was conducted to determine whether the slope coefficients in the cointegration equation were homogeneous. This test is crucial because the assumption of homogeneity among cross sections is unrealistic for panel data (H. Liu, Alharthi, et al., 2022; H. Liu, Khan, et al., 2022). Table 5 presents the results. These findings suggest that the null hypothesis (H0) can be rejected at the 1% significance level, indicating that the slope coefficients are heterogeneous for the entire panel.

5.3 | Panel estimates

5.3.1 | Effect of trade openness on carbon emissions

Table 6 presents the findings of the first equation, which tests the relationship between CO_2 and trade openness, along with the existence of the Environmental Kuznets Curve (EKC) hypothesis. The results from the three estimators (AMG, CCE-MG, and PMG) strongly support the EKC hypothesis. The coefficients of both the linear and nonlinear terms of GDP per capita were highly significant, suggesting that the relationship between economic growth and CO_2 emissions follows an inverted U-shape in OECD countries. This finding is consistent with some previous studies (such as Awan et al., 2022; Azam et al., 2023; Bilgili et al., 2016; Churchill et al., 2018; Iwata et al., 2011) but contradicts others (such as Destek & Sinha, 2020; Dong et al., 2018; Halkos & Tzeremes, 2009). Additionally, the income turning point level varied across the estimation techniques, with the PMG estimator indicating the lowest level at \$21,914 and the AMG estimator showing the highest level at \$45,700. It is worth noting that all the turning points of income were within the range of the given dataset for the three estimators. However, to be more precise, the root mean square error value obtained from the AMG estimator (reported at the bottom of

TABLE 6 Effect of trade openness on carbon emissions.

Variables	AMG	CCE-MG	PMG
Long-run			
LnGDP	2.533** (0.955)	2.594*** (0.985)	5.897*** (0.514)
LnGDP2	−0.118** (0.051)	−0.121*** (0.054)	−0.295*** (0.029)
LnTRA	0.095*** (0.043)	0.173*** (0.048)	0.095** (0.033)
LnFD	−0.090 (0.049)	−0.070 (0.048)	0.032 (0.032)
LnPOP	−0.523 (0.549)	−0.909* (0.554)	0.252*** (0.075)
DV1893	0.065 (0.053)	0.076 (0.050)	0.053 (0.049)
DV1922	1.738*** (0.324)	−0.051 (0.132)	0.134 (0.122)
DV1947	−0.044 (0.121)	−0.052 (0.124)	−0.003 (0.102)
DV1981	0.027 (0.067)	0.038 (0.067)	0.003 (0.056)
DV1997	0.123* (0.109)	0.009* (0.100)	0.111 (0.009)
C_D_P	0.870*** (0.130)		
Constant	0.561 (9.265)	0.724*** (9.364)	−2.439*** (0.552)
Short-run			
ETC			−0.102*** (0.022)
D.LnGDP			2.544*** (0.895)
D.LnGDP2			−0.104** (0.047)
D.LnTRA			0.152*** (0.041)
D.LnFD			−0.039 (0.055)
D.LnPOP			1.692* (0.947)
Turning point	10.72	10.53	9.99
Turning point ($)	$45,700	$37,536	$21,914
RMSE	0.22	0.27	
Number of id	20	20	20

Note: Standard errors in parentheses.
Abbreviations: AMG, Augmented Mean Group; CCE-MG, Common Correlated Effect Mean Group; ETC, Error correction term; PMG, pooled mean group; RMSE, Root mean square error.
****p* < .01; ***p* < .05; **p* < .1.

Table 6) was slightly lower than that of the CCE-MG estimator, meaning that the AMG result is preferable. Therefore, the turning point for income per capita is around $45,700 for the OECD countries.

The AMG, CCE-MG, and PMG estimates reveal that the coefficient of trade openness is positively and significantly associated with long-term CO_2 emissions in the long run. Specifically, a 1% increase in trade was found to lead to 0.095%, 0.173%, and 0.095% increases in CO_2 emissions for the AMG, CCE-MG, and PMG, respectively, indicating that trade openness has a significant negative impact on the environment in OECD countries. These findings are consistent with those of Churchill et al. (2018), who observe a similar positive direct effect in 20 OECD countries.

These results can be attributed to two key mechanisms. Transportation plays a central role in this context. Trade inherently involves the cross-border movement of goods, which often relies heavily on fossil-fuel-driven transportation methods, resulting in increased greenhouse gas emissions (WTO, 2023). For instance, petroleum accounts for approximately 95 percent of total energy consumption in the global transportation sector, making it a significant contributor to greenhouse gas emissions. In 2022, the International Energy Agency (IEA) estimated that worldwide carbon dioxide emissions from the transportation sector would increase by over 250 million metric tons (Mt CO_2), reaching nearly 8 gigatons (Gt CO_2), a 3% increase from the previous year. It is worth noting that road transport is responsible for more than half of trade-related CO_2 freight emissions due to its higher emission intensity per ton-kilometer and its dominant role in the transport sector (Stojanović et al., 2021). Furthermore, while international trade constitutes approximately 10% of ton-kilometers, it contributes to approximately 30% of CO_2 emissions, primarily because road transport is frequently used in the initial and final stages of international supply chains. This preference for road transport is mainly due to its competitiveness in these phases (Stojanović et al., 2021). Additionally, countries sharing extensive land borders, such as OECD nations (including European countries and North American counterparts such as the United States and Canada), have intensified their commercial exchanges via land transport, leading to increased CO_2 emissions. Moreover, the production processes involved in creating goods for trade can also be substantial contributors to CO_2 emissions, especially in industries that rely heavily on fossil fuels in their operations, as emphasized by the World Trade Organization (WTO) in 2023.

Results concerning population and financial development are inconclusive. Financial development was found to be statistically insignificant across all estimation techniques, which is consistent with the findings of Jiang and Ma (2019). Some empirical studies have suggested that the relationship between financial development and CO_2 emissions is negative, as financial development can provide funding for innovative and environmentally friendly projects that boost productivity and energy efficiency (Islam et al., 2013; Tamazian et al., 2009). Other studies have shown that this can stimulate energy consumption and production expansion, leading to higher carbon emissions (Dogan & Turkekul, 2016; Zhang, 2011). However, Dogan and Seker (2016) suggested that the net effect is subject to the relative sizes of the positive and negative impacts.

We speculate that the lack of a significant relationship between financial development and CO_2 emissions in OECD countries is due to their strong industrial systems and severe environmental conditions. Consequently, companies tend to invest in clean technologies, and their governments encourage the development of green finance. Although financial development can stimulate consumption, which can increase CO_2 release, these positive and negative effects tend to offset each other, neutralizing the negative impact of financial development on carbon emissions, particularly in developed countries.

Second, the consequences of population on the environment in general are discussed in the literature from two conflicting points of view: the Boserupian view, which states that population can have a positive effect on the environment through technological change; and the Mal = an view, which posits that a larger population could increase CO_2 emissions through an increased demand for energy for industrial production and transport (Fan et al., 2006; Shuai et al., 2017).

In conclusion, PMG analysis enabled us to examine the short-term impact of our variables on CO_2 emissions, revealing that a 1% increase in trade openness resulted in a 0.152% increase in CO_2 emissions per capita. Moreover, the long-run trade elasticity results indicate that a 1% increase in trade openness increases CO_2 emissions by 0.095% in OECD countries. These findings demonstrate that the trade coefficient is larger in the short run than in the long run, implying that the effect of trade on environmental harm diminishes over time.

5.3.2 | The effect of trade openness on per capita income

Before determining the total effect of trade on CO_2, we examined the link between GDP per capita and trade openness, as explained in Section 3 (Equation (2)). Table 7 presents the results of the three estimators. In all estimations, trade openness was found to have a positive and statistically significant influence on per capita income. This result is in line with Sachs and Warner (1995), Edwards (1998), and Frankel and Romer (1999), who find that trade promotes economic growth. The findings of the AMG, CCE-MG, and PMG estimators indicate that a 1% increase in trade openness improves GDP per capita by 0.13%, 0.15%, and 0.25%, respectively, in OECD countries (Table 7). The results also show that investment and financial development have a positive long-run effect on GDP per capita, in line with Fetahi-Vehapi et al. (2015) and Al-Yousif (2002).

TABLE 7 The effect of trade openness on per capita income.

Variables	AMG	CCE-MG	PMG
Long-run			
LnTRA	0.134*** (0.040)	0.150*** (0.038)	0.257*** (0.013)
LnPOP	0.362 (0.319)	0.233** (0.389)	0.223 (0.131)
LnINV	0.098** (0.045)	0.165* (0.099)	0.334*** (0.046)
LnFD	0.006* (0.034)	0.075** (0.142)	0.290*** (0.032)
DV1893	−0.045 (0.036)	−0.157** (0.049)	−0.107** (0.009)
DV1922	0.050 (0.048)	−0.086 (0.087)	−0.106 (0.007)
DV1947	0.026** (0.015)	0.167** (0.097)	0.111 (0.077)
DV1981	0.026** (0.015)	0.197** (0.085)	0.008** (0.005)
DV1997	2.051** (0.402)	0.014 (0.066)	0.004* (0.003)
C_D_P	0.839*** (0.169)		
Constant	0.292 (4.748)	−7.182 (5.734)	0.180 (0.145)
Short-run			
ETC			−0.056*** (0.050)
D.LnTRA			−0.003 (0.017)
D.LnPOP			0.473 (0.794)
D.LnINV			0.103*** (0.031)
D.LnFD			−0.106*** (0.029)
Number of groups	20	20	20

Note: Standard errors in parentheses.
Abbreviations: AMG, Augmented Mean Group; CCE-MG, Common Correlated Effect Mean Group; ETC, Error correction term; PMG, pooled mean group.
***$p < .01$; **$p < .05$; *$p < .1$.

5.3.3 | Total effect of trade openness on CO_2 emissions

After examining the effects of trade openness on both per-capita income and carbon emissions, we quantified the total effect of trade on CO_2 emissions. Table 8 provides the direct, indirect, and total effects of trade on air pollution, calculated by combining the results of the income model in Table 7 and those presented in Table 6 (as explained in Equation (3)). The total effects in Table 8 are calculated before and after the income turning-point levels reported in Table 6. This approach was used to capture the differences in and evolution of the total effect of trade openness through the EKC framework. Therefore, we calculate the total effect using the sample mean income level for OECD countries, which is below the income turning point level. The results reported at the top of Table 8 reveal that the direct and indirect effects of trade were positive; thus, the total effect on CO_2 emissions was positive. This means that a 1% rise in trade openness led to a 0.15%–0.30% rise in CO_2 emissions in OECD countries.

In the second step, we consider the total effect after the income turning point level. The results in Table 8 show that, contrary to the previous results, the coefficient of the indirect effects switched to a negative sign. This negative indirect effect reflects the negative relationship between carbon emissions and income beyond the mean income level; thus, a trade openness-induced rise in income leads to a reduction in CO_2 emissions. This result was expected, because the indirect effect was calculated at the income level, which was above the estimated turning point reported in Table 6. This result implies that in the second stage of the EKC hypothesis, there was an increase in income, which led to a decrease in emissions owing to the increase in demand for a clean environment coupled with a high level of

TABLE 8 Total effect of trade openness on CO_2 emission.

	AMG	CCE-MG	PMG-LR
Before the TP level (LnGDP = 8.857)			
Direct	0.095***	0.173***	0.095***
Indirect	0.059***	0.067***	0.209***
Total	0.154	0.24	0.304
After the TP level (LnGDP = 13)			
Direct	0.095***	0.173***	0.095***
Indirect	−0.07***	−0.08***	−0.462***
Total	0.025	0.093	−0.367

Note: The indirect effect is calculated using the sample means of income (8.857) and at income level exceeding the turning point (LnGDP = 13).
Abbreviations: AMG, Augmented Mean Group; CCE-MG, Common Correlated Effect Mean Group; PMG, pooled mean group; TP, GDP turning point level.
***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

environmental awareness. Thus, the more income increases, the more the indirect effect of trade increases, which, in turn, increases the total effect.

5.3.4 | Robustness check

In this section, we assess the robustness of our findings by employing the ecological footprint as a dependent variable, measured on a per capita basis and sourced from the Global Footprint Network (2023). Our objective was to determine whether our results would remain consistent when utilizing an alternative proxy for measuring environmental quality, as suggested in previous studies (Hassan et al., 2023; I. Khan et al., 2022; H. Liu, Alharthi, et al., 2022; H. Liu, Khan, et al., 2022; Ulucak & Bilgili, 2018). Table 9 presents the results of this analysis.

The main findings in Table 9 provide two significant insights. First, the Environmental Kuznets Curve (EKC) hypothesis remains valid for OECD countries, even when utilizing ecological footprint as a proxy, with turning points ranging between $26,000 and $38,177. This outcome aligns with the results of Majeed and Mazhar (2020) as well as those of Ulucak and Bilgili (2018), reinforcing our earlier findings using CO_2 emissions as a dependent variable (as shown in Table 6).

Second, as expected, the coefficients associated with trade openness are consistently positive and highly significant across all specifications. This result is consistent with the findings of Majeed and Mazhar (2020) and Ulucak and Bilgili (2018). Our findings suggest that trade openness has a notable adverse effect on the environment in OECD countries. These results align with our earlier findings, reported in Table 6, which employed CO_2 emissions as a measure.

6 | DISCUSSION RESULTS

6.1 | Effect of trade openness on economic growth

Our findings indicate that trade openness positively affects economic growth, supporting the hypothesis that increased trade leads to better economic performance and enhanced national welfare. This result aligns with various previous studies such as Sachs and Warner (1995), Edwards (1998), Frankel and Romer (1999), and Grossman

TABLE 9 Effect of trade openness on ecological footprint.

DV: Ecological footprint			
Variables	**AMG**	**CCE-MG**	**PMG**
Long-run			
LnGDP	3.989** (1.881)	6.397*** (2.161)	0.183*** (0.051)
LnGDP^2	−0.189** (0.094)	−0.303*** (0.108)	−0.009*** (0.002)
LnTRA	0.094*** (0.043)	0.181*** (0.086)	0.143** (0.026)
LnFD	−0.017 (0.046)	−0.024 (0.048)	−0.019 (0.032)
LnPOP	−0.816 (0.549)	−1.075* (0.554)	−0.565*** (0.075)
DV1979	−0.039** (0.053)	−0.083 (0.124)	−0.050** (0.039)
DV1997	0.025 (0.324)	0.032 (0.132)	0.134 (0.122)
DV2008	−0.001* (0.041)	−0.056** (0.016)	−0.003* (0.102)
C_D_P	0.622*** (0.112)		
Constant	−5.794 (9.295)	−1.724*** (10.36)	−2.439*** (0.552)
Short-run			
ETC			−0.169*** (0.022)
D.LnGDP			7.893*** (2.598)
D.LnGDP^2			−0.370** (0.047)
D.LnTRA			0.107*** (0.041)
D.LnFD			−0.052 (0.055)
D.LnPOP			0.769* (0.465)
Turning point	10.55	10.54	10.16
Turning point ($)	$38,177	$37,797	$26,021
RMSE	0.24	0.27	
Number of id	20	20	20
Period	1961–2019	1961–2019	1961–2019

Note: Standard errors in parentheses. Estimation period (1961–2019).
Abbreviations: AMG, Augmented Mean Group; CCE-MG, Common Correlated Effect Mean Group; ETC, Error correction term; RMSE, Root mean square error; PMG, pooled mean group.
****p* < .01; ***p* < .05; **p* < .1.

and Helpman (1991), who find a positive correlation between trade openness and economic growth. The WTO's 1998 Annual Report also concluded that most studies on this topic found a positive relationship between trade openness and economic growth, with few studies showing negative correlations that are usually statistically insignificant.

Despite considerable research on the relationship between trade and GDP growth, the debate continues, particularly after Rodriguez and Rodrik (2000) questioned Sachs and Warner's (1995) conclusions. They suggested that the causality between trade openness and growth may not be straightforward and that trade openness is only one aspect of the overall economic organization. Countries that opt for trade openness are typically well-organized internally, with strong institutions, political and macroeconomic stability, and the rule of law, among other factors. Therefore, the growth of open countries can be attributed to the quality of their internal organizations and not necessarily to openness. Prosperity may be the cause of trade liberalization rather than the other way around, as countries that are capable of benefiting from it are the ones that would naturally choose to pursue openness (Rodriguez & Rodrik, 2000).

Nevertheless, it can also be argued that international openness can serve as a powerful incentive for internal reforms. For instance, the reforms undertaken by countries in Central and Eastern Europe to prepare for their agreement with the European Union, or China for its accession to the WTO, provide good examples in this regard. Additionally, the intensification of international competition prompts private agents to adapt by seeking productivity gains or investing more in R&D. Moreover, integration into the international economy facilitates access to the material and intellectual methods that are crucial for enhancing internal economic efficiency (Alsamara et al., 2022). It is likely that a positive feedback loop exists between trade liberalization and economic growth, where periods of high growth encourage market opening, which promotes growth. Therefore, trade and financial openness could be useful policies for accelerating growth in countries with good internal political and economic governance, as is the case in OECD countries. Consequently, if we acknowledge that openness stimulates growth as our results demonstrate, we can explore the impact of trade openness on the environment via this avenue.

6.2 | The total impact of trade openness on CO_2

Our results provide strong evidence that trade openness has both direct and indirect effects on the growth of CO_2 in OECD countries, and these two effects could have opposite signs depending on the validity of the EKC hypothesis. The results show that the direct effect of trade openness on CO_2 emissions is positive and significant in the OECD countries, suggesting that trade openness worsens environmental conditions. This positive correlation can be explained in two ways.

First, international trade encourages industrialized and developing countries to concentrate on activities based on a larger comparative advantage (Antweiler et al., 2001). As developed countries generally have more capital than developing countries, the former have a comparative advantage in capital-intensive industries, whereas the latter have an advantage in labor-intensive industries (Managi et al., 2009). According to Antweiler et al. (2001), countries with capital-intensive industries are prone to severe pollution. Indeed, developed countries concentrate on capital-intensive industries in sectors with highly polluting activities (e.g., paper, metals, chemicals for agriculture and industry, iron and steel, and petroleum refining). This result suggests that OECD countries may have a comparative advantage in terms of pollution-intensive products. Consequently, the direct effect of trade openness on the composition of production can lead to a degradation in environmental quality.

Second, several studies establish a direct link between free trade and increases in international freight transport (Block, 2003; Grossman & Krueger, 1991; Poynter & Holbrook-White, 2002). For instance, Poynter and Holbrook-White (2002) showed an absolute increase in the concentrations of atmospheric pollutants at border-crossing points between Mexico and the United States and between the United States and Canada due to the intensification of road freight transport. We can imagine the same pattern between European countries because of the Schengen Agreement and the proximity effect between these countries. Thus, the intensification of the transport of goods (maritime, air, or road) in association with trade can significantly increase CO_2 emissions in OECD countries.

Our study discovered that trade openness has a positive influence on economic growth, which, in turn, leads to a decrease in carbon emissions after reaching the turning point estimated earlier. This negative relationship between income growth and CO2 emissions can be attributed to the "technical effect," whereby as incomes increase, people demand a cleaner environment. This effect is more pronounced in OECD countries owing to their high levels of economic development.

Similarly, regulations and policies that favor pollution reduction are reinforced by the awareness of individuals and their preferences for improving the quality of the environment. These preferences translate into individuals' ability to pay for the consumption of environmentally friendly and green goods. Therefore, an increase in income increases the strictness of environmental norms and rules (Lovely & Popp, 2011). Thus, our findings indicate that the indirect role of trade openness, through its effect on increasing income, reduces air pollution in OECD countries.

7 | CONCLUSION AND POLICY IMPLICATIONS

This study investigates the impact of trade openness on CO_2 emissions in OECD countries by decomposing the total effect into direct and indirect effects within the framework of the Environmental Kuznets Curve (EKC). Using a panel dataset of 20 OECD countries spanning from 1870 to 2019, we found robust evidence that trade openness has both direct and indirect effects on CO_2 emissions. The direct effect indicates a positive relationship between trade openness and CO_2 emissions, whereas the indirect effect shows a negative relationship between trade openness and carbon emissions through increased income. Our results validate the EKC hypothesis that explains how these two effects occur in opposite directions.

We also found that an increase in income leads to a rise in demand for environmental quality, indicating that economic growth induced by trade openness can result in people demanding more stringent environmental criteria and clean production technologies. This suggests that industrialized countries can achieve their income growth and trade openness targets without causing long-term environmental degradation in the long run. Therefore, our analysis suggests that trade openness can have a beneficial and reducing effect on CO_2 emissions in OECD countries, when the EKC hypothesis is validated.

We provide four recommendations to ensure consistency between trade and environmental policies. First, it is necessary to respond to environmental challenges by strengthening the multilateral cooperation between OECD countries. Leveraging multilateral cooperation and strengthening environmental policies at the local, national, and international levels will help ensure that trade contributes to the application of innovative technological solutions and fosters shifts toward more sustainable consumption and production patterns.

Second, trade openness could play a positive role in this process by facilitating the diffusion of environmentally friendly technologies in OECD and developing countries. Thus, OECD countries should facilitate and reduce barriers to the import of modern technologies and environmental services.

Third, it is vital to acknowledge that trade significantly contributes to greenhouse gas emissions, particularly CO_2, primarily through the transportation of goods (the direct effect). To overcome this problem, OECD countries should target transportation efficiency in order to reduce emissions. This entails investing in sustainable transportation infrastructure, providing incentives for the adoption of electric vehicles and promoting transport decarbonization. Initiatives to improve goods transportation networks, develop charging infrastructures, and offer subsidies for electric vehicle purchases are essential steps in this direction.

Fourth, it should promote the development of green financial instruments and markets. Encouraging the issuance of green bonds and other sustainable financial products can help fund environmentally friendly projects and initiatives. To drive this initiative forward, OECD governments should provide incentives for financial institutions to invest in low-carbon and sustainable assets.

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DATA AVAILABILITY STATEMENT

Data are available upon request.

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ENDNOTES

[1] The data are available at: https://www.sciencedirect.com/science/article/pii/S0140988318303736#s0055.

[2] The data are available at: https://www.sciencedirect.com/science/article/pii/S0140988320302474.

[3] Table A1 in the appendix present the definition and the source of all our variables.

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APPENDIX

TABLE A1 Definition and source of variables.

Variables	Measure	Source	Data availability
CO_2 emissions	Per capita emissions in metric tons	Churchill et al. (2018)	https://www.sciencedirect.com/science/article/pii/S0140988318303736#s0055
Trade Openness	Trade-to-GDP ratio	Churchill et al. (2018)	https://www.sciencedirect.com/science/article/pii/S0140988318303736#s0055
GDP per capita	Real GDP per capita	Churchill et al. (2018)	https://www.sciencedirect.com/science/article/pii/S0140988318303736#s0055
Population	Population size	Yao et al. (2020)	https://www.sciencedirect.com/science/article/pii/S0140988320302474
Financial development	Private credit-to-GDP ratio	Yao et al. (2020)	https://www.sciencedirect.com/science/article/pii/S0140988320302474
Investment	Ratio of physical investment to capital stock	Yao et al. (2020)	https://www.sciencedirect.com/science/article/pii/S0140988320302474
Ecological footprint	Per capita	Global footprint network (2023)	https://api.footprintnetwork.org/v1/data/5001/all/BCtot,EFCtot