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The role of financial and trade globalization in enhancing environmental sustainability: Evaluating the effectiveness of carbon taxation and renewable energy in EU member countries

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ABSTRACT

The study addresses the pressing issue of environmental degradation, pinpointing carbon dioxide (CO_2) emissions as its primary driver, posing a threat to global environmental sustainability, including the member countries of the European Union (EU). Global warming problems persist, but previous studies have not adequately explored the factors that contribute to a reduction in carbon emissions in EU countries. The paper fills the gap by assessing the efficacy of carbon tax and eco-innovation in mitigating CO_2 levels from 1994 to 2019, considering the influence of renewable energy and various aspects of globalization. The study establishes long-term associations among the indicators examined using advanced methodologies, including the cross-sectional autoregressive distributed lag approach and the Westerlund cointegration method. Notably, the results highlight that carbon taxes, eco-innovation, renewable energy, and globalization contribute to slowing environmental deterioration, and economic progress plays a role in mitigating environmental sustainability challenges in EU member states. These findings reinforce the importance of robust strategies for reducing CO_2 emissions and minimizing adverse environmental impacts.

1. Introduction

Climate change and global warming, caused by a rise in the concentration of carbon dioxide (CO_2) in recent decades, endanger environmental sustainability (Adebayo & Ullah, 2023; Sarkodie & Strezov, 2018). In 2020, global CO_2 emissions from fossil fuels fell 5.3 percent compared to the levels observed in 2019. This decline was primarily attributed to the impact of the Covid-19 pandemic, as reported by the Joint Research Center (JRC) in 2023. However, in 2021 global emissions substantially rebounded, nearly returning to the 2019 level, at 37.9 gigatons (Gt) of CO_2, a decrease of merely 0.36 percent from the level in 2019. This resurgence signals the world's return to pre-pandemic levels of CO_2 (JRC, 2023). Taking a broader perspective, over the past two decades, the 27 member states of the European Union (EU27) consistently reduced CO_2 due to fossil fuels. In 2021, these emissions reached 2.78 Gt, a reduction of 27.4 percent from the 1990 level (JRC, 2023). At the same time, the proportion of global emissions by the EU27 notably fell over time, declining from 16.8 percent in 1990 to 8.5 percent in 2015 and further diminishing to 7.3 percent in 2021 (JRC, 2023).

Despite rising concerns about CO_2 emissions concentration and climate change, a large share of economic growth in the member countries of the European Union (EU) is reliant on fossil fuels (Kirikkaleli & Kalmaz, 2020). In reality, countries hesitate to slow environmental deterioration if it jeopardizes greater prosperity. More precisely, as economic growth continues, more energy must be consumed, which raises CO_2. Several papers argue that the balance between environmental sustainability and economic growth can be

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achieved by using renewable energy (Dogan & Seker, 2016). European climate law mandates a reduction in greenhouse gas (GHG) emissions by EU member states of at least 55 percent by 2030, with an overarching objective of achieving climate neutrality in the EU by 2050 (EU Climate Report, 2023). As an interim milestone in their journey toward the 2050 goal, these countries committed to a reduction of more than 50 percent in the EU's GHG emissions, compared with the 1990 level, by 2030 (EU Climate Report, 2023). The 2030 climate objectives set by the EU encompass a proposal to revise its Renewable Energy Directive to raise the current target of 32 percent renewable energy sources in the EU's overall energy composition by 2030 to a minimum of 40 percent (EU Climate Report, 2023).

Furthermore, in light of financial integration on a worldwide scale, globalization is currently the most debated subject. The most important factors in accelerating the liberalization of economies and openness are investment, trade, and finance (Wang, Ramzan, Salahodjaev, Hafeez, & Song, 2023). By easing laws and intensifying their economies, all countries encourage foreign direct investment (FDI) and the global stock of liabilities and assets (Ahmad et al., 2021a). Financial markets can develop more easily as a result of financial globalization. It offers additional resources for funding investment in ecofriendly initiatives, including those in agriculture, information and communication technologies, construction, clean energy, and other sectors (Akpan, Adebayo, Akadiri, & Aladenika, 2022; Sheraz, Deyi, Sinha, Mumtaz, & Fatima, 2022). One consequence of financial globalization, however, is that the expansion of economic operations and funding for sectors that are not ecofriendly might lead to more environmental damage. Globalization has strengthened environmental protection movements around the world, which are advantageous for environmental conservation in economies at varying degrees of development (Miao, Razzaq, Adebayo, & Awosusi, 2022).

On average, the EU's financial globalization index rose from 54.22 in 1994 to 90.80 in 2019. Additionally, over the past 25 years, the mean financial globalization index of the EU member states has increased by 28 percent to 76.86 percent (KOF, 2023). Therefore, financial globalization is expected to have a significant role in affecting environmental conditions across the EU, given the strong development of financial globalization. It is noteworthy in this connection that these countries account for a significant share of the world's overall FDI flows (World Bank, 2023). As FDI is a significant mechanism of financial globalization, the pollution haven hypothesis (PHH) can be used to examine the environmental effects of financial globalization on EU member states. This hypothesis assumes that greater foreign financial inflows worsen host economies' environmental conditions (Shahbaz, Nasir, & Roubaud, 2018). Hence, the PHH is confirmed if financial globalization (FGLO) has a negative impact on the environment in the EU member states. Increasing climate change concern and the inability of the market to address environmental externalities have led several countries, in particular EU member states, to enact carbon taxes to reduce emissions and the use of fossil fuels (Cheng, Sinha, Ghosh, Sengupta, & Luo, 2021). Nevertheless, whereas the impact of carbon taxes on reducing CO_2 has been studied in various countries and regions, little data is found on EU countries (Hao, Umar, Khan, & Ali, 2021). Because several earlier panel investigations on the drivers of CO_2 in the EU neglected to include carbon taxes as a predictor of CO_2 (Adebayo, 2022a; Ozturk & Acaravci, 2016), the addition of a variable for carbon taxes is intended to address in part the bias from an omitted variable. As a result, adopting a carbon price may help address missing factors and changes in CO_2 (Çitil et al., 2023).

Various causes of environmental deterioration are discussed in the literature on environmental economics. Among the most common explanations of CO_2 are economic expansion, financial development, economic complexity, and natural resources (Abbasi, Hussain, Haddad, Salman, & Ozturk, 2022; Adebayo & Ullah, 2023; Bekun et al., 2019; Kirikkaleli, Sofuoğlu, & Ojekemi, 2023; Olanrewaju et al., 2022). Natural resource rent is considered in recent investigations of the connection between CO_2 and economic progress (Ahmad et al., 2021a; Ali, Nathaniel, Uzuner, Bekun, & Sarkodie, 2020; Sinha, 2015). But few studies have looked at the connection between CO_2 and deglobalization. Additionally, the interrelationship between REC and CO_2 has also been thoroughly studied, but without reaching any consensus (Alam & Murad, 2020; Armeanu, Joldes, Gherghina, & Andrei, 2021; Balcilar, Bekun, & Uzuner, 2019). Furthermore, as innovation is a powerful tool for halting environmental deterioration, eco-innovation is considered a critical component of environmental deterioration in recent research on the relationship between growth and the environment (Acheampong, 2018; Badeeb, Lean, & Smyth, 2016; Baniya & Aryal, 2022). Thus, earlier research indicates that the link between the parameters mentioned earlier and CO_2 is unstable. The studies are insufficient, with conflicting findings, creating a need for more research. More specifically, using a recently created financial globalization index, prior studies have not examined the combined effect of deglobalization, renewable energy, carbon taxes, and eco-innovation on CO_2 in EU member states.

The paper is structured as follows. Section 2 gives a quick summary of the pertinent literature. Section 3 describes the techniques and data. Section 4 contains a discussion and describes our findings. Section 5 offers a conclusion and suggests some policy implications.

2. Theoretical framework and literature review

The growing global discourse on environmental sustainability is inextricably linked to economic strategies, innovation, globalization, and renewable energy. The focus primarily falls on CO_2, a major contributor to climate change. This literature review explores scholarly work in these areas, illuminating the complex nature of CO_2. This analysis takes an overview of knowledge from 30 peer-reviewed articles, emphasizing carbon taxes and their influence on CO_2, the role of eco-innovation in curbing emissions, the impact of globalization on environmental quality, and the role of renewable energy in reducing CO_2.

Carbon taxes are intended to incentivize reduction in CO_2 economically. However, the policy's effectiveness differs across regions and socioeconomic landscapes, warranting a comparative analysis. Eco-innovation is another approach that promises emissions reduction via technological progress and corporate responsibility. The effect of globalization on CO_2, which is a complex topic, requires understanding of both developed and developing economies. Lastly, the shift to renewable energy, though a potential way to lower CO_2, necessitates research into varying energy policies and geographic scenarios.

2.1. *CO_2 emissions and carbon (or environmental) taxes*

Central to this discussion is the idea of implementing a carbon tax, a monetary policy measure designed to reduce CO_2 by imposing a tax on the carbon content of fossil fuels (Agostini, Botteon, & Carraro, 1992). The theoretical premise of this strategy is the economic principle that imposing a cost on a negative externality will discourage its creation or use of what creates it. The carbon tax is a powerful strategy for combating the detrimental environmental side effects of using fossil fuels, nudging corporations toward adopting cleaner, more sustainable energy alternatives (Zhou, Wang, Zhou, and Wang, 2011). The tax creates a natural financial deterrent to carbon-heavy activities, potentially fostering a transition to low-carbon or carbon-neutral options (Alola, 2019). Consequently, the carbon tax performs a dual role: effective reduction in CO_2 emissions and stimulation of innovation as well as the adoption of environmentally conscious technologies (Usman & Alola, 2022).

China uses fossil fuels and emits a great deal of CO_2; thus, a carbon pricing policy could harm its environment and economy. Zhou et al. (2011) investigate China's carbon pricing and potential for cutting emissions while enhancing growth. However, the successful execution of such a policy depends on finding a delicate balance between environmental preservation and economic advancement. Adebayo and Ullah (2023) highlight the importance of designing sustainable development policies under particular socioeconomic conditions and with government stability. When meticulously implemented, a carbon tax could become a pivotal tool in the battle against climate change. It offers a tangible economic way to cut carbon emissions, spark technological innovation, and create a greener, more sustainable future. Nevertheless, because of each country's unique socioeconomic circumstances, the potential negative economic repercussions highlight the importance of meticulous policy design.

The carbon tax, a strategic tool designed to discourage the financial appeal of carbon-intense activities, has substantially influenced CO_2 emissions. Pioneering researchers Li and Lin (2011) explore the effects of a carbon tax on per capita CO_2. Their empirical findings indicate that an intricately designed and efficiently executed carbon tax could lead to a significant reduction in emissions. They postulate that the carbon tax imposes a high price on pollution, prompting industries and consumers to find greener alternatives that are more cost effective, subsequently driving a decline in CO_2. Supporting this viewpoint, Ghazouani, Xia, Ben Jebli, and Shahzad (2020) confirm this conclusion by comparing CO_2 emissions in European countries that have implemented carbon tax policies and that have not done so. The study reveals a notable disparity in emissions levels, emphasizing the strength of carbon taxes as a policy instrument for combating carbon emissions. Building on these studies, Dogan, Hodžić, and Fatur Šikić (2022) look at the relationship between environmental taxation and carbon emissions in the context of the G7 economies. Their observations echo the direct association between the imposition of a carbon tax and the consequent decline in CO_2.

Even though the efficacy of a carbon tax is evident, it is crucial to consider the nuances of each distinct scenario in structuring and implementing such a policy. Socioeconomic conditions, technological innovation, and the prevailing political environment could affect the effectiveness of a carbon tax (Ghazouani et al., 2020). Therefore, policy makers must exercise prudence, ensuring that the tax does not disproportionately burden low-income households or cause job losses in sectors that rely heavily on carbon. A carbon tax can be an effective tool in the global effort to mitigate climate change by addressing these contingencies (Dogan et al., 2022). The implementation and impacts of carbon taxes vary considerably across different countries, reflecting their unique economic, political, and environmental contexts.

It is essential to recognize this variability and adapt carbon tax strategies accordingly, taking a customized approach that reflects the realities and demands of each specific setting (Doğan et al., 2022). By doing so, we can maximize the potential of carbon taxation to drive down CO_2 globally. Jiang, Liu, and Deng (2022) present a compelling comparative analysis of taxes on carbon, sulfur, and nitrogen in China. Although each of these taxes can help reduce emissions, a combined tax approach is more effective, suggesting the need for comprehensive tax policies rather than siloed measures. In stark contrast, as explored by Khastar, Aslani, and Nejati (2020), Finland successfully uses a carbon tax policy to promote social welfare and reduce emissions. Finland's carbon tax, one of the world's highest, highlights an essential policy design feature that can mitigate potential socioeconomic impacts. This tax redistribution mechanism returns tax revenue to households and businesses.

Nong, Simshauser, and Nguyen (2021) perform a global analysis that broadens this comparative view by discussing the implications of a carbon tax on GHG versus CO_2 emissions. Their study emphasizes the need for targeted policies based on the emissions types most prevalent in a given country, underscoring the necessity of tailored approaches in different countries. Achieving a balance between carbon taxation and its subsequent implications for social welfare and emissions reduction is crucial.

Renner, Lay, and Greve (2018) examine Mexico's energy and carbon tax programs, providing a nuanced understanding of this interplay. Mexico, an upper-middle-class country with a significant carbon footprint, presents a cautionary tale on the potential socioeconomic ramifications of carbon taxes if not handled with the necessary delicacy. Renner et al. (2018) find that implementing carbon taxes led to an increase in energy prices, negatively affecting the most impoverished households more than their wealthier counterparts because a larger share of their income is spent on energy. This regressive impact, if not properly addressed, can exacerbate social inequality.

However, despite these social implications, the study also finds a significant reduction in CO_2 emissions, highlighting the potential efficacy of such measures in environmental conservation. This creates conflict between the social and environmental objectives. Policy ingenuity is required to navigate this tension. For instance, Renner et al. (2018) propose using revenue from the carbon tax to offset the burden on poorer households, thereby promoting social welfare while maintaining environmental benefits. This highlights the need for the adoption of a holistic approach when implementing carbon taxes, ensuring that environmental benefits do not come at the cost of social equity. This balance is essential in crafting sustainable and just carbon taxation policies.

2.2. *CO_2 emissions and innovation (eco-innovation)*

Eco-innovation, a transformative approach to business practice and policy, is pivotal for addressing the issue of CO_2. It is driven by the need to improve environmental performance directly by producing greener goods and services or indirectly by promoting cleaner processes and systems (Fethi & Rahuma, 2019). The existing literature highlights the role of eco-innovation in CO_2 reduction. Fethi and Rahuma (2019), in their study on the top 20 refined oil-exporting countries, find a significant link between eco-innovation and lower CO_2, thus demonstrating the impact of eco-innovation at a macro scale. This relationship is due to the advent of technologies and strategies that minimize the environmental footprint of oil extraction and processing, a traditionally high-emissions industry. Eco-innovation also shows promise at the firm level. Fethi and Rahuma (2020) research selected petroleum companies, revealing a similar positive correlation between eco-innovation and lower CO_2 emissions. Companies that invest in innovative practices and technologies reduce their emissions levels significantly.

Ji, Umar, and Ji (2020) examine fiscally decentralized countries and support the role of eco-innovation in promoting a sustainable environment. Their research demonstrates the potential for fiscal decentralization to spur eco-innovation, spurring reduction in CO_2.

The role of eco-innovation in reducing CO_2 emissions has been a topic of substantial interest in developed economies, particularly the G-7 countries. These countries, which have robust economic machinery, are committed to sustainability and environmental conservation, particularly through eco-innovation (Ding, Khattak, & Ahmad, 2021). Ding et al. (2021) provide an insightful examination of the relationship between energy productivity, eco-innovation, and CO_2 in the G-7 countries. The findings reveal a significant negative relationship between eco-innovation and CO_2. This correlation reflects the efficacy of eco-innovation strategies in mitigating the environmental impact of consumption practices, further emphasizing the need for countries to foster and adopt such strategies.

Qureshi, Ahsan, and Gull (2022) explore the role of country-level eco-innovation in reducing corporate CO_2 emissions, specifically in the European context. According to their research, eco-innovation may reduce business CO_2 by promoting greener manufacturing processes. Fareed, Han, Rehman, Ullah, and Afridi (2022) examine financial inclusion, environmental degradation, and innovative activity in the eurozone. Innovation activity considerably moderates the association between financial inclusion and environmental deterioration. This indicates that the integration of eco-innovation can mitigate the negative environmental impacts of corporations and encourage more sustainable practices, even in the financial sector. Therefore, eco-innovation is a promising route for reducing corporate CO_2. As some research suggests, adopting eco-innovation practices at the corporate level can facilitate a shift to sustainability and promote environmental responsibility (Fareed et al., 2022).

Hordofa et al. (2022) offer intriguing insights into the potential effects of eco-innovation and green investment on CO_2 in China. They establish a solid connection between eco-innovation and CO_2 mitigation, and green capital investment is crucial to this relationship. They assert that as China bolsters its dedication to green capital infusion, which sparks the incorporation of eco-innovation across many sectors, expediting the transition to a low-carbon economy. As a result, this helps curtail CO_2 emissions and proposes a practical method for tackling the challenges of climate change. Adebayo and Ullah (2023) highlight the necessity of designing sustainable development strategies within the framework of China's socioeconomic environment and political stability. They emphasize that China's governing body has shifted to sustainable development agendas that integrate green investment and endorse eco-innovative initiatives. These approaches reduce CO_2 and promote sustainability. However, the success of these tactics is contingent on the country's economic strength and political will.

2.3. *CO_2 emissions and globalization*

Globalization, characterized by increased economic interconnectivity, has profound implications for CO_2 emissions. Herrmann and Hauschild (2009) shed light on the effects of globalization on the carbon footprint of products. They argue that globalization leads to a complex interplay of global supply chain processes, often resulting in a significant increase in CO_2 due to increased energy use and transportation needs. The internationalization of production processes thus has a significant environmental cost, which is often overlooked in conventional economic analyses. Corroborating these views, Ansari, Haider, and Khan (2022) delve further into the relationship between productivity, globalization, and carbon emissions. They assert that productivity enhancements associated with globalization often increase the consumption of fossil fuels, leading to higher carbon emissions. Their study focuses in particular on the emissions from coal, oil, and gas, highlighting that globalization might inadvertently exacerbate environmental degradation if not managed judiciously. Collectively, these studies present a compelling case for integrating carbon emissions considerations in the discourse on globalization.

The relationship between globalization and environmental quality in developed economies is complex. Shahbaz, Shafiullah, Papavassiliou, and Hammoudeh (2017) raise a question of considerable significance: Does the march of globalization exacerbate environmental degradation in developed economies? Their research indicates that although globalization propels economic development in mature economies, it intensifies the strain on environmental resources, escalating CO_2. Consequently, the repercussions of globalization on environmental integrity present a paradox; even as it stimulates economic expansion and prosperity, at the same time, it jeopardizes the environment by amplifying carbon emissions. This dual nature of globalization heightens the urgency of devising strategic environmental policies capable of counteracting the negative environmental impact while also benefiting from the advantages of globalization. Harmonizing economic advancement with environmental preservation is particularly relevant in developed economies, significantly influencing the global level of CO_2. This highlights the need for a revitalized focus on sustainable development strategies in the age of globalization.

Yameogo, Omojolaibi, and Dauda (2021) give an unparalleled view, offering insights into the ramifications of economic globalization on environmental quality in the context of sub-Saharan Africa. Their research reveals that the inflow of foreign capital and commodities has stimulated an increase in industrial activity in the region, raising the use of energy-intensive resources. This higher demand for energy, derived predominantly from fossil fuels, increases CO_2 emissions. Consequently, although economic globalization has raised economic growth in sub-Saharan Africa, it has also degraded environmental quality because of rising pollution levels (Yameogo et al., 2021). Nevertheless, Yameogo et al. (2021) also contend that the impact of globalization on environmental quality is not just unidirectional, stressing the crucial role of institutions in mediating this relationship. More robust institutional quality, characterized by stronger regulatory policies and improved governance structures, can mitigate the detrimental environmental impacts of globalization. This finding highlights the importance of strengthening institutions in sub-Saharan Africa to leverage the benefits of globalization while minimizing its negative impacts on environmental quality (Yameogo et al., 2021). Thus, while globalization presents certain environmental challenges, its effects can be moderated through effective institutional mechanisms, providing a path for sustainable development in the sub-Saharan region.

Sun, Raza, Taghizadeh-Hesary, and Iram (2021) explains the intricate relationship between eco-innovation, globalization, and carbon neutrality in the United States. They argue that eco-innovation, fostered by globalization, is pivotal in achieving carbon neutrality. Their research posits that globalization, through the diffusion of innovative technologies and practices, can significantly reduce the carbon footprint of industries. In particular, the rapid global transmission of clean technologies and renewable energy solutions, underpinned by globalization, is seen as instrumental in driving down carbon emissions in the US. However, the transition to carbon neutrality through eco-innovation in the context of globalization is complex. Although globalization creates access to eco-innovative technologies, it also amplifies the need for implementation because of increased industrial activity and the resulting emissions (Sun et al., 2021). Moreover, effectively deploying these technologies requires a supportive policy framework and considerable infrastructural adjustments. Therefore, Sun et al. (2021) argues for a strategic coordination between eco-innovation and globalization, supported by robust policy measures, to effectively address the challenges posed by carbon emissions. This strategy involves policies that encourage the adoption of clean technologies, foster international collaboration for sharing knowledge, and implement reforms in domestic industries to accommodate eco-innovative practices (Sun et al., 2021).

2.4. *CO_2 emissions and renewable energy*

Chiu and Chang (2009) indicate the potential role of renewable energy in mitigating CO_2 emissions in The Organization for Economic Co-operation and Development (OECD) member countries. Their research highlights a crucial correlation between adopting renewable energy and the initial mitigation of CO_2 emissions. Expanding renewable energy sources reduces our carbon footprint, as suggested by Chiu and Chang (2009). More specifically, replacing fossil fuels with renewable energy may significantly cut CO_2 emissions, highlighting the importance of adopting renewable energy in climate change initiatives. Building on the previous findings, Namahoro, Wu, Zhou, and Xue (2021) examine the impact of renewable energy on CO_2 emissions in the context of African regions across various income levels. They demonstrate that renewable energy use has a pronounced negative effect on CO_2 emissions, especially in high-income African countries. This negative correlation signifies that as renewable energy consumption increases, CO_2 emissions decrease. Additionally, Namahoro et al. (2021) stress the influence of energy intensity and economic growth as further factors that affect emissions. They suggest that incorporating these aspects into strategic planning and policy creation bolsters the effectiveness of renewable energy in diminishing CO_2 emissions.

Like renewable energy, nuclear power is viewed as a feasible substitute for fossil fuels, considering its ability to generate considerable amounts of power with minimal carbon emissions. Saidi and Mbarek (2016) explore this correlation in nine developed countries. They find that nuclear energy, in conjunction with renewable energy, significantly reduces CO_2 emissions, identifying a causal relationship. Building on the earlier study, Saidi and Omri (2020) investigate the role of nuclear and renewable energy in reducing CO_2 in OECD countries. Their findings corroborate previous research by revealing a substantial inverse correlation between fossil fuels energy and CO_2 emissions. However, they place special significance on the function of renewable energy, arguing that its role will only become more crucial because of the environmental and safety concerns related to nuclear energy. This infers that although both types of energy can help in reducing CO_2 emissions, renewable energy should be emphasized in the long-term strategy.

In an insightful review of Pakistan's renewable energy policies, Qudrat-Ullah and Nevo (2022) unravels the connection between these policies and CO_2 in the country. Qudrat-Ullah explains that implementing robust and comprehensive renewable energy policies has the potential to diminish CO_2 considerably. Despite the increasing attention to renewable energy sources in policy discussions, a substantial reduction in CO_2 remains elusive for many complex and interrelated reasons, including the slow transition from traditional energy sources and infrastructural constraints. Liu, Yan, and Zhou (2021) assess the intertwined relationship between environmental performance, international trade, renewable energy, and eco-innovation in the Chinese context. Their findings demonstrate that adopting renewable energy and eco-innovation practices improves environmental performance, particularly by reducing CO_2. This improvement, in turn, drives the competitiveness of Chinese products in the international market, thus facilitating international trade.

Liu et al. (2021) stress the synergistic combination of adopting renewable energy and eco-innovation. This combination has environmental benefits and promotes economic growth through enhanced trade opportunities. These findings highlight the multifaceted implications of renewable energy and eco-innovation, emphasizing their role as catalysts for fostering environmental sustainability. At the same time, they spur economic growth and international trade competitiveness in China. Therefore, their research implies strategically incorporating renewable energy and eco-innovation into national development and trade policies.

2.5. Gaps in the literature

Although the literature surveyed is comprehensive, it has some gaps that need to be filled. First, although many papers discuss the relationship between CO_2 emissions and eco-innovation, renewable energy, and globalization, more emphasis is needed on deglobalization. Second, although some research has examined the influence of globalization on CO_2 (Shahbaz et al., 2017; Yameogo et al., 2021), few papers have conducted a detailed investigation on how economic globalization, trade globalization, and financial integration—which are critical aspects of globalization—influence CO_2. Third, most of the studies employ first-generation techniques that do not address the issue of cross-sectional dependence and slope heterogeneity. Fourth, none of the aforementioned studies examines the role of a carbon tax and deglobalization in curbing environmental degradation, specifically in EU countries. Our investigation fills these gaps by exploring the role of the carbon tax and deglobalization on CO_2 while considering the role of renewable energy and eco-innovation in the EU, using data from 1990 to 2019.

3. Data and methods

3.1. Data

This study investigates the impact of a carbon tax, eco-innovation, and renewable energy on mitigating CO_2 emissions. It also considers other factors that influence CO_2 emissions, such as economic growth, economic globalization, trade globalization, and financial globalization. The study focuses on EU member states as a case study, examining the relationship among these variables from 1990 to 2019. The sample period is based on data availability. The variables used in the analysis are transformed using logarithmic scaling to address skewness. Table 1 lists detailed information on the dependent and independent variables. Furthermore, Fig. 1 illustrates the minimum, maximum, and mean values of the variables, and Fig. 2 gives a scatter plot depicting the relationship among the variables.

3.2. Models

In this study, three different models are used in the empirical analysis, as follows:

$$\mathrm{LnCO}_{2\mathrm{it}} = f(\mathrm{Ln\ GDP}_{\mathrm{it}}, \mathrm{LnREC}_{\mathrm{it}}, \mathrm{LnCATAX}_{\mathrm{it}}, \mathrm{LnECO}_{\mathrm{it}}, \mathrm{LnTGLO}_{\mathrm{it}}) \tag{1}$$

$$\mathrm{LnCO}_{2\mathrm{it}} = f(\mathrm{Ln\ GDP}_{\mathrm{it}}, \mathrm{LnREC}_{\mathrm{it}}, \mathrm{LnCATAX}_{\mathrm{it}}, \mathrm{LnECO}_{\mathrm{it}}, \mathrm{LnEGLO}_{\mathrm{it}}) \tag{2}$$

$$\mathrm{LnCO}_{2\mathrm{it}} = f(\mathrm{Ln\ GDP}_{\mathrm{it}}, \mathrm{LnREC}_{\mathrm{it}}, \mathrm{LnCATAX}_{\mathrm{it}}, \mathrm{LnECO}_{\mathrm{it}}, \mathrm{LnFGLO}_{\mathrm{it}}) \tag{3}$$

where CO_2 is the level of carbon dioxide emissions, CATAX is the carbon tax, ECO is eco-innovation, REC is renewable energy, GDP is economic growth, EGLO is economic globalization, TGLO is trade globalization, FGLO is financial globalization, i is the country, and t is the time. The economic models used are as follows:

$$\mathrm{LnCO}_{2\mathrm{it}} = \beta_0 + \beta_1\ \mathrm{Ln\ GDP}_{\mathrm{it}} + \beta_2\ \mathrm{Ln\ REC}_{\mathrm{it}} + \beta_3\ \mathrm{Ln\ CATAX}_{\mathrm{it}} + \beta_4\ \mathrm{Ln\ ECO}_{\mathrm{it}} + \beta_5\ \mathrm{Ln\ TGLO}_{\mathrm{it}} + \varepsilon_{it} \tag{4}$$

$$\mathrm{LnCO}_{2\mathrm{it}} = \beta_0 + \beta_1\ \mathrm{Ln\ GDP}_{\mathrm{it}} + \beta_2\ \mathrm{Ln\ REC}_{\mathrm{it}} + \beta_3\ \mathrm{Ln\ CATAX}_{\mathrm{it}} + \beta_4\ \mathrm{Ln\ ECO}_{\mathrm{it}} + \beta_5\ \mathrm{Ln\ EGLO}_{\mathrm{it}} + \varepsilon_{it} \tag{5}$$

$$\mathrm{LnCO}_{2\mathrm{it}} = \beta_0 + \beta_1\ \mathrm{Ln\ GDP}_{\mathrm{it}} + \beta_2\ \mathrm{Ln\ REC}_{\mathrm{it}} + \beta_3\ \mathrm{Ln\ CATAX}_{\mathrm{it}} + \beta_4\ \mathrm{Ln\ ECO}_{\mathrm{it}} + \beta_5\ \mathrm{Ln\ FGLO}_{\mathrm{it}} + \varepsilon_{it} \tag{6}$$

where the variables are the same as those in Equations (1)–(3), with the addition of β_0, a constant, and ε, an error term.

3.3. Methodology

This paper explores slope heterogeneity and cross-sectional interdependence, in particular, the order of integration for the variables under scrutiny. The application of cross-sectional dependence (CD) tests by Pesaran (2004) plays a critical role in this inquiry. The cross-sectionally augmented unit-root test by Im, Pesaran, and Shin (IPS) and the Westerlund cointegration test assume slope heterogeneity and CD. Advanced Pesaran CD tests guarantee robust results.

The slope heterogeneity test by Pesaran and Yamagata (P&Y; 2008)

Table 1
Data source and measurement.

Symbol	Variables	Measurement	Source
CO_2	Carbon Emissions	Metric Tonnes Per Capita	OWD Database
CATAX	Carbon Tax	Total environmental tax as % of GDP	OECD Database
ECO	Eco-innovation	Patent Environmental related Tax % of GDP	OECD Database
REC	Renewable Energy	Renewables per capita (kWh - equivalent)	OWD Database
GDP	Economic Growth	GDP Per Capita Constant US$ 2015	World Bank Database
EGLO	Economic Globalization	Index	KOF Database
TGLO	Trade Globalization	Index	KOF Database
FGLO	Financial Globalization	Index	KOF Database

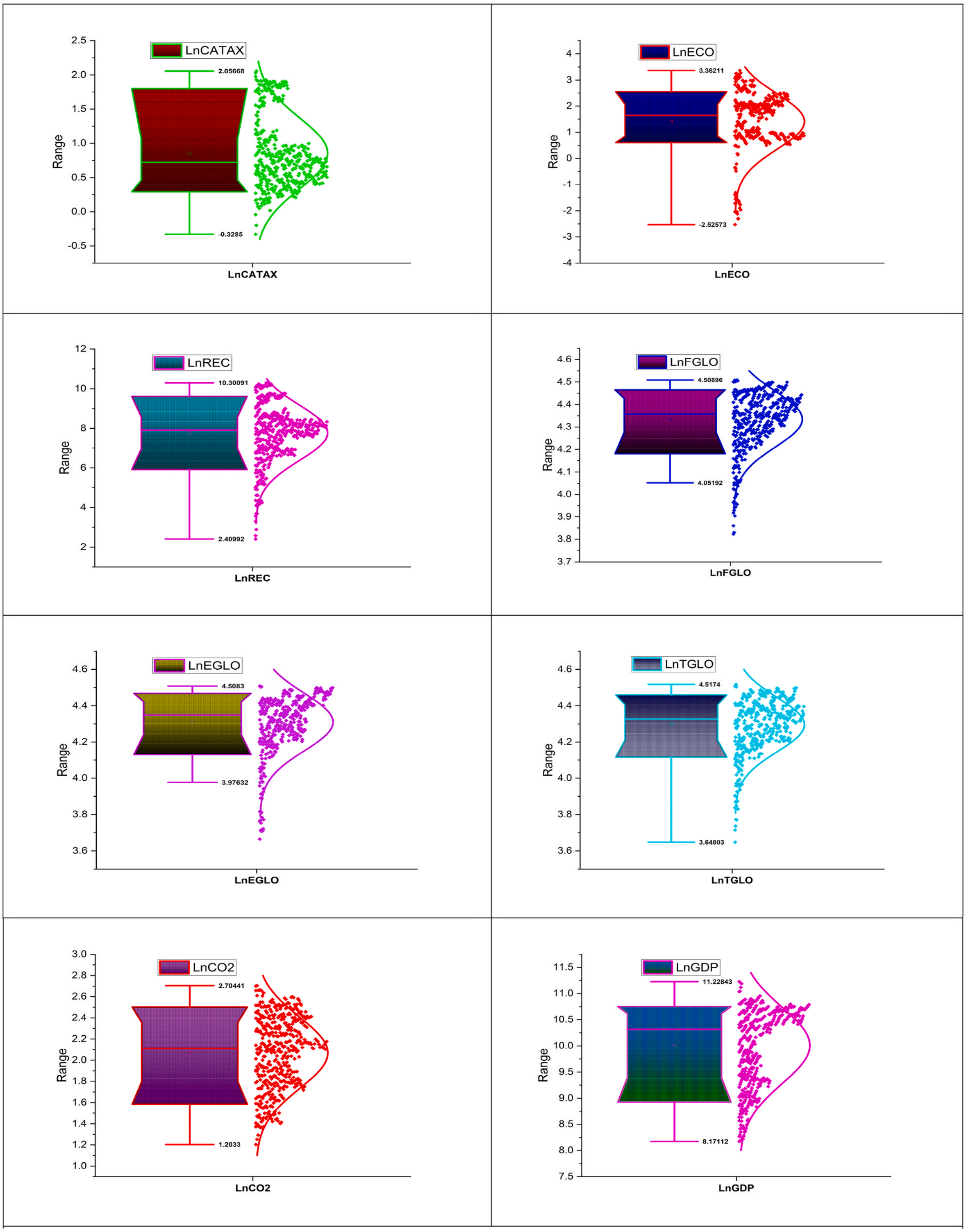

Fig. 1. Statistics summary (box plot).

is used. CD makes the P&Y test superior to the seemingly unrelated regression equation (SURE) framework (Atasoy, 2017). The SURE test works on both large and small cross sections, but the P&Y test works best when T is long, N is small, or T > N. This study uses the P&Y test because the data have CD and a long time series with a small cross section.

Slope homogeneity (SH) test equations:

$$\widetilde{\Delta}_{SH} = (N)^{\frac{1}{2}}(2k)^{-\frac{1}{2}}\left(\frac{1}{N}\widetilde{S} - k\right) \tag{7}$$

$$\widetilde{\Delta}_{ASH} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1)}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\widetilde{S} - 2k\right) \tag{8}$$

The variable integration order was determined using the Im, Pesaran, and Shin (IPS, 2003) test, cross-sectionally augmented Dickey-Fuller (CADF), and the Cross-sectionally augmented Im-Pesaran-Shin (CIPS) tests. First- and second-generation unit-root tests are used. The CIPS test is more appropriate because traditional panel unit-root testing may produce incorrect findings. The study uses all previous unit-root tests to

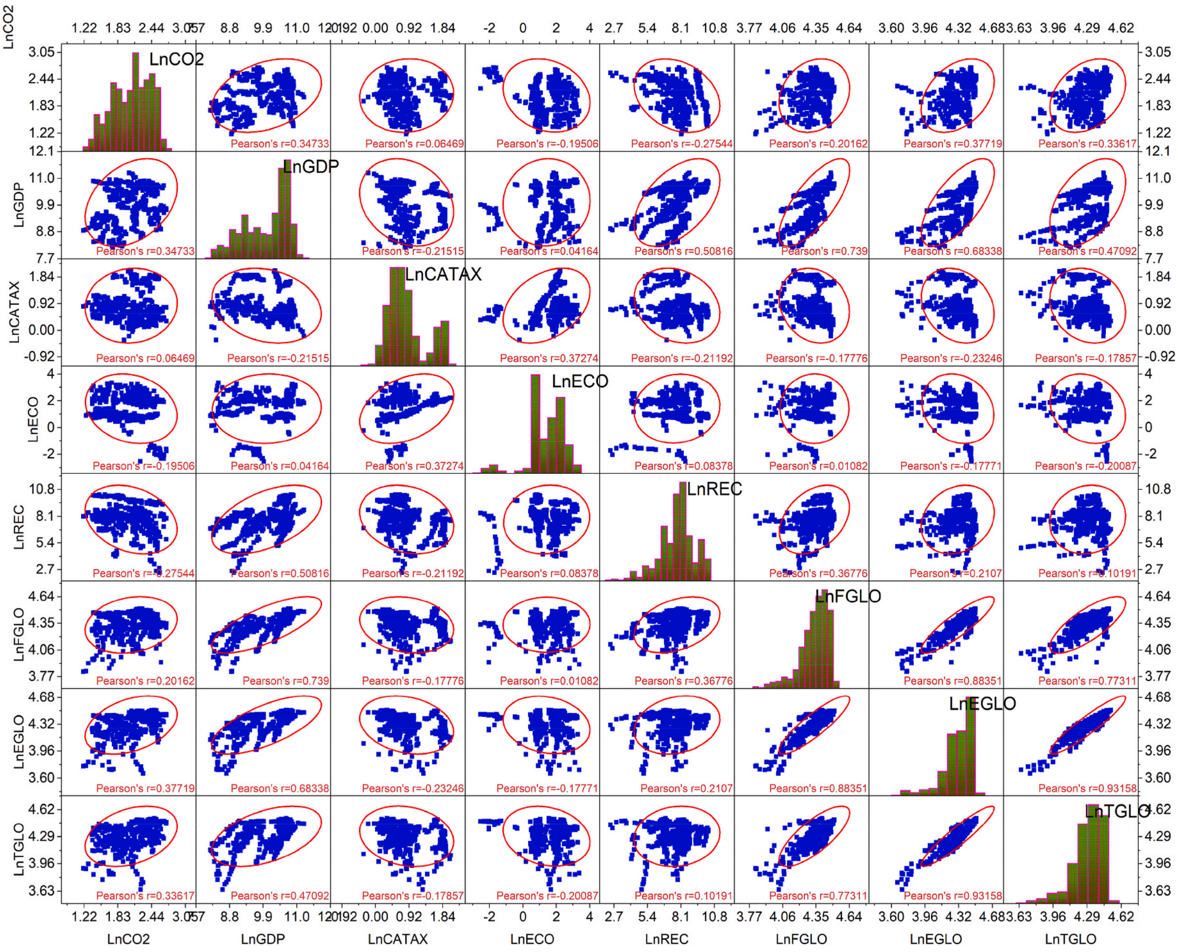

Fig. 2. Scatter plot.

avoid bias. The CIPS equation is as follows:

$$\alpha i(L)\Delta y_{it} = y2_{it} + \beta_i(y_{it} - 1 - \acute{\alpha}_i \mathrm{x}_{\mathrm{it}}) + \lambda_{\mathrm{i}}(\mathrm{L})\mathrm{v}_{\mathrm{it}} + \eta_{\mathrm{i}} \tag{9}$$

where

$$\delta_{1i} = \beta_i(1)\widehat{\vartheta}_{21} - \beta_i\lambda_{1i} + \beta_i\widehat{\vartheta}2_i \text{ and } y2_i = -\beta_i\lambda 2_i \tag{10}$$

This study employs Westerlund's (2007) cointegration test to investigate the correlation between consumption-based carbon emissions (cbe) and factors such as trade, income, green technology innovation, energy consumption, and industrial value added for G7 countries. This test is suitable for cross-sectionally dependent error terms (Kapetanios, Pesaran, & Yamagata, 2011) and imposes no common factor constraints. It does not assume cointegration, avoiding errors associated with traditional panel data methodologies. In equations, β_i is the error correction coefficient, and αi signifies the cointegration vector between x and y. The test statistics are as follows:

$$G_t = \frac{1}{N}\sum_{i-1}^{N}\frac{\acute{\alpha}_i}{SE(\acute{\alpha}_i)} \tag{11}$$

$$G_\alpha = \frac{1}{N}\sum_{i-1}^{N}\frac{\mathrm{T}\acute{\alpha}_i}{\acute{\alpha}_i(1)} \tag{12}$$

$$P_T = \frac{\acute{\alpha}}{SE(\acute{\alpha})} \tag{13}$$

$$P_\alpha = \mathrm{T}\acute{\alpha} \tag{14}$$

The panel (Pa and Pt) and group mean (Ga and Gt) statistics in Westerlund's 2007 test evaluate the speed of equilibrium adjustment. Adjusting Pα = T in Equation (14) computes the error correction parameter (ά), signifying the annual error correction percentage in short-run disequilibrium. The study employs (CS-ARDL) (Chudik & Pesaran, 2013) to analyse the long-term relationship between the variables as follows:

$$CNR_{it} = \beta_0 + \sum_{j=1}^{q}\pi_{it}CNR_{i,t} + \sum_{j=0}^{q}\theta_{i1}^{t}X_{i,t-j} + \sum_{j=0}^{q}\varphi_{i1}^{t}\gamma_{i,t-1}\overline{Z}_{i,t-j} + e_{it} \tag{15}$$

To test the robustness of the CS-ARDL, three additional estimators are adopted: a common correlated effects mean group, an augmented mean group, and the panel quantile regression models. The study also investigates the direction of causality using a heterogeneous (Dumitrescu & Hurlin, 2012) approach. Because of the diverse characteristics of the cross sections, this research employs fully modified Ordinary Least Square (OLS). Fig. 3 reflects the flow of the analysis.

4. Discussion of the results

4.1. Preliminary test results

Before conducting panel unit-root tests to assess the stationarity of the variables, we check for the presence of CD. Economic liberalization and globalization have made the world more closely interconnected. It is critical to address CD in panel statistics to avoid biased results from cointegration and unit-root testing because policy actions in one country can affect the economies of neighboring countries (Alola et al., 2023). To do so, we rely on Pesaran (2007), and the results are listed in Table 2.

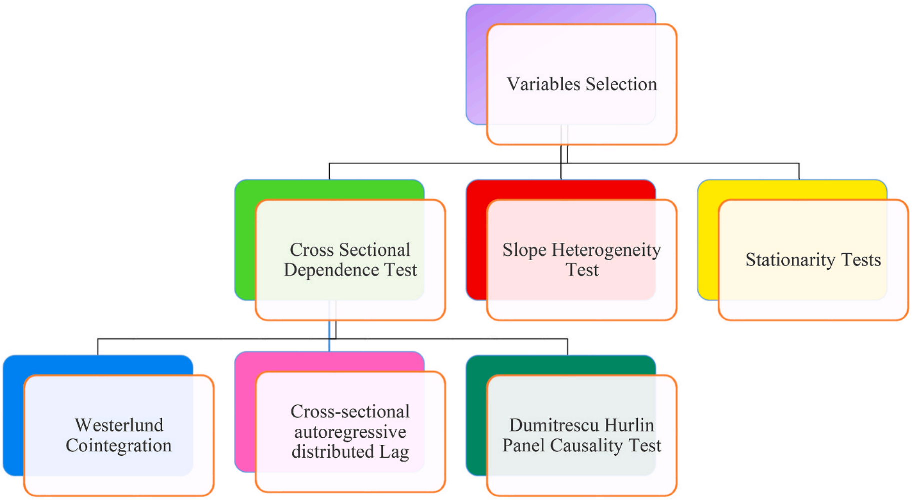

Fig. 3. Flow of the analysis.

Table 2
CD tests.

Tests	$LnCO_2$	LnGDP	LnREC	LnCATAX	LnECO	LnTGLO	LnEGLO	LnFGLO
Breusch-Pagan LM	2029.5***	3357.4***	2657.7***	1010.1***	952.95***	2947.3***	3135.6***	4011.1***
Pesaran scaled LM	100.50***	172.30***	134.46***	45.373***	42.283***	150.12***	160.31***	207.64***
Bias-corrected scaled LM	100.12***	171.92***	134.08***	44.993***	41.903***	149.74***	159.93***	207.26***
Pesaran CD	37.276***	56.159***	50.126***	4.8026***	4.1000***	47.120***	54.726***	63.244***

Note: ***P<1%.

The null hypothesis is disregarded because the results show the presence of CD in the panel data. Hence, any alteration in a factor such as carbon taxes, CO_2, economic growth, globalization (trade, economic, and financial), and eco-innovations in one EU country would affect them in the other countries.

It is vital to confirm the presence of CO2, as failing to perform the CD test can lead to inconsistency in the results, size distortion, and bias (Pesaran, 2006). However, despite the existence of CD, countries can still maintain their individual dynamism. Assuming a homogeneous slope coefficient might lead to inaccurate conclusions (Hashem Pesaran & Yamagata, 2008). Consequently, we need to test the null hypothesis of uniform slopes by conducting a slope homogeneity test, as mentioned earlier. Table 3 reveals the presence of country-specific variability and significant differences in the variables across individual cross sections at a significance level of 1 percent. In light of these findings, the CS-ARDL is deemed suitable as it accommodates heterogeneity.

We use the second-generation unit-root tests, which consider the CD features of the data, as our data are CD linked (Pesaran, 2007). Table 4 shows that all indicators are I (1) after the CIPS and CADF tests are performed.

Before conducting the main analysis, we need to address cointegration. Thus, we examine the cointegration among two or more stationary variables. After determining the data's integration characteristics, we perform the cointegration test (Westerlund, 2007) to test for cointegration considering both CD and SH (see Table 5). Then, we explore the connection between the series in the long term, and the results confirm a long-term connection among the variables.

Table 3
Slope heterogeneity.

	(Model 1)	(Model 2)	(Model 3)
	11.585***	10.201***	9.084***
adj.	12.753***	11.441***	10.213***

Note: ***P<1%.

Table 4
CIPS and CADF results.

Variables	CIPS		CADF	
	I (0)	I(I)	I (0)	I(I)
$LnCO_2$	−1.930	−4.453***	−0.894	−4.831***
LnGDP	−2.128	−4.739***	−2.337	−4.447***
LnREC	−2.027	−3.959***	−1.386	−3.901***
LnCATAX	−3.503**	–	−3.739	–
LnECO	−1.113	−4.533***	−1.877	−4.455***
LnTGLO	−2.228	−3.783***	−2.244	−3.645***
LnEGLO	−2.393	−3.870**	−0.735	−4.501***
LnFGLO	−1.747	−4.622***	−1.203	−4.331***

Note: ***P<1% and **P<5%.

Table 5
Cointegration results.

Statistic	Model-1	Model-2	Model-3
Gt	−3.448***	−2.901**	−1.793***
Ga	−10.933**	−14.01***	−3.113
Pt	−11.302***	−10.841*	−4.205*
Pa	−10.116*	−11.220***	−2.928

Note: ***P<1%, **P<5% and *P<10%.

After confirming the occurrence of cointegration among the variables under examination, we employed the CS-ARDL test, which enables us to identify SH and CD, as shown in Tables 6 and 7. According to Yang, Khan, and Olanrewaju (2024), using the CS-ARDL test is a robust approach for capturing short- and long-run interrelationships. The long-run findings reveal that the impact of GDP on CO_2 is statistically significant at 1 percent, indicating that an increase in GDP leads to intensification in CO_2 (see Models 1–3). Similarly, the results in the short run also have a positive association.

Furthermore, the effect of REC on CO_2 is negative in all models,

Table 6
Long-run CS-ARDL results.

	Model-1		Model-2		Model-3	
	Coefficient	Z-stat	Coefficient	Z-stat	Coefficient	Z-stat
LnGDP	0.387	4.741***	0.373	3.07	0.360	2.87***
LnREC	−0.028	−2.250**	−0.036	−2.70	−0.058	−2.27**
LnCATAX	−0.004	−4.073***	−0.021	−0.31	−0.161	1.83*
LnECO	−0.035	−2.620***	−0.102	−1.80*	−0.198	−2.18**
LnTGLO	−0.021	−2.201**	–	–	–	–
LnEGLO	–	–	−0.148	−0.71	–	–
LnFGLO	–	–	–	–	−0.549	−2.44**

Note: ***P<1%, **P<5% and *P<10%.

Table 7
Short-run CS-ARDL results.

	Model-1		Model-2		Model-3	
	Coefficient	Z-stat	Coefficient	Z-stat	Coefficient	Z-stat
LnGDP	0.779	4.830***	0.766	3.160***	0.682	2.766***
LnREC	−0.055	−2.245**	−0.064	−2.441**	−0.101	−2.191**
LnCATAX	−0.017	−0.167	−0.049	−0.493	0.301	1.915*
LnECO	−0.079	−0.680	−0.185	−1.86*	−0.370	−2.250**
LnTGLO	0.012	0.079	–	–	–	–
LnEGLO	–	–	−0.355	−0.81	–	–
LnFGLO	–	–	–	–	−1.1352	−2.522**
ECT (−1)	−0.934	−17.06***	−0.605	−12.96***	−0.902	−13.97***

Note: ***P<1%, **P<5% and *P<10%.

suggesting a emissions-dampening effect in each model. Likewise, the short-run results confirm a similar connection between CO_2 and emissions reduction. In addition, the effect of CATAX on CO_2 is negative, in both the short and long term, suggesting an emissions-mitigating effect of CATAX in all the models. In the short term, we also observe probable results that confirm the role of CATAX in reducing CO_2. Moreover, ECO has a dampening effect on CO_2 in both the short and long term, which suggests overall that the effect of CATAX on CO_2 is negative, suggesting that it improves the ecosystem.

Furthermore, in Model 1, we observe a negative TGLO effect on CO_2 in both the short and long run, suggesting that TGLO plays a role in the mitigation of emissions in the EU states. The same results are reported by the effect of EGLO and FGLO in the short and long term, suggesting that deglobalization (economic, financial, and economic) promote environmental quality by decreasing CO_2. Additionally, the corresponding coefficient parameters have negative signs, which supports the pollution halo hypothesis.

The models' error correction terms (ECT), which have values of 0.934 (Model 1), 0.876 (Model 1), and 0.902 (Model 3) are notably negative. In light of this, the high ECT values suggest rapid long-term integration into the equilibrium. This implies that any CO_2 out of equilibrium over the long term is adjusted in the present at a rate of about 93 percent, 87 percent, and 0.90 percent over the next year. Fig. 4 gives a summary of the findings.

4.2. Panel causality test

We examine the path of causality using a panel Granger-causality test (Dumitrescu & Hurlin, 2012) because the studies mentioned above do not reveal the path of Granger causality among the indicators in question. Table 8 list the results of the test, showing unidirectional causality from financial globalization, economic growth, economic globalization,

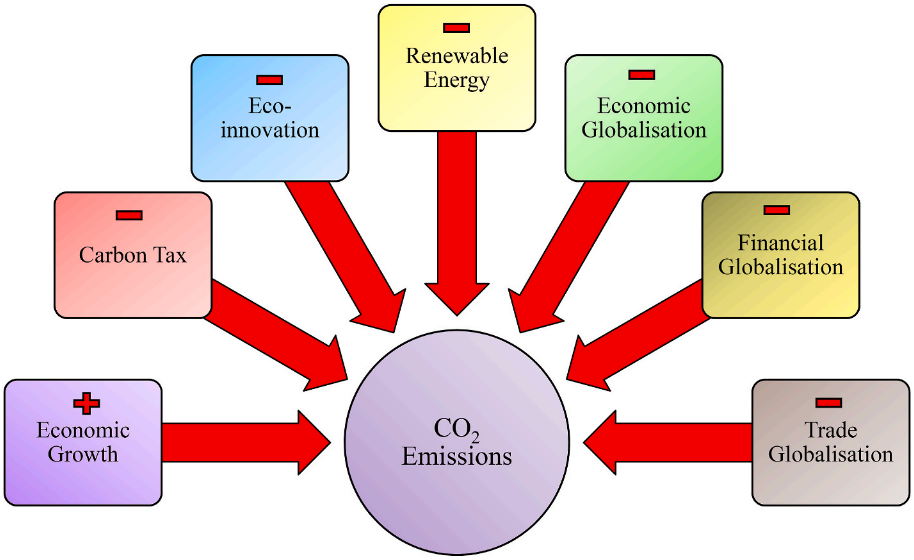

Fig. 4. Summary of findings.

Table 8
DH causality tests results.

Dependent Variables	Independent Variables							
	$LnCO_2$	LnGDP	LnREC	LnCATAX	LnECO	LnTGLO	LnEGLO	LnFGLO
$LnCO_2$		6.865***	7.267***	4.528***	4.401***	2.653***	1.229	8.408***
LnGDP	1.094		0.243	12.88***	9.915***	4.289***	3.724***	0.401
LnREC	1.166	6.401***		0.996	2.992***	1.978*	2.606***	9.582***
LnCATAX	3.720***	7.142***	5.316***		0.364	0.278	1.173	3.101***
LnECO	2.172**	6.585***	4.790***	2.792***		1.877*	2.661***	2.847***
LnTGLO	1.288	3.812***	3.931***	1.649*	−0.196		2.484**	7.629***
LnEGLO	1.338	1.538	1.788*	4.243***	2.039**	1.747*		0.138
LnFGLO	−0.962	3.649***	5.581***	1.687*	1.559	1.398	0.911	

Note: ***P<1%, **P<5% and *P<10%.

renewable energy, trade globalization, and economic globalization to CO_2. Furthermore, there is feedback causality between CO_2 and carbon tax and eco-innovation.

4.3. *Discussion of findings*

In each model, the positive effect of economic progress on CO_2 is positive, signifying that the rise in emissions is due to acceleration in economic progress. These results are consistent with those by Acheampong (2018), Alam and Murad (2020), Ozturk and Acaravci (2016), and Adebayo (2022a) and a similar association is seen in emerging economies (Acheampong, 2018; Adedoyin, Gumede, Bekun, Etokakpan, & Balsalobre-lorente, 2020; Aye & Edoja, 2017). Rising incomes typically result in greater consumption of services and goods, which, in turn, drives greater transportation of products and production, consequently resulting in higher energy consumption and CO_2. Furthermore, individuals with higher wealth may have larger homes, engage in energy-intensive activities, and own more vehicles. The EU states are among the most rapidly growing and the most sophisticated, and their domestic income levels have risen steadily for the past 50 years, making the growing impact of economic expansion on CO_2 likely. However, when income levels grow, consumer demand also rises, stimulating the use of resources above and beyond what is necessary for any economy. This tendency is not exclusive to the member states of the EU. As a result, as the economies of the EU members developed, a trade-off emerges between higher economic growth and deterioration in the ecosystem.

Our finding that FGLO has a negative impact on CO_2 is comparable to that made by Ulucak, Erdogan, and Bostanci (2020) for a subset of developing countries but different from the results by Awosusi et al. (2022) and Adebayo (2022b). Financial globalization can help with the shift to renewable energy by incorporating comparatively sustainable and greener energy sources into the country's energy mix, which has positive environmental effects (Ahmad et al., 2021b; Le & Ozturk, 2020). Furthermore, financial globalization has the potential to foster international collaboration and the development of agreements designed to tackle worldwide environmental issues, such as climate change. International financial institutions can contribute to these efforts by offering funding and supporting the implementation of these agreements. Several prior investigations have also noted the negative environmental effects linked to various types of financial globalization (Jahanger, Usman, Murshed, Mahmood, & Balsalobre-Lorente, 2022; Zaidi et al., 2019). Additionally, financial globalization may have a green technology spillover effect, which may help slow down environmental deterioration. Therefore, the finding that financial globalization reduces CO_2 in the EU states suggests that this mechanism is essential for producing the method and composition effects necessary for reducing the trade-off between economic development and environmental damage. Moreover, financial globalization enhances environmental integrity in the EU states, which can be due to technological diffusion from the inflow of ecofriendly FDI to these economies.

The EU countries have very strict environmental standards, which are expected to have a significant role in preventing the entrance of unclean FDI into the EU member states. Although higher trade globalization have relatively minor environmental effects compared to financial globalization, the discovery of a negative relationship between trade globalization and CO_2 emissions indicates that it can be used to supplement financial globalization strategies, which jointly account for environmental progress in the EU (Ahmad et al., 2021b; Wang et al., 2023). Hence, the strict environmental regulations in place are anticipated to play a crucial role in preventing the influx of environmentally detrimental FDI into the EU member states (Sheraz et al., 2022). Moreover, identifying a negative interrelationship between the trade globalization index and CO_2 emissions suggests that integrating trade globalization strategies alongside financial globalization strategies can contribute to environmental advancement in EU countries, despite the relatively limited environmental impacts associated with higher trade globalization compared to financial globalization. In addition, the fact that economic globalization encompasses indexes of both financial and trade globalization explains the finding of a negative association between EGLO and CO_2. Our finding is consistent with the results by Ojekemi, Rjoub, Awosusi, and Agyekum (2022), showing that, in industrialized countries, such as the EU states, environmental conditions have improved due to economic globalization.

Furthermore, Afshan and Yaqoob (2022), Costantini, Crespi, Marin, and Paglialunga (2017), and Ding et al. (2021) support the positive environmental impact of eco-innovation. The finding of a negative coefficient of environmentally friendly innovations is confirmed, given that environmental innovation is a crucial component of environmentally friendly growth in the EU economies and helps achieve low-carbon transformation and energy efficiency. Additionally, the degree of development is a key factor in assessing how much environmental innovation reduces emissions. Importantly, eco-innovations have the capacity to prompt changes in corporate and consumer behavior, fostering the embrace of sustainable practices and thus mitigating CO_2 emissions. This finding is consistent with those of Jin, Razzaq, Saleem, and Sinha (2022) and Zhao, Liu, and Huang (2022), who argued that in developed countries, environmentally friendly innovations are successful in reducing GHG emissions. In this light, the negative relationship between environmental innovation and CO_2 is logical, given that EU member countries are highly industrialized.

5. Conclusion and policy directions

5.1. *Conclusion*

Although they are highly developed, EU member states face unprecedented environmental issues. This implies that, despite their economic achievements, several countries have struggled to safeguard their environmental assets. Therefore, these countries must identify the macroeconomic indicators that can address their escalating environmental concerns. Thus, this paper evaluates the effectiveness of carbon taxes and eco-innovation in mitigating CO_2 in EU countries from 1994 to 2019. The paper also examines the impact of renewable energy and various aspects of globalization (trade, economic, and financial). The investigation uses the innovative CS-ARDL approach to examine the short- and long-term interrelationships, whereas the Westerlund cointegration method is employed to assess the cointegration among the variables selected, and the results on cointegration confirm a long-run association. Furthermore, eco-innovation, renewable energy, and deglobalization reduce environmental deterioration, but economic progress mitigates environmental sustainability in the EU countries. Furthermore, the cointegration results show unidirectional causality from FGLO, GDP, EGLO, REC, TGLO and EGLO to CO_2. In addition, feedback linkage is found between CO_2 and carbon tax and eco-innovation.

5.2. Policy recommendations

Our findings lead to the following policy implications. Our results suggest that carbon taxes and clean energy can both be useful tools for lowering CO_2 emissions, but they are not enough on their own to support environmental sustainability. These two policy tools should be complemented by other measures that will increase their ability to reduce CO_2. By offering incentives such as tax breaks and financial support for green technology, the advancement of clean energy should be strengthened. Businesses that employ environmentally harmful technologies should be prohibited. As a result of our findings, the EU should decrease its reliance on fossil fuels and change its energy mix to include more clean sources of energy. Environmental awareness and public engagement in environmental problems should also be promoted in order to support behavioral changes by consumers and businesses.

Moreover, financial globalization has a decreasing impact on environmental deterioration, the EU member states should become more financially linked to the international economy. The governments of the EU member states should endorse financial liberalization in this respect, which illustrates that the political system should promote greater inflows of foreign funds. Nevertheless, this foreign funding should be used to support environmentally friendly manufacturing methods. Likewise, with respect to the beneficial impact of economic globalization on advancing environmental quality, it is essential for EU policy makers and governments to set forth criteria for evaluating the environmental consequences of international initiatives, especially those of global significance, to ensure their compliance with environmental quality benchmarks.

Furthermore, it is imperative for EU governments and policy makers to design intellectual property measures that strike a balance between promoting innovation incentives and ensuring the widespread dissemination of eco-innovations to maximize their broader environmental advantages. This may involve measures to facilitate the sharing of green technologies and patents. In addition, public strategies must include support for technical innovation strategies, especially those targeted at creating green technologies that can balance rapid economic expansion and less environmental deterioration. Creating ecofriendly technology is essential for reducing the negative environmental impacts of economic expansion in the EU member states. Lastly, to reach their various domestic income turning points, beyond which economic development would not have a negative impact on the environment, EU members should aim to accelerate their economic growth rates. Nevertheless, the national output of the EU countries must be produced using environmentally friendly resources as part of their growth strategy.

5.3. Limitations of the study and future directions

This study has certain limitations that could be addressed in future research, in particular on CO_2. Specifically, the study overlooks several key drivers of CO_2, including economic policy uncertainty, financial development, climate policy uncertainty, and trade openness. The omission of these influential factors restricts the study's scope and depth. Furthermore, the study relies on CO_2 as a proxy for environmental degradation, focusing solely on air pollution while disregarding potential impacts on land and water. To offer a more comprehensive assessment of environmental deterioration, future investigations should consider alternative proxies, such as the environmental footprint and the load capacity factor. Another limitation arises from the study's exclusive reliance on quantitative data from EU economies, which may not apply to other countries worldwide. For broader generalizability, future research should encompass a more diverse range of economic blocs, including MINT (Mexico, Indonesia, Nigeria, and Türkiye), BRICS (Brazil, Russia, India, China, and South Africa), the Association of Southeast Asian (ASEAN), Australia (AU), and the Belt and Road Initiatives (BRI).

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