Journal of Environmental Management 341 (2023) 118018

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Environmental impact of globalization: The case of central and Eastern European emerging economies

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ARTICLE INFO

Keywords:
Pollution haven hypothesis
Economic complexity
Carbon emissions
Cointegration

ABSTRACT

Against the backdrop of piling environmental concerns in the modern era of globalization, this study aims to check the validity of the Pollution Haven Hypothesis (PHH) in Eastern European emerging countries and the relevance of globalization. The study targets to reduce the lack of consensus on the globalization-economic complexity-environment in European countries. Besides, we also intend to explore the existence of an N-shaped economic complexity-related Environmental Kuznets Curve (EKC) controlling for the bearing of renewable energy on environmental degradation. For analytical purposes, both parametric and non-parametric quantile regression approaches are employed. Overall, we find a non-linear relationship between economic complexity and carbon emissions, and N-shaped EKC is verified. Globalization and renewable energy consumption boost and inhibit emissions, respectively. More importantly, the results confirm the moderating role of economic complexity in neutralizing the carbon emissions-boosting effect of globalization.

On the other hand, the non-parametric findings show that the N-shaped EKC hypothesis does not hold for high emissions quantiles. Furthermore, for all emissions quantiles, it is found that globalization boosts emissions, economic complexity, and globalization jointly curbs emissions and renewable energy curbs emissions. Based on the overall findings, some vital environmental development policies are recommended. The conclusions support shaping policy options promoting economic complexity and renewable energy as key factors in mitigating carbon emissions.

1. Introduction

The participants at the latest COP26 Summit recognized that environmental issues are more critical than ever, and ignoring them is no longer an option. Following the ratification of the Paris Accord, the world leaders agreed to keep global warming at the limit of 1.5°, which is a severely challenging task as climate change requires global communities to build resilience against the associated adversities and adopt measures that can mitigate the consequences (Zheng et al., 2022; Murshed et al., 2023). As many emerging economies still depend on fossil fuels, especially coal, one of the priorities at the COP26 is to phase out coal consumption and invest more in renewable energy sources to reach global net-zero emissions by the middle of this century. These goals must involve financial support for less developed countries and genuine cooperation between the world's countries, as the effects of climate change are borderless. From a financial perspective, the framework can be interpreted as redistributing economic welfare from developed countries to less developed and poor ones. The last category

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https://doi.org/10.1016/j.jenvman.2023.118018
Received 9 February 2023; Received in revised form 14 April 2023; Accepted 24 April 2023
Available online 6 May 2023
0301-4797/

will ensure social and economic development without damaging the environment. Human development is still strongly connected to carbon emissions. It remains to be seen how significant economies will carry their economic growth policies and, even more intricate, how emerging economies will find ways to strive without generating more carbon emissions. These rapidly developing low and middle-income economies are exceedingly complex, as they must fight against poverty and increase their population welfare. As the primary and manufacturing sectors are still important for these countries, their investment attractiveness may be determined by a less strict regulatory environment with broader pollution limits (Santos and Forte, 2021; Cansino et al., 2021), transforming the lack of environmental protection regulations into comparative environmental advantages (Mabey and McNally, 1999).

Some evidence has validated that the dependence on coal and this great exhaustion of coal emits high carbon emissions in Central and Eastern European (CEE), generating environmental pressure and energy dependence in the region (Calel and Dechezleprêtre, 2016). Under this view, some programs have tried to assist the environment via established programs in Poland or Hungary (Saud et al., 2019). In this context, globalization has affected the environment and economic growth through FDI and trade openness (Vongpraseuth and Choi, 2015). Hence, globalization leads policymakers to adopt measures to enhance economic growth, but its impact on the environment is adverse (Khan and Ullah, 2019). On the other hand, some studies assume that globalization ameliorates environmental quality through trade openness and green technologies transfer in the region. Globalization reduces environmental damage by interconnecting world economies through trade and the development of the financial sector (Shahbaz et al., 2018), mainly when the financial resources are oriented toward supporting green technological advancement and developing renewable energy sources (Zafar et al., 2019).

Our study advances in empirical literature advocating that European nations can get advanced technologies from developed realms via globalization, which can improve their energy efficiency. Also, globalization would assist developing economies by controlling unemployment because easy access to a low-wage labour force from developing nations is only passable in a globalized economic environment (Shahbaz et al., 2019). Some evidence has confirmed the influence of globalization on environmental quality in the EKC framework, validating that globalization can present trade-related competitive advantages and get high economic growth in a sustainable environment (Shahbaz et al., 2017a). Consequently, this study advances the analysis of measures for sustainable growth, where the government should accept regulations for foreign capital in the host country (Haseeb et al., 2018). Hence, our empirical work contributes to existing energy-economics literature reducing the lack of consensus on globalization–economic complexity-environment nexus in European countries from the perspective of the One Belt and One Road (OBOR) initiative.

Besides all the environmental and energy issues the world has to deal with, the war in Ukraine is a significant risk that needs to be addressed beyond the immediate human tragedy. It shatters the energy market, urges the European economies to readjust, and threatens to rearrange the global market and globalization process. In terms of environmental degradation, besides the direct impact on the Ukrainian territory, the spillover effect upon neighbouring regions (including the Black Sea) is still to be assessed. Still, recent studies have already highlighted it (Pereira et al., 2022). Many European economies were captive for an essential share of their energy consumption to Russian fossil fuels (natural gas and oil) and needed to adjust their consumption patterns. Some are rethinking the phase-down option for coal (The Economist, 2022), which will impact carbon emissions. The situation is familiar, as the United States and Europe already discussed the emergency of increasing the usage of renewable energy in light of the 2014 Ukrainian crisis (Goldthau and Boersma, 2014).

All the selected Eastern European countries contribute to total carbon emissions at the European and global levels (Russia, Poland, and Turkey). The other countries selected for our analysis are ex-communist emerging economies (Romania, Czech Rep., and Hungary), which implemented significant structural reforms and transformations during the last three decades. Greece is a developed, high-income economy with established social and economic rules and institutional frameworks. Still, the economic crisis of 2008 affected this country tremendously and shattered its institutional stability. Unemployment rose almost to 30%, and income dropped. Social exclusion, extreme poverty risk, and corruption increased following the economic crisis. The country is also in the top 50 nations with the world's highest levels of industrial carbon dioxide, with biodiversity and agriculture-related pollution problems. Many countries consider their right to do so even if that means increasing energy consumption and emissions as the developed countries did before them (Douglas, 2006). A moral issue arises in imposing emissions targets for these economies. They encounter difficulties accessing international financial resources and have other challenging problems such as poverty, corruption, and low institutional development.

In Central and East Europe, significant linkages have been demonstrated between globalization, GDP, and growth rates (Lean and Tan, 2011). In this sense, globalization processes invigorate the business environment (Vučković et al., 2020), stimulate capital flows, trade, and employment, facilitate knowledge transfers, and help modernize economic sector institutions and adjust economies to international standards (Nwaogu and Ryan, 2015). At the same time, previous research sampled findings on the impact of economic growth, industrial activities, urban development, and environmental degradation (Nuţă et al., 2021), suggesting that this part of Europe adopted the typical development pattern to Western developed economies. In addition, the globalization process would stimulate economic growth when the host country has developed financial markets or a developed financial system with a relevant RDD industry (Kamal et al., 2021; Ullah et al., 2022). For instance, Kamal et al. (2021) described that FDI would increase sustainable growth in host countries with solid regulatory police focused on promoting innovation processes. At the same time, we can confirm that economic growth depends on the level of trade openness and trade policy. By contrast, we can also use hypotheses that globalization is not always identified as having a direct positive effect on economic growth (Durham, 2004) when the dependence on foreign capital is high (Kentor, 1998). Verhorn et al. (2011) proved that FDI and domestic investment are significant determinants of economic growth in Central and East European countries when accompanied by a prudent fiscal and monetary policy.

The current empirical work inspects the influence of globalization on economic complexity and the following effect on the European countries' environmental quality from the OBOR initiative's perspective. By including renewable energy, the current study extends the umbrella of empirical evidence. We will put a comprehensive view in front of environmental activists and policymakers regarding the role of globalization and energy regulation on environmental quality in the region. According to our best knowledge, this is the first study to investigate the impact of globalization and renewable energy on the environment (CO2 emissions) in the context of the EKC framework for CEE countries. Our study contributes to the advancement of energy economics literature in three ways. First, we are using a large sample. Second, our study is the first to combine the concept of environmental degradation and economic complexity, using globalization and renewable energy as control variables. Third, the combined contribution is expected to be related to economic complexity and global policy developments related to carbon emissions. Besides that, our research explores the relevance of renewable energy and how the energy structure connects with the economic structure.

The rest of the study is organized as follows: in Section II, we present empirical literature. In Section III, we develop the empirical methodology. Section IV presents empirical results, and Section V presents conclusions and policy implications.

2. Literature review

The environmental inequalities are related to the environmental burden borne by disadvantaged regions and how the economic growth of some emerging economies is under scrutiny for environmental reasons. It has been proved that globalization promotes economic growth (Dreher, 2006). The rapidly developing economies of Central and Eastern Europe are looking to achieve economic growth. One way is to get involved in global markets and promote free international trade. *Globalization* is a complex process involving various activities and approaches considered in previous research (Rehman et al., 2023; Murshed et al., 2022; Jahanger et al., 2022). Economic, social, political, and overall globalization were identified, each with features and components. Previous studies identified three environmental effects of globalization: scale effect, technique effect, and composition effect (Aluko et al., 2021). In an earlier study, Shahbaz et al. (2016) recognized that globalization has been largely ignored in previous research on environmental issues arising from economic activities. It also discussed the difficulty of identifying globalization as a singular factor rather than being described by other processes such as international trade, industrial production, industrial capital relocation, or transportation. Other studies disclosed that financial development and increased openness, and free trade requires a more significant amount of energy consumption, generating ascending carbon emissions (Shahbaz et al. 2015, 2017a, 2017b, Ahmed et al., 2017, Ansari et al., 2020, Fang et al., 2019, Dou et al., 2021). Suki et al. (2020) approached how globalization affects natural resource depletion and deforestation, as the two are critical environmental features. This process is especially essential for emerging economies with poor institutional quality and environmental protection regulations (Le and Ozturk, 2020), which are still strongly dependent on traditional energy sources (Shahbaz et al., 2015; Yang et al., 2019).

Moreover, by separating the two components of trade, namely imports, and exports, Dou et al. (2021) find that while imports tend to increase carbon emissions, exports can lower CO2 production. Some researchers hold globalization accountable for transferring energy-intensive and polluting industries and technologies between states, putting much pressure on carbon emissions in developing countries (Fitzgerald and Auerbach, 2016; Mair et al., 2016, Arce Gonzalez et al., 2012). This process benefits technology gaps between developed and developing countries diminish (Wang et al., 2021a, 2021b, 2021c, 2021d). Some cases observed a different environmental impact when splitting globalization into economic, social, and political components. Thus, economic globalization contributes to environmental degradation, but social and political globalization may reduce carbon emissions in the long run (Suki et al. (2020). In one of the few studies involving Central and Eastern European countries, Destek (2019) finds that economic globalization increases CO2 emissions, while social globalization has a neutral impact. However, political one tends to reduce emissions, meaning green agreements are helpful. As mentioned, trade openness and liberalizations are globalization features and ways to measure it. One of the theories discussing how emerging economies' environment is affected by the relocated industrial capital, the Pollution Haven Hypothesis (PHH) (Mani and Wheeler, 1998), explains how developed countries' corporations seek low environmental regulations regions to move their energy-intensive production. They add environmental degradation and pollution to the host countries during this process. The existence of environmental regulatory gaps between highly regulated developed and low-regulated developing economies gave the second the "Pollution Haven Hypothesis" status and an opportunity to use it as a competitive advantage in attracting dirty industries. Previous studies confirm the PHH that trade liberalization brings pollution-intensive industries and environmental damage to emerging economies. In this line of discussion, Onwachukwu et al. (2021) state that even if trade liberalization affects the developing countries' environment, it is wise to use the economic benefits of this process and improve the environment in return. Recent research identified inequalities between developing and developed countries, meaning that while globalization promotes environmental degradation in the first group, it tends to improve carbon emissions for the developed countries (Xia et al., 2021).

Depending on the component involved in the study, some scholars discovered beneficial effects on environmental quality. Thus, economic openness and globalization may decrease emissions, accompanied by knowledge and technological development, newer and less energy-intensive technologies transferred between countries, and green solutions arising from the competition of multinational companies (Shahbaz et al., 2016). Balsalobre-Lorente et al. (2019) identify the technical effect of globalization as a feature that improves the environment and promotes clean growth. Financial globalization as a component of economic globalization was identified as a feature that mitigates environmental damage by Ulucak et al. (2020). Meanwhile, Koc and Bulus (2020) and Gozgor (2017) find that trade openness does not increase carbon emissions or benefit the environment. At the same time, Lv and Xu (2018) document that economic globalization reduces environmental degradation in emerging countries. Using the EKC approach, Shahbaz et al. (2019) find that globalization affects the environment initially but improves environmental quality after exceeding a certain threshold. Confirming the EKC hypothesis, Chien et al. (2021) found that economic activity and globalization increase carbon emissions, and technological innovation is the main factor that mitigates this environmental issue. Putting things together means that as globalization promotes economic growth and technological innovation, the national economy will reach a point when these elements are developed enough to decrease carbon emissions.

Accordingly, our study explores the validation of the N-shaped EKC hypothesis, investigating the linkage between economic complexity and environmental degradation for selected Eastern European countries. The exploration of the ECI-EKC tries to validate the existence of a transition from a developing to a developed stage in selected European East countries covering the period of 1993–2017. Hence, our research suggests that economic complexity is a critical indicator of knowledge, skills, and technology related to environmental degradation. Otherwise, economic complexity also considers knowledge between social agents and institutions, which is crucial for understanding the structural transformation and how countries direct toward ascending productivity areas (Hidalgo and Hausmann, 2009, Poncet et al., 2013). Consequently, the analysis of the ECI-EKC hypothesis advances in the empirical literature, assuming the evaluation of the promotion of new processes and trade of complex outputs via PHH (Sweet and Maggio, 2015; Hidalgo et al., 2007, 2009).

Consequently, we advance in the energy economics empirical literature, supporting the concept of environmental deterioration and economic complexity together. At the same time, our study also explores the relevance of renewable energy and how the energy structure is closely connected with the economic structure. In consequence, the promotion of renewable sources will generate advances in the application of more efficient energy processes and positively impact the reduction of emissions (Yin et al., 2015; Yan et al., 2017; Chen et al., 2018; Abban et al., 2022). The significance of green innovations and renewable energy sources was validated by Habiba et al. (2022) for some top carbon-emitting countries. Green technologies and renewable energy sources are a subject of development options for most developing economies as they need to find a suitable trade-off between economic growth and sustainability regarding environmental degradation. Besides eco-innovations and renewables, Yunzhao (2022) finds that environmental taxes are a good policy instrument for reducing carbon emissions and achieving sustainable growth. Besides having a coherent taxation system to adjust high pollution activities, Ma et al. (2021) consider it essential to double it with R&D expenditures and investments in the energy sector, encouraging innovation and facilitating a carbon emissions cap. Indeed, environmental innovation has limitations and is not a standalone solution for mitigating carbon emissions. Yildirim et al. (2022) suggest that eco-innovation is a good instrument for reducing environmental degradation. Moreover, in a global market, green innovations are less attractive to private enterprises and need to be empowered by governments to prevail and be beneficial in mitigating environmental issues.

The buildings sector and mainly commercial buildings show a significant potential for improving energy efficiency and decarbonization (Xiang et al., 2022). The trend of decoupling carbon emissions of economic development and energy use is present in the policy paths for commercial buildings operating in big urban agglomerations (Ma et al., 2022a), integrating into the new development patterns based on energy efficiency and sustainable economic growth. However, there is still scope for improvement, especially for residential buildings (Ma et al., 2022b), and as the level of living increases and depends on many modern commodities, the need for an energy mix with an essential share of renewable energy sources is critical.

Assuming a gap exists between fossil and renewable energy technologies, suitable energy policies would attract high-tech companies specializing in using renewable energy technologies (Noailly and Smeets 2015; Balsalobre-Lorente et al., 2019). So, integrating different types of environmental-friendly energy technologies would be critical for obtaining efficient environmental-friendly productivity for businesses (Aldieri and Vinci, 2017). Aldieri and Vinci (2017) provided empirical evidence about a connection between environmental-friendly technologies and businesses' productivity. In this sense, the relevance of complexity over energy use and environment, our study advances in comprehending the relationship between economic complexity, energy use, and carbon emissions. This analysis has not been widely explored in previous literature except for some researchers like Can and Gozgor (2017), who tested the validity of the EKC hypothesis in the French economy using ECI. Many previous studies have used GDP or GDP-related features to measure the impact of economic activity on environmental degradation or test the validity of EKC (Shahbaz et al., 2013; Al-Mulali et al., 2016, Apergis and Ozturk, 2015; Isık et al., 2019). However, more recent studies, mainly in the last decade, included the economic complexity index (ECI) (Hidalgo and Hausmann, 2009) in the discussion of dealing with environmental impacts and economic growth (Hidalgo, 2021), identifying a connection between it and the reduction of environmental deterioration (Can and Gozgor, 2017, Romero et al., 2021). Ahmad et al. (2021) discovered that economic complexity degrades the environment by increasing the environmental footprint while renewable energy decreases it. Further, institutional quality moderates the relationship between economic complexity and environmental footprint and promotes sustainability. Balsalobre-Lorente et al. (2018) also identified the role of renewable energy usage in reducing carbon emissions as a key factor for sustainable economic growth. Zheng et al. (2021), analyzing the top 16 global exporting economies, consider ECI an important tool for assessing environmentally friendly economic policies and find that economic complexity reduces carbon emissions in renewable energy consumption. Li et al. (2021) also see renewable energy sources as a key factor in ensuring carbon neutrality but consider economic complexity a menace to carbon emissions reduction goals. Economic complexity favours carbon emissions is explained by the current energy consumption structure. This is mostly based on non-renewable sources, and some industrial developments have become more harmful to the environment than classic technologies (e.g., modern chemical fertilizers in agriculture). The commonly identified option in previous studies is transitioning from fossil fuels to renewable energy sources to ensure environmental sustainability and economic growth. Besides, a growth model based on renewable energy sources is vital for emerging economies as energy consumption is a key factor in their development (Shahzad et al., 2021). Investigating the effect of economic complexity and natural resource rents on the ecological footprint in Latin America, Alvarado et al. (2021) concluded that economic complexity increases the ecological footprint of high-income and upper-middle-income nations. By contrast, this study reveals that the situation is reversed for the lower-middle-income economies. This evidence that a more sophisticated economy presumably has more industrial processes, hence more pollution. Similar to this study's approach, Ikram et al. (2021) also investigated the nexus between economic complexity, economic growth, and ecological footprint in the case of a developed country (Japan). They discovered that the three features are strongly connected. The importance of economic complexity for ecological footprint reveals that a higher degree of technological sophistication promotes the efficient usage of resources and increases environmental awareness of external markets where high-tech products are exported. Shahzad et al. (2021a,b) researched the case of the USA, another developed economy and one of the biggest carbon contributors, describing the relationship between economic complexity, energy use, and ecological footprint, agreeing that the two features (economic complexity and energy consumption) mitigate environmental issues efficiently. Hence, regulations must consistently change economic growth and energy consumption patterns. In opposition to these two previous studies, this research focuses on emerging economies that still need to enhance their economic complexity potential and, in some cases, recover structural development gaps. Romero et al. (2021), investigating whether economic complexity ensures income growth and better environmental quality simultaneously, find that an increased economic complexity generates a reduction of carbon emissions and mitigates climate change. Moreover, their empirical results show that medium and high technology products obtaining processes produce fewer emissions than the primary products and economic goods. They also consider that the only choice for ensuring future economic prosperity and protecting the environment is only possible by deploying structural changes in how economic activity is organized. Despite the results from previous studies showing that the transition to a richer and more developed economy would bring along the premises for ensuring sustainability and environmental welfare, fitting the EKC hypothesis, there are fears that ecological damages are irreversible for a long amount of time (Baek, 2015; Laverde-Rojas et al., 2021). Environmental degradation is a serious matter for most countries worldwide and is strongly connected to economic activity and energy usage. Adedoyin et al. (2021), discussing this complex relationship between the economy and the environment, conclude that economic complexity neutrally influences carbon emissions. Khezri et al. (2022), assessing a group of Asia-Pacific countries, emphasize the role of economic complexity in mitigating climate change. Their findings show that better energy efficiency involving renewable energy is a side effect of economic complexity. It is a fact that energy consumption is effectively connected to economic growth. All major European economies developed from the industrial age because of high non-renewable energy consumption. However, a recent study proposed by Dogan et al. (2020) showed that renewable energy consumption has surprisingly more economic development potential than non-renewable and the premises for ensuring environmental sustainability. Conducting the study on the RCEP countries, a group of important emerging economies, Bashir et al. (2022) highlight the relevance of economic complexity in mitigating climate change under renewable energy consumption. Their empirical results indicate that transitioning from a carbon-intensive economic growth model to another based on high-tech and renewable energy consumption is critical for overcoming environmental issues and climate change goals.

The core idea of the PHH states the beneficial effect of economic growth on environmental damages after reaching a certain level, as stated by the EKC. This could be due to the pollution exported from developed economies to countries less regulated in environmental protection (Kearsley and Riddel, 2010). Starting from this logic, a substantial amount of studies validated or denied the validity of this hypothesis by assessing different regions or contexts. Most of these studies discuss environmental regulations that influence investment flows or the effects of investment(s) on environmental quality. From the premise that countries compete in environmental protection regulations, Kellemberg (2009) sets up the first cross-country study to find that environmental policies affect investment flows.

Moreover, Kellenberg discovers that the pollution haven effect is substantial for US industrial activities in foreign countries, especially when discussing developing countries. As the sustainability goals become critical, Singhania and Saini (2021) discuss the tendency of developed countries to relocate their "dirty" industries to developing countries and find that pollution decreases in developed countries and increases in developing ones. The fact is considered mainly due to a less advanced institutional framework for environmental protection in the host countries. Still, the decision-makers in these countries should mitigate the undesirable features of the investments. BRICS are among the top destinations for FDI. Still, Yilanci et al. (2020) describe that economic growth is made on account of environmental degradation in most of these countries. Few studies found that investments in high-tech industries and energy-saving activities, mainly in the tertiary sector, benefit the environment and reduce carbon emissions (Zhang and Zhou, 2016). In their study on high pollution in developing economies, Sarkodie and Strezov (2019) find that under globalization and free movement of capital, less developed economies tend to use weaker environmental standards as a competitive advantage to attract foreign investment to ensure their economic growth. Setting the premise that, if PHH is true, the developed countries' imports of "dirty" products from developing economies will rise, Cave et al. (2008) investigate the EU situation and argue in favour of the hypothesis. Indeed, their results show that when the environmental regulations become more stringent in EU-developed countries, the amount of "dirty" industry products imported from poorer economies is higher. Depending on the complexity of the imported products, a shadowed PHH may be discussed, meaning that even if trade goods are not a result of energy-intensive industries, it incorporates intermediary products supplied by highly-polluting activities. Duan and Jiang (2021) confirm that foreign companies contribute considerably to world carbon emissions, recognizing that these enterprises have a dirtier supply chain than domestic ones. Simulating scenarios in which the whole production is realized by domestic companies, practically eliminating the world movement of investment capital, they found that emissions would be reduced; as a result, hence confirming the PHH for both developed and developing countries. Inconclusive results in determining whether the PHH is valid may indicate the importance of how investment is conducted, in which industries, and, highly significant, based on what sources of energy (Rafindadi et al., 2018).

3. Estimation methodology

3.1. Theoretical framework and model build-up

Theoretically, the EKC hypothesis postulates that the environmental impacts of economic growth-promoting activities are not a statistic but rather dynamic. Consequently, these impacts are expected to change with time, whereby it is important to understand the factors driving these changes. As per the EKC theory, in the initial stage of economic growth, the scale and composition effect prioritizes economic well-being over environmental welfare; consequently, economic growth is realized at the expense of environmental hardships. On the other hand, in the later stage of economic growth, the technique effect, in a nutshell, puts more emphasis on environmental welfare over economic well-being; consequently, simultaneity between economic and environmental development is established. Thus, identifying the factors triggering the scale, composition, and technique effects is relevant in environmental policymaking. Although the EKC hypothesis conventionally argues that the non-linear relationship between economic growth and environmental quality is inverted U-shaped (i.e. initially, economic growth dampens environmental quality but ultimately improves it). Recent studies have concluded that the EKC is N-shaped since environmental problems re-emerge into the scene to neutralize the efficacies of the technique effect in controlling environmental pollution whereby. Once again, the trade-off between economic growth and environmental degradation can take place.

On the other hand, the PHH theory links globalization with environmental complications. According to this theory, globalization activities trigger higher use of unclean resources, particularly fossil fuels, whereby greenhouse gas emissions will likely surge and impose adverse environmental impacts. It is also argued that a technological spillover impact drives the environmental hardships alongside globalization, which, about the technical effect of the EKC theory, can be used to explain the N-shape of the EKC. Accordingly, it can be assumed that although economic growth, later on, can lead to the discovery of green technologies to control environmental degradation. Hence, globalization may be a way for cross-border flows of unclean technologies to compromise the efficacy of the technique effect in addressing the adverse environmental consequences. Hence, linking the theoretical underpinnings concerning the N-shaped EKC hypothesis and the PHH, this study aims to test the existence of these hypotheses using the non-linear function below:

$$\mathrm{CO2}_{it} = \beta_0 + \beta_1 \mathrm{ECI}_{it} + \beta_2 \mathrm{ECI}_{it}^2 + \beta_3 \mathrm{ECI}_{it}^3 + \beta_4 \mathrm{GLOB}_{it} + \beta_5 (\mathrm{GLOB} * \mathrm{ECI})_{it} + \beta_6 \mathrm{RNW}_{it} + \varepsilon_{it} \tag{1}$$

In equation-1, $i = 1, \ldots, 5$ and $t = 1993, \ldots, 2017$ reveal the country and time, respectively. ε_{it} refers to the error term. The dependent variable $CO2_{it}$ is per capita CO_2 emissions which are chosen as an environmental impact indicator. The relevance behind this proxy is that higher emissions of CO_2, the major greenhouse gas, are linked with climate change problems, whereby mitigating CO_2 emissions can be deemed credible for improving environmental quality. Among the independent variables, ECI_{it} is an index of economic complexity level that considers how well an economy manages the skill level and utilizes the technologies at its disposal, mainly for using modern energy technologies for greening economic output. Consequently, it is referred to as a more holistic measure of economic affluence than the national income level, traditionally considered the proxy for economic growth. This is because an economy's output level may increase while its ECI value may not increase simultaneously due to the excessive use of traditional technologies. Under such circumstances, the inverted U-shape of the EKC may not hold and instead depict an N-shape due to employing conventional environmentally-unfriendly inputs for facilitating growth. Similarly, under a scenario of low economic complexity, the PHH can also be assumed to hold due to the technique effect not being adequate to trigger environmental welfare-enhancing impacts. Hence, the squared and cubic terms of the (ECI_{it}^2 and ECI_{it}^3) are included in the model to test whether the EKC depicts an N-shaped. For the N-shaped EKC to be verified, the coefficients attached to ECI_{it}, ECI_{it}^2, and ECI_{it}^3 should be positive, negative, and positive, respectively.

The other explanatory variable $GLOB_{it}$ stands for globalization, measured in terms of the index. This index considers different forms of globalization to explain how well a particular economy is integrated with other economies through economic, political, and social ties. However, the decision to include this variable in our model is influenced by globalization, considering foreign financial flows, including foreign direct investment, whereby the associated coefficient can help us check the authenticity of the PHH. Under this coefficient's positive sign, the PHH can be deemed valid and vice-versa. $ECI_{it}*GLOB_{it}$ is the interaction between ECI_{it} and $GLOB_{it}$ whereby the estimate of the associated coefficient would give an idea of the extent to which a rise in economic complexity and globalization jointly affect CO_2 emissions. Including this variable is important because, along with the independent (i.e. direct) impacts of such variables on the environment, it is also relevant to understand their joint (i.e. indirect) environmental impacts. This possible joint impact can help design interactive environmental development policies. Lastly, RNW_{it} renewable energy consumption as a share of total final energy consumption measures clean energy and the extent of fossil fuel dependency in the countries of concern. Its inclusion in our model is influenced by the underlying assumption that renewable energy resources are clean sources of energy compared with traditional fossil fuels, whereby scaling renewable energy use within the economy can be assumed to address environmental concerns by reducing CO_2 emissions. Under such circumstances, the associated coefficient can be assumed to be negative.

3.2. Estimation strategy

We apply the proposed econometric techniques to validate our main hypotheses, such as FMOLS (Phillips and Hansen, 1990) and DOLS (Saikkonen, 1991; Stock and Watson, 1993) econometric methodologies. The FMOLS model ameliorates the issue of serial correlation and endogeneity owing to the presence of a cointegrating relationship (Phillips, 1995). The FMOLS (fully modified ordinary least square) regression was first developed by Phillips and Hansen (1990). Pedroni developed the technique as a residual-based test that proved more efficient in estimating results for cointegrated variables (Pedroni, 2001). Moreover, the tool developed by Pedroni uses a semi-parametric correction for endogeneity and residual autocorrelation, which allows a high level of heterogeneity in the panel. According to Kao and Chiang, DOLS is a better estimator than FMOLS eliminating the correlation among regressors (Kao and Chiang, 2001). The FMOLS model evaluates the estimator, which employs semi-parametric correction to eliminate the issues about the long-run correlation between the cointegration equation and stochastic regressors. The estimator is observed to be asymptomatically unbiased and possesses a fully efficient mixture asymptomatic. This technique allows for employing standard Wald Tests, which use asymptomatic Chi-square statistical inference (Hansen, 1992a, 1992b). The FMOLS estimator makes the preliminary estimation of the residuals' symmetric and one-sided long-run covariance matrices. According to Pedroni (2001), the FMOLS model can be represented as follows:

$$\mathrm{Y}_{\mathrm{i,t}} = \alpha_{\mathrm{i}} + \beta_{\mathrm{i}}\mathrm{X}_{\mathrm{i,t}} + \varepsilon_{\mathrm{i,t}}\forall_{\mathrm{t}} = 1, \ldots, \mathrm{T}, \mathrm{i} = 1, \ldots.\mathrm{N} \tag{2}$$

$\mathrm{Y}_{\mathrm{i,t}}$ and $\mathrm{X}_{\mathrm{i,t}}$ are cointegrated with slopes β_{i}. Once we have obtained a long-run relationship among variables, we apply the FMOLS estimation methodology (Phillips and Hansen, 1990), which offers an adjustment for serial correlation and endogeneity due to the presence of cointegrating relationships (Phillips, 1995). Hence, the following equation was considered (Pedroni, 2001):

$$Y_{i,t} = \alpha_i + \beta_i X_{i,t} + \varepsilon_{i,t}\forall_t = 1, \ldots, T, i = 1, \ldots.N \tag{3}$$

$Y_{i,t}$ and $X_{i,t}$ are cointegrated with slopes β_i, where β_i may or may not be homogeneous across i. Hence, the equation becomes:

$$Y_{i,t} = \alpha_i + \beta_i X_{i,t} + \sum_{k=-K_i}^{K_i} \gamma_{i,k}\Delta X_{i,t-k} + \varepsilon_{i,t}\forall t = 1, 2, \ldots, T, i = 1, \ldots \quad .N \tag{4}$$

$\xi_{i,t} = (\widehat{\varepsilon}_{i,t}, \Delta X_{i,t})$ and $\Omega_{i,t} = \underset{T\to\infty}{lim} E\left[\frac{1}{T}(\sum_{i=1}^{T}\xi_{i,t})(\sum_{i=1}^{T}\xi_{i,t})\right]$ are the long covariance. The long covariance is divided into $\Omega_i = \Omega_i^0 + \Gamma_i + \Gamma_i'$, being Ω_i^0 the simultaneous covariance and $\Gamma_i + \Gamma_i'$ is a weighted sum of autocovariance. The panel FMOLS estimator is given as:

$$\widehat{\beta}^*_{FMOLS} = \frac{1}{N}\sum_{i=1}^{N}\left[\left(\sum_{i=1}^{T}(X_{i,t} - \overline{X}_i)^2\right)^{-1}\left(\sum_{i=1}^{T}(X_{i,t} - \overline{X}_i)Y^*_{i,t} - T_{\widehat{\gamma}_i}\right)\right] \tag{5}$$

where

$$Y^*_{i,t} = Y^*_{i,t} - \overline{Y}_i - \frac{\widehat{\Omega}_{2,1,i}}{\widehat{\Omega}_{2,2,i}}\Delta X_{i,t} and \widehat{\gamma}_i = \widehat{\Gamma}_{2,1,i} + \widehat{\Omega}^0_{2,1,i} - \frac{\widehat{\Omega}_{2,1,i}}{\widehat{\Omega}_{2,2,i}}\left(\widehat{\Gamma}_{2,2,i} + \widehat{\Omega}^0_{2,2,i}\right). \tag{6}$$

The Dynamic Ordinary Least Squares (DOLS) model augments the cointegrating regression with the lags and leads, which results in an orthogonal cointegrating equation error term for the stochastic regressor innovations. The DOLS model employs intercept–trend specification for the cointegrating equation, with no additional deterministic components in the regressor equations and one lag and lead of the differenced cointegrating regressor to eliminate the long-run correlation between the innovations. The DOLS model constitutes the cointegrating regression comprising lags and leads and considers the orthogonality in the equation term. The cointegrating DOLS can be represented as follows:

$$\mathrm{Y_t} = \alpha_{\mathrm{i}} + \beta\, \mathrm{X}_{\mathrm{t}}' + \mathrm{D}_{1\mathrm{t}}'\mathrm{D}'\gamma_1 \sum\nolimits_{\mathrm{j}=-\mathrm{q}}^{\mathrm{r}}\Delta \mathrm{X}_{\mathrm{t+j}}'\rho + \mathrm{v}_{1,\mathrm{t}} \tag{7}$$

However, before conducting the regression analysis, we tested the existence of a long-run equilibrium relationship between the variables, though three to test the stationarity properties of the selected variables via traditional unit root test(s), and confirmed that variables are cointegrated I(1). Secondly, we apply and Johansen (1991) cointegration tests and the second generation of unit root test proposed by Pesaran panel cointegration tests. Kao's (1999) cointegration test, which follows a similar methodology, develops cross-section intercepts and homogeneous coefficients on the first-stage regressors. In the bivariate case described in Kao (1999), we have:

$$y_{i,t} = \alpha_i + \beta_{1i}X_{1,t} + \varepsilon_{it} \tag{8}$$

or

$$y_{i,t} = y_{1,t-1} + u_{i,t} \tag{9}$$

$$x_{i,t} = x_{1,t-1} + \varepsilon_{i,t} \tag{10}$$

for $t = 1,..,T$; $i = 1,..,N$. More generally, we may consider running the first stage regression (Equation-5), lacking the α_i to be heterogeneous, β_i to be homogeneous across cross-sections and setting all the trend coefficients ρ_i to zero. Kao (1999) then runs either the pooled auxiliary regression as follows:

$$\varepsilon_{it} = \rho_i\varepsilon_{i,t-1} + u_{it} \tag{11}$$

or the augmented version of the pooled specification:

$$\varepsilon_{it} = \widehat{\rho}_i\varepsilon_{i,t-1} + \sum\nolimits_{j=1}^{\rho}\varphi_{ij}\Delta\varepsilon_{i,t-j} + v_{it} \tag{12}$$

Under the null of no cointegration, Kao (1999) presents that the augmented version ADF test statistic for $\rho>0$ is:

$$ADF = \frac{\tau ADF + \frac{\sqrt{N6\widehat{\sigma_v}}}{2\widehat{\sigma_{0v}}}}{\sqrt{\frac{\widehat{\sigma_0^2 v}}{2\widehat{\sigma_v^2}} + \frac{3\widehat{\sigma_v^2 v}}{10\widehat{\sigma_{0v}^2}}}} \tag{13}$$

which converges to N(0,1) asymptotically. Finally, Johansen-Fisher's (1991) panel cointegration test aggregates the *p-values* of individual Johansen maximum Eigen-value and trace statistics (Lean and Smyth, 2010). The Johansen-Fisher test combines individual tests for testing cointegration, connecting tests from individual cross-sections. If Π_i is the *p-value* from an individual cointegration test for cross-section i then under the null hypothesis for the panel:

$$-2\sum_{i=1}^{N}\log\left(\Pi_i\right)\rightarrow\chi^2 2N \tag{14}$$

χ^2 values based on MacKinnon et al. (1999) *p-values* for Johansen's cointegration trace and maximum eigenvalue tests are reported.

After these tests, we estimate the proposed models by the FMOLS estimation process. Finally, we exhibit Dumitrescu-HurlinPairwise Granger causality to test causality among variables. The presence of cointegration suggests a possible causal relationship between the variables. To identify a causal relationship's existence and direction, we apply the Dumitrescu and Hurlin (2012) causality test. This test is performed for each cross-section from which test statistic averages are generated. In the pairwise causality test, two variables are usually tested together with an expectation of either of these results: unidirectional causality (X→Y, Y→X), bidirectional causality (X↔Y), and no causality (X ≠Y). The Dumitrescu-Hurlin (Dumitrescu and Hurlin, 2012) causality test is deployed to check the causality among variables, as shown in Table-5. The DH test hypothesizes that a homogeneous non-causality is valid by considering the regression model's heterogeneity and causal relation. We achieve the Wbar and Zbar, allowing common factors in the cross-equation covariance to be detached. Dumitrescu-Hurlin causality test considers two different statistics: the *Wbar-statistic*, which takes the average of the test statistics, and the *Zbar-statistic,* which shows a standard (asymptotic) normal distribution. To test the null hypothesis, firstly, Wald statistics ($W_{i,\ T}$) are computed for each of the cross-sections and then averaged for each individual to find out the panel Wald statistic ($W_{N,T}^{HNC}$). The Dumitrescu and Hurlin (2012) is also supposed to use $Z_{N\ and\ T}^{HNC}$ statistics. When $T > N$ and use Z_{N}^{HNC} statistic when $T < N$.

$$Z_{N,T}^{HNC}=\sqrt{\frac{N}{2K}}\left(W_{N,T}^{HNC}-K\right) \tag{15}$$

$$Z_{N}^{HNC}=\frac{\sqrt{N\left[W_{N,T}^{HNC}-N^{-1}\sum_{i=1}^{N}E\left(W_{i,T}\right)\right]}}{\sqrt{N^{-1}\sum_{i=1}^{N}Var\left(W_{i,T}\right)}} \tag{16}$$

4. Empirical results and discussion

In this section, we first report and interpret the results derived from the unit root analysis (see Table 1). First, IPS and LLC unit root tests are carried out to check the variables' stationarity order. The results shown in Table-2 reveal that all the variables are stationary at the first differences. On the other hand, the Augmented Dickey-Fuller and Phillips-Perron unit root tests confirm that carbon emissions and economic complexity are stationary at first difference while globalization is stationary at level. Once stationarity is confirmed, we apply the panel cointegration test proposed by Kao (1999) and the Fisher-type test (Johansen methodology). The results from the cointegration analysis are shown in Table-3. According to the Kao test, we reject the null hypothesis and discover a cointegration between carbon emissions, economic complexity, globalization, and renewable energy consumption. A long-run association exists, which is also confirmed by the Johansen cointegration approach. Overall, the panel cointegration test results confirm a long-run relationship between the variables.

The regression analysis is performed following the analysis of unit root and cointegration, and the coefficient estimates are reported in Table-4. The results obtained by FMOLS and DOLS parametric econometric estimation methodology confirm the N-shaped EKC as the predicted signs of coefficients attached to ECI_{it}, ECI_{it}^2, and ECI_{it}^3 are positive, negative, and positive, respectively. Thus, the results verify the non-linear connection between ECI and CO_2 emissions. In the first stage of development, the empirical evidence reveals that ECI directly affects CO_2 emissions, increasing pollution, so in the early stages, the PHH is validated. In the second stage (the composition and technical effect stage), when economic complexity continues to increase, environmental

Table-1
Studies on pollution haven hypothesis.

Region/Countries	Main Findings	Authors, Year
US and world countries where US MNEs invest	PHH confirmed especially in developing countries; 'footloose' industries are more affected by environmental regulations than traditionally 'dirty' industries	Kellemberg (2009)
China	PHH is not confirmed; FDI have a neutral influence on pollution but should be a driver for energy innovation	Danish and Ulucak (2022)
20 developed and developing countries	PHH confirmed especially for developing countries;	Singhania and Saini (2021)
BRICS countries	PHH confirmed for India; mixed results for Brazil and Russia	Yilanci et al., 2020
Turkey	PHH confirmed; that energy usage from renewable sources may reduce pollution, but the share of these sources in total is still limited to benefit the environment	Bulut et al. (2021)
ASEAN countries	PHH confirmed; that energy consumption has an important influence on carbon emissions; using the current development model, if ASEAN countries would cut the FDI to protect the environment would negatively affect the economic growth	Baek (2016)
China	The pollution halo hypothesis confirmed; that FDI reduces environmental degradation, mainly when directed to tech-intensive industries and energy-saving technologies	Zhang and Zhou (2016)
China, India, Iran, Indonesia, and South Africa	PHH confirmed; that GHG emissions may decline when the FDI inflows exceed a certain threshold	Sarkodie and Strezov (2019)
Developing region in China	PHH confirmed	Shen et al. (2019)
40 countries	PHH confirmed; that international trade became more environmentally damaging after the crisis in 2008, which raises questions related to the crisis' environmental impacts	Zhang et al. (2017)
EU	PHH confirmed; that shadowed PHH may occur when the EU countries import final products that incorporate "dirty" goods even though the final product cannot be categorized as "dirty".	Cave et al. (2008)
PIIGS countries	PHH confirmed; that renewable sources of energy and sustainable urban areas may mitigate the environmental issues	Balsalobre-Lorente et al. (2022)
Sub-Saharan African countries	PHH confirmed; that economic growth and urbanization have negative impacts on the environment, suggesting that the countries analyzed in the study are still at the early stages of development	Gyamfi et al. (2021)
China	PHH is not confirmed; EKC is confirmed, and the energy consumption is still damaging the environmental quality, suggesting that the renewable sources are insufficiently used to support the economic growth	Liu et al. (2019)
World	PHH confirmed for both developed and developing countries	Duan and Jiang (2021)
China	PHH is not confirmed; FDI improves China's environmental performance in the presence of nuclear energy consumption, considered a clean source of energy	Danish et al. (2021)
Gulf Cooperation Countries	No significant evidence of PHH since the FDI tends to improve environmental performance while the energy consumption associated with the FDI flows tends to damage it	Rafindadi et al. (2018)

degradation will diminish, followed by an increased degradation due to the technical obsolesce effect (stage 3). The empirical results confirm the N-shape EKC for the selected European countries included in the analysis. So, we can argue that economic complexity can represent the scale, structure, and technological effects in a holistic approach within the EKC hypothesis. If a country is poor or developing, as economic complexity increases, CO_2 emissions may be expected to rise to a certain level of development. It is possible to observe the decline in CO_2 emissions by providing structural transformation and increasing knowledge and skill-based technology-intensive production (Imbs and Wacziarg, 2003). The index's high value indicates the highly sophisticated production capabilities of the country's production structure (Hidalgo and Hausmann, 2009). In this context, since this process shows the transformation from an energy-intensive economy to a technology-intensive economy, structural changes in the economy should be expected to reduce the CO_2 emissions of an advanced country. However, if policymakers are not implementing environmental regulations in this process, positive developments regarding environmental quality may not be observed (Tsurumi and Managi, 2010).

The other important results show that globalization directly links to environmental degradation (i.e. more globalization accounts for more significant emissions of CO_2). This evidence implies that the globalization policies executed by the Eastern European nations do not foster the environmental sustainability target. This could also have verified the N-shaped EKC for these countries. Furthermore, the coefficient concerning the interaction between economic complexity and globalization (ECI*-GLOB) is negative, indicating that these factors jointly improve environmental quality by boosting CO_2 emissions. Intuitively, this finding suggests that economic complexity exerts a moderating effect in reducing environmental pressure proceeding from globalization. This is because complex economic processes attract high-tech businesses in host countries; consequently, if sophisticated production capabilities can be promoted for transforming economic systems through clean technologies, environmental pollution can be effectively controlled. Finally, the econometric results confirm that more renewable energy and less use of fossil fuels (denoted by a rise in the renewable energy share in the total final energy consumption level) reduces CO_2 emissions. This finding is per the *a priori* expectation regarding environmental welfare improvement following a transition from fossil fuel to renewable energy. Figure-1 reflects how the relationship between CO_2 and ECI moves from preindustrial economy to advanced economy in the case of our selec ted European countries, transiting from the scale effect stage to the composition and technical effect stage, describing an N-shaped EKC (see Fig. 2).

Further, to check if the findings are homogeneous at different levels of CO_2 emissions, we perform the quantile regression analysis by segregating the sample of countries in terms of low emissions quantile (25th quantile), medium emissions quantile (50th quantile), and high emissions quantile (75th quantile). The quantile estimates in Table-4 show that the N-shape EKC holds low and medium emissions quantile but not for high emissions quantile. The coefficient estimate attached to the variable EC_{it}^2 is statistically insignificant for the high emissions quantile. On the other hand, we can see that more globalization leads to more CO_2 emissions for all three emissions quantiles. However, the marginal effects (shown by the magnitude of the coefficient estimates) are relatively more extensive for the comparatively lower emissions quantiles. This process indicates that globalization hurts environmental well-being the most in relatively less-polluted economies. The quantile estimates regrinding the interaction term reveal that economic complexity and globalization jointly inhibit CO_2 emissions in all three emission quantiles. However, the CO_2 emissions-reducing effect is relatively more significant in the comparatively lower emissions quantile. This finding indicates that the moderating effect of economic globalization in neutralizing CO_2 emissions-boosting impact of globalization is more pronounced in countries with relatively low CO_2 emissions. Lastly, we also find that renewable energy use homogeneously contributes to curbing CO_2 emissions in all three emission quantiles. However, the CO_2 emissions-impeding impact is comparatively higher in the low emissions quantile. This finding suggests that reducing emissions through renewable energy transition is more effective in less-polluted countries. It is essential to plan and execute renewable energy transition-facilitating policies as soon as possible (see Fig. 3).

Lastly, the causality analysis is performed. Accordingly, the results from the Dumitrescu-Hurlin panel causality analysis, shown in Table-5, find the existence of bidirectional causality between renewable energy

Table-3
Kao residual cointegration analysis.

	t-Statistic	Prob.		
ADF	−2.287454	0.0111		
Residual variance	0.081551			
(HAC) variance	0.085656			
Johansen Fisher Panel Cointegration Test				
Unrestricted Cointegration Rank Test (Trace and Maximum Eigenvalue)				
Hypothesized No. of CE(s)	Fisher Stat.* (from trace test)	Prob.	Fisher Stat.* (from max-Eigen value test)	Prob.
None	72.76	(0.0000)	51.24	(0.0000)
At most 1	33.72	(0.0023)	22.13	(0.0759)
At most 2	23.08	(0.0589)	12.42	(0.5724)
At most 3	35.86	(0.0011)	35.86	(0.0011)

Note: * Probabilities are computed using asymptotic Chi-square distribution.

Table 2
Panel unit root analysis.

At Level	CO2PC		ECI		GLOB		REN	
	Statistic	Prob.**	Statistic	Prob.**	Statistic	Prob.**	Statistic	Prob.**
Levin, Lin & Chu t*	0.4121	0.6599	−1.16414	0.1222	−6.66179	0.0000	−0.3457	0.364
Im, Pesaran and Shin W-stat	1.0686	0.8574	−0.74485	0.2282	−3.21635	0.0006	1.3589	0.9129
ADF - Fisher Chi-square	8.8413	0.8411	15.5214	0.3435	37.6365	0.0006	8.7884	0.8444
PP - Fisher Chi-square	11.6519	0.6342	14.8889	0.3858	63.6467	0.0000	11.1795	0.6719
At First-Diference	**D(CO2PC)**		**D(ECI)**		**D(GLOB)**		**D(REN)**	
	Statistic	Prob.**	Statistic	Prob.**	Statistic	Prob.**	Statistic	Prob.**
Levin, Lin & Chu t*	−4.9449	0.0000	−7.84428	0.0000	−4.5942	0.0000	−3.6278	0.0001
Im, Pesaran and Shin W-stat	−5.1572	0.0000	−7.01108	0.0000	−4.1076	0.0000	−4.5874	0.0000
ADF - Fisher Chi-square	54.4176	0.0000	73.1396	0.0000	42.4548	0.0001	50.091	0.0000
PP - Fisher Chi-square	86.9093	0.0000	103.314	0.0000	80.9448	0.0000	201.023	0.0000

Note: ** Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.

Table-4
FMOLS, DOLS, and panel quantile regression analysis.

Dependent Variable: CO2PC					
Variable	FMOLS	DOLS	Q 25	Q 50	Q 75
ECI	21.0610*** (3.2980)	18.21035*** (3.3458)	17.8023*** (4.3845)	17.8023*** (4.3845)	13.4463*** (3.5260)
ECI^2	−8.9991** (4.0787)	−7.3021* (4.2684)	−7.4985** (3.4735)	−7.4985** (3.4735)	−4.7731 (4.6499)
ECI^3	6.3039*** (1.6811)	5.4859*** (1.7676)	5.1389** (1.7419)	5.1389*** (1.7419)	3.6266* (1.8718)
GLOB	0.1551*** (0.0082)	0.1562*** (0.0086)	0.1559*** (0.0077)	0.1559*** (0.0077)	0.1739*** (0.0096)
ECI*GLOB	−0.2641*** (0.0415)	−0.2412*** (0.0409)	−0.2179*** (0.0502)	−0.2179*** (0.0502)	−0.1785*** (0.02876)
RNW	−0.3475*** (0.0331)	−0.3402*** (0.0343)	−0.3706*** (0.0418)	−0.3706*** (0.0418)	−0.36626*** (0.0194)

Note: Standard errors in parentheses***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

usage and economic complexity (Huang et al., 2022). The causality test also confirms unidirectional causality between globalization and renewable energy consumption (Dingru et al., 2021, Padhan et al., 2020). A similar unidirectional relationship is observed from globalization to carbon emissions (Martins et al., 2021; Abbasi et al., 2021) but also from renewable energy to carbon emissions (Wang et al., 2021a, 2021b, 2021c, 2021d).

5. Conclusion and policy implications

This paper applied FMOLS and DOLS econometric techniques to provide an N-shaped connection between economic complexity and carbon emissions. Our results confirm, as expected, that if the share of renewable sources of energy increases by 1%, carbon emissions will decrease by 0.3475%. Recent studies argue that economic sophistication and quality economic growth influence carbon emissions reduction (Chandrarin et al., 2022). Economic growth remains one of the most relevant drivers of carbon emissions, mainly based on high energy intensity. World countries search for policy options for decoupling the two (Zhao et al., 2022). At the same time, globalization harms environmental degradation, meaning that carbon emissions increase by 0.1551% for each per cent of the globalization coefficient. However, if globalization is accompanied by increased economic complexity, carbon emissions will decrease. This process may result from economic development based on innovation and growing environmentally friendly industries. In contrast, globalization, at its early stages, is based on exploiting intensive natural resources and brown investments (validating the PHH).

Further, the quantile regression analysis reveals that the N-shaped EKC does not hold for high emission quantiles. Besides, greater globalization is found to homogeneously boost CO2 emissions across all emission quantiles, although the CO2 emission-boosting impacts tend to increase as the pollution level increases. Moreover, the quantile analysis also verified that for all emissions quantiles, economic complexity exerts a moderating effect to neutralize the CO2 emissions-boosting impact of globalization; however, the moderating effect is evidenced to be more in

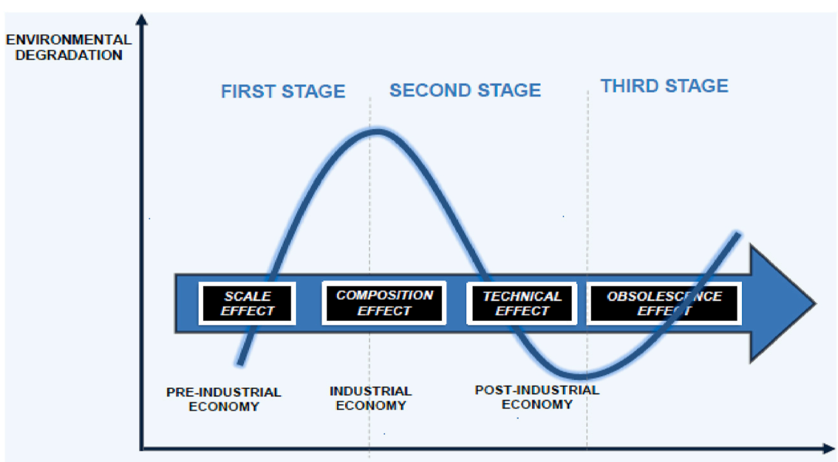

Fig. 1. N-shaped ECI (EKC).

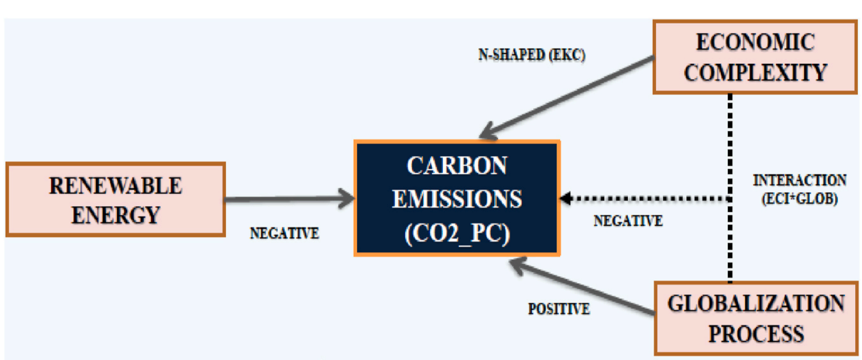

Figure-2. Illustration of the findings from regression analysis.

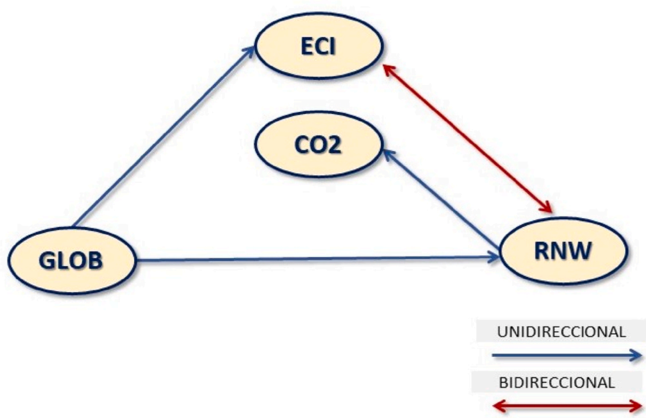

Figure-3. Direction of causality.

low emission quantiles. Lastly, it is seen that renewable energy use homogeneously reduces CO2 emissions across all quantiles, although this CO2 emissions-reducing effect is comparatively higher for the low-emission quantile. Considering the leads and lags (DOLS), we obtain the same relationship and the confirmation that globalization may negatively influence environmental degradation and the need for economic development based on innovation and renewable energy sources. The results confirm previous studies, such as Zheng et al. (2021), that trade openness coupled with economic complexity and renewable sources of energy work together in mitigating carbon emissions. Also, the production of complex goods involves technological advancement and innovation. Participating in the global market helps developing economies achieve economic complexity that simultaneously reduces carbon emissions and enhances economic development (Romero et al., 2021). Our study proves that using renewable energy sources is vital for mitigating environmental degradation, as recent studies have shown (Mirziyoyeva and Salahodjaev, 2022). This result confirms previous studies' findings that renewables are essential for both environmental purposes and for ensuring steady economic growth. In this context, when societies enhance their energy uses contributes, via composition and technical effect, it contributes to obtaining more efficient and cleaner energy uses, helping to control environmental degradation.

The main results of the study may be summarized as follows:

1. Renewable energy usage is a major contributor to mitigating carbon emissions. Hence, if the share of renewable sources of energy increases by 1%, carbon emissions will decrease by 0.3475%. Knowing that economic growth, through energy intensity, remains a major driver of carbon emissions, it is desirable to reconsider the energy efficiency targets and the diversification of energy sources by increasing the share of renewables and phasing out or decreasing the classic ones.
2. Globalization is contributing to environmental degradation. For each per cent of the globalization coefficient, the carbon emissions will increase by 0.1551%. However, if the national economy is increasing its economic complexity, globalization will help curb the emissions trend by supporting economic development based on innovation and green technologies. At early stages, globalization confirms the Pollution Haven Hypothesis being accompanied by economic growth based on the intensive exploitation of raw natural resources and brown investments.
3. The results confirm that trade openness coupled with economic complexity and a diversified energy mix having an important share of renewable sources help mitigate carbon emissions and improve environmental quality. It is important for developing economies to participate actively in the global market to support their internal mechanism to switch from raw exploitation of natural resources to produce more complex goods and adopt technological advancements and innovation. As renewable energy sources are vital for keeping the economic processes running, public policies need to support investments for developing innovation in the energy sector for exploiting efficient renewable energy potential.

Table-5
Pairwise Dumitrescu and hurlin panel causality analysis.

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.	Remarks
ECI ⇎ CO2PC	2.86592	0.63874	0.5230	ECI ⇎ CO2PC
CO2PC ⇎ ECI	2.21574	−0.03553	0.9717	
GLOB ⇎ CO2PC	3.61190	1.41234	0.1578	GLOB ⇎ CO2PC
CO2PC ⇎ GLOB	3.28916	1.07765	0.2812	
RNW ⇎ CO2PC	6.51758	4.42564	1.E−05	RNW → CO2PC
CO2PC ⇎ RNW	2.92579	0.70082	0.4834	
GLOB ⇎ ECI	6.59198	4.50279	7.E−06	GLOB → ECI
ECI ⇎ GLOB	1.80490	−0.46159	0.6444	
RNW ⇎ ECI	4.17853	1.99996	0.0455	RNW ↔ ECI
ECI ⇎ RNW	4.42315	2.25363	0.0242	
RNW ⇎ GLOB	1.58522	−0.68940	0.4906	GLOB → RNW
GLOB ⇎ RNW	7.48825	5.43226	6.E−08	

Note: The symbols "→,↔, and ⇎" show the unidirectional, bidirectional, and non-homogeneous causality relationship between features.

The empirical findings are exciting and confirm the relevance of economic complexity to globalization. In this sense, the selected panel should promote the attraction of high-technology machinery and equipment, which are more environmentally friendly than traditional technologies. As expected, the empirical findings highlighted renewable energy consumption's significant and negative response to carbon emissions. Otherwise, selected countries depend on several energy sources for industrialization and economic purposes. The paper presents innovative findings in the literature. Forecasting the future level of carbon emissions from past energy consumption, GDP per capita, population, renewable energy consumption, and economic complexity is possible.

Our innovative empirical finding contributes to the literature with a new direction. The findings indicate that economic complexity might be a policy factor in mitigating carbon emissions. In addition, the empirics suggest that economic complexity is a variable that must be considered while shaping national economic and energy policies and regional environmental regulations. Economic complexity refers to the productive system in the host economy, which has specific environmental effects. The innovations' effects and technical improvements are expected to continue to increase energy efficiency and tackle environmental degradation. At the same time, governments need to implement restrictive policies in terms of environmental protection for local and foreign investors, empowering green policies to curb environmental degradation and promote sustainable economic growth. These countries still need the foreign capital inflows available through trade openness and governmental incentives but must direct the investments to achieve new technologies and highly developed industries. High-value-added products with higher energy efficiency would help them diminish their carbon footprint and benefit from global market participation and environmental preservation. Future studies should fill this gap, including some variables related to the technology process or extending the analysis to a heterogeneous panel. Finally, due to recent political and military developments caused by the war in Ukraine, decision-makers need to hurry the transition toward a carbon-free economy and implement those policies to escape from the dependence on fossil fuels.

Credit author statement

Daniel Balsalobre-Lorente: Methodology, Validation, Formal analysis, Writing - Original Draft, Writing - Review & Editing. **Muhamamd Shahbaz:** Conceptualization, Supervision, Project administration. **Muntasir Murshed:** Formal analysis, Writing - Original Draft.

Florian Marcel Nuta: Conceptualization, Writing - Original Draft, Writing - Review & Editing, Visualization.

Funding

This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

Abban, O.J., Hongxing, Y., Nuţă, A.C., Dankyi, A.B., Ofori, C., Cobbinah, J., 2022. Renewable energy, economic growth, and CO2 emissions contained Co-movement in African oil-producing countries: a wavelet-based analysis. Energy Strategy Rev. 44, 100977 https://doi.org/10.1016/j.esr.2022.100977.

Abbasi, K.R., Lv, K., Radulescu, M., Shaikh, P.A., 2021. Economic complexity, tourism, energy prices, and environmental degradation in the top economic complexity countries: fresh panel evidence. Environ. Sci. Pollut. Control Ser. 28 (48) https://doi.org/10.1007/s11356-021-15312-4.

Adedoyin, F.F., Agboola, P., Ozturk, I., Bekum, F.V., Agboola, M.O., 2021. Environmental consequences of economic complexities in the EU amidst a booming tourism industry: accounting for the role of Brexit and other crisis events. J. Clean. Prod. 305, 127117 https://doi.org/10.1016/j.jclepro.2021.127117.

Ahmad, M., Ahmed, Z., Majeed, A., Huang, B., 2021. An environmental impact assessment of economic complexity and energy consumption: does institutional quality make a difference? Environ. Impact Assess. Rev. 89 https://doi.org/10.1016/j.eiar.2021.106603.

Ahmed, K., Rehman, M.U., Ozturk, I., 2017. What drives carbon dioxide emissions in the long-run? Evidence from selected South Asian Countries. Renew. Sustain. Energy Rev. 70, 1142–1153. https://doi.org/10.1016/j.rser.2016.12.018.

Aldieri, L., Vinci, C.P., 2017. The Role of Technology Spillovers in the Process of Water Pollution Abatement for Large International Firms. Sustainability 9 (5), 868. https://doi.org/10.3390/su9050868.

Al-Mulali, U., Ozturk, I., Solarin, S.A., 2016. Investigating the environmental Kuznets curve hypothesis in seven regions: the role of renewable energy. Ecol. Indicat. 67, 267–282. https://doi.org/10.1016/j.ecolind.2016.02.059.

Aluko, O.A., Opoku, E.E.O., Ibrahim, M., 2021. Investigating the environmental effect of globalization: insights from selected industrialized countries. J. Environ. Manag. 281, 11892 https://doi.org/10.1016/j.jenvman.2020.111892.

Alvarado, R., Tillaguango, B., Dagar, V., Ahmad, M., Isik, C., Mendez, P., Toledo, E., 2021. Ecological footprint, economic complexity and natural resources rents in Latin America: empirical evidence using quantile regressions. J. Clean. Prod. 318, 128585 https://doi.org/10.1016/j.jclepro.2021.128585.

Ansari, M.A., Haider, S., Khan, N.A., 2020. Does trade openness affects global carbon dioxideemissions. Management of Environmental Quality 31, 32–53. https://doi.org/10.1108/MEQ-12-2018-0205.

Apergis, N., Ozturk, I., 2015. Testing environmental Kuznets curve hypothesis in asian countries. Ecol. Indicat. 52, 16–22. https://doi.org/10.1016/j.ecolind.2014.11.026.

Arce Gonzalez, G., Cadarso, Vecina M.A., Lopez Santiago, L., 2012. Indirect pollution haven hypothesis in a context of global value chain. In: Final WIOD Conference. Causes and Consequences of Globalization, Groningen, The Netherlands.

Baek, J., 2015. Environmental Kuznets curve for CO2 emissions: the case of Arctic countries. Energy Econ. 50, 13–17. https://doi.org/10.1016/j.eneco.2015.04.010.

Baek, J., 2016. A new look at the FDI-income-energy-environment nexus: dynamic panel data analysis of ASEAN. Energy Pol. 91, 22–27. https://doi.org/10.1016/j.enpol.2015.12.045.

Balsalobre-Lorente, D., Shahbaz, M., Roubaud, D., Farhani, S., 2018. How economic growth, renewable electricity and natural resources contribute to CO2 emissions? Energy Pol. 113, 356–367. https://doi.org/10.1016/j.enpol.2017.10.050.

Balsalobre-Lorente, D., Driha, O.M., Shahbaz, M., Sinha, A., 2019. The effects of tourism and globalization over environmental degradation in developed countries. Environ. Sci. Pollut. Control Ser. 27, 7130–7144. https://doi.org/10.1007/s11356-019-07372-4.

Balsalobre-Lorente, D., Ibanez-Luzon, L., Usman, M., Shahbaz, M., 2022. The environmental Kuznets curve, based on the economic complexity and the pollution haven hypothesis in PIIGS countries. Renew. Energy 185, 1441–1445. https://doi.org/10.1016/j.renene.2021.10.059.

Bashir, M.F., Ma, B., Hussain, H.I., Shahbaz, M., Koca, K., Shahzadi, I., 2022. Evaluating environmental commitments to COP21 and the role of economic complexity, renewable energy, financial development, urbanization, and energy innovation: empirical evidence from the RCEP countries. Renew. Energy 184, 541–550. https://doi.org/10.1016/j.renene.2021.11.102.

Bulut, U., Ucler, G., Inglesi-Lotz, R., 2021. Does the pollution haven hypothesis prevail in Turkey? Empirical evidence from non-linear smooth transition models. Environ. Sci. Pollut. Control Ser. 28, 38563–38572. https://doi.org/10.1007/s11356-021-13476-7.

Calel, R., Dechezleprêtre, A., 2016. Environmental policy and directed technological change: evidence from the European carbon market. Rev. Econ. Stat. 98, 173–191. https://doi.org/10.1162/REST_a_00470.

Can, M., Gozgor, G., 2017. The impact of economic complexity on carbon emissions: evidence from France. Environ. Sci. Pollut. Control Ser. 24, 16364–16370. https://doi.org/10.1007/s11356-017-9219-7.

Cansino, J.M., Carril-Cacia, F., Molina-Parrado, J.C., Roman-Collado, R., 2021. Do environmental regulations matter on Spanish foreign investment? A multisectorial approach. Environ. Sci. Pollut. Control Ser. 28, 57781–57797. https://doi.org/10.1007/s11356-021-14635-6.

Cave, L.A., Blomquist, G.C., 2008. Environmental policy in the European Union: fostering the development of pollution havens? Ecol. Econ. 65, 253–261. https://doi:10.1016/j.ecolecon.2007.12.018.

Chandrarin, G., Sohag, K., Cahyaningsih, D.S., Yuniawan, D., 2022. Will economic sophistication contribute to Indonesia's emission target? A decomposed analysis. Technol. Forecast. Soc. Change 181, 121758. https://doi.org/10.1016/j.techfore.2022.121758.

Chen, Y.J., Li, P., Lu, Y., 2018. Career concerns and multitasking local bureaucrats: Evidence of a target-based performance evaluation system in China. J. Dev. Econ. 133, 84–101. https://doi.org/10.1016/j.jdeveco.2018.02.001.

Chien, F., Ajaz, T., Andlib, Z., Chau, K.Y., Ahmad, P., Sharif, A., 2021. The role of technology innovation, renewable energy and globalization in reducing environmental degradation in Pakistan: a step towards sustainable environment. Renew. Energy 177, 308–317. https://doi.org/10.1016/j.renene.2021.05.101.

Danish, K., Ulucak, R., 2022. Analyzing energy innovation-emissions nexus in China: a novel dynamic simulation method. Energy 244, 123010. https://doi.org/10.1016/j.energy.2021.123010.

Danish, Khan, S.U.D., Ahmad, A., 2021. Testing the pollution haven hypothesis on the pathway of sustainable development: accounting the role of nuclear energy consumption. Nucl. Eng. Technol. 53, 2746–2752. https://doi.org/10.1016/j.net.2021.02.008.

Destek, M.A., 2019. Investigation on the role of economic, social, and political globalization on the environment: evidence from CEECs. Environ. Sci. Pollut. Control Ser. 27, 33601–33614. https://doi.org/10.1007/s11356-019-04698-x.

Dingru, L., Ramzan, M., Irfan, M., Guelmez, O., Isik, H., Adebayo, T.S., Husam, R., 2021. The role of renewable energy consumption towards carbon neutrality in BRICS nations: does globalization matter? Front. Environ. Sci. 569 https://doi.org/10.3389/fenvs.2021.796083.

Dogan, B., Balsalobre-Lorente, D., Nasir, M.A., 2020. European commitment to COP21 and the role of energy consumption, FDI, trade and economic complexity in sustaining economic growth. J. Environ. Manag. 273, 111146 https://doi.org/10.1016/j.jenvman.2020.111146.

Dou, Y., Zhao, J., Malik, M.N., Dong, K., 2021. Assessing the impact of trade openness on CO_2 emissions: evidence from China-Japan-ROK FTA countries. J. Environ. Manag. 296, 113241 https://doi.org/10.1016/j.jenvman.2021.113241.

Douglas, J., 2006. India Claims its Emissions Cause No Harm to World's Atmosphere. Natural news.

Dreher, A., 2006. Does globalization affect growth? Evidence from a new index of globalization. Appl. Econ. 38 (10), 1091–1110. https://doi.org/10.1080/00036840500392078.

Duan, Y., Jiang, X., 2021. Pollution haven or pollution halo? A Re-evaluation on the role of multinational enterprises in global CO2 emissions. Energy Econ. 97, 105181 https://doi.org/10.1016/j.eneco.2021.105181.

Dumitrescu, E., Hurlin, C., 2012. Testing for Granger non-causality in heterogeneous panels. Econ. Modell. 29 (4), 1450–1460. https://doi.org/10.1016/j.econmod.2012.02.014.

Durham, J., 2004. Absorptive capacity and the effects of foreign direct investment and equity foreign portfolio investment on economic growth. Eur. Econ. Rev. 48 (2), 285–306. https://doi.org/10.1016/S0014-2921(02)00264-7.

Fang, J., Gozgor, G., Lu, Z., Wu, W., 2019. Effects of the export product quality on carbon dioxide emissions: evidence from developing economies. Environ. Sci. Pollut. Control Ser. 26, 12181–12193. https://doi.org/10.1007/s11356-019-04513-7.

Fitzgerald, J., Auerbach, D., 2016. The political economy of the water footprint: a cross-national analysis of ecologically unequal exchange. Sustainability 8, 1263. https://doi.org/10.3390/su8121263.

Goldthau, A., Boersma, T., 2014. The 2014 Ukraine-Russia crisis: implications for energy markets and scholarship. Energy Res. Social Sci. 3, 13–15. https://doi.org/10.1016/j.erss.2014.05.001.

Gozgor, G., 2017. Does trade matter for carbon emissions in OECD countries? Evidence from a new trade openness measure. Environ. Sci. Pollut. Control Ser. 24, 27813–27821. https://doi.org/10.1007/s11356-017-0361-z.

Gyamfi, B.A., Bein, M.A., Udemba, E.N., Bekun, F.V., 2021. Investigating the pollution haven hypothesis in oil and non-oil sub-Saharan Africa countries: evidence from quantile regression technique. Resour. Pol. 73, 102119 https://doi.org/10.1016/j.resourpol.2021.102119.

Habiba, U., Xinbang, C., Anwar, A., 2022. Do green technology innovations, financial development, and renewable energy use help to curb carbon emissions? Renew. Energy 193, 1082–1093. https://doi.org/10.1016/j.renene.2022.05.084.

Hansen, Bruce E., 1992a. Efficient estimation and testing of cointegrating vectors in the presence of deterministic trends. J. Econom. 53, 87–121. https://doi.org/10.1016/0304-4076(92)90081-2.

Hansen, Bruce E., 1992b. Tests for parameter instability in regressions with I(1) processes. J. Bus. Econ. Stat. 10, 321–335. https://www.jstor.org/stable/1392149.

Haseeb, A., Xia, E., Danish, Danish, Baloch, M.A., Abbas, K., 2018. Financial development, globalization, and CO2 emission in the presence of EKC: evidence from BRICS countries. Environ. Sci. Pollut. Res. 25, 31283–31296. https://doi.org/10.1007/s11356-018-3034-7.

Hidalgo, C.A., 2021. Economic complexity theory and applications. Nat. Rev. Phys. https://doi.org/10.1038/s42254-020-00275-1.

Hidalgo, C.A., Hausmann, R., 2009. The building blocks of economic complexity. Proc. Natl. Acad. Sci. U. S. A 106, 10570–10575. https://doi.org/10.1073/pnas.0900943106.

Hidalgo, C.A., Klinger, B., Barabási, A.-L., Hausmann, R., 2007. The product space conditions the development of nations. Science 317, 482–487. https://doi.org/10.1126/science.1144581.

Huang, Y., Haseeb, M., Usman, M., Ozturk, I., 2022. Dynamic association between ICT, renewable energy, economic complexity and ecological footprint: is there any difference between E-7 (developing) and G-7 (developed) countries? Technol. Soc. 68, 101853 https://doi.org/10.1016/j.techsoc.2021.101853.

Ikram, M., Xia, W., Fareed, Z., Shahzad, U., Rafique, M.Z., 2021. Exploring the nexus between economic complexity, economic growth and ecological footprint: contextual evidences from Japan. Sustain. Energy Technol. Assessments 47, 101460. https://doi.org/10.1016/j.seta.2021.101460.

Imbs, J., Wacziarg, R., 2003. Stages of Diversification. Am. Econ. Rev. 93 (1), 63–86. https://doi.org/10.1257/000282803321455160.

Isık, C., Ongan, S., Özdemir, D., 2019. Testing the ekc hypothesis for ten us states: an application of heterogeneous panel estimation method. Environ. Sci. Pollut. Control Ser. 26 (11), 10846–10853. https://doi.org/10.1007/s11356-019-04514-6.

Jahanger, A., Yang, B., Huang, W.C., Murshed, M., Usman, M., Radulescu, M., 2022. Dynamic linkages between globalization, human capital, and carbon dioxide emissions: empirical evidence from developing economies. Environ. Dev. Sustain. https://doi.org/10.1007/s10668-022-02437-w.

Johansen, S., 1991. Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. Econometrica J. Econom. Soc. 59 (6), 1551–1580. https://doi.org/10.2307/2938278. JSTOR 2938278.

Kamal, M., Usman, M., Jahanger, A., Balsalobre-Lorente, D., 2021. Revisiting the role of fiscal policy, financial development, and foreign direct investment in reducing environmental pollution during globalization mode: evidence from linear and non-linear panel data approaches. Energies 14 (21), 6968. https://doi.org/10.3390/en14216968.

Kao, C., 1999. Spurious regression and residual-based tests for cointegration in panel data. J. Econom. 90, 1–44. https://doi.org/10.1016/S0304-4076(98)00023-2.

Kao, C., Chiang, M.H., 2001. On the estimation and inference of a cointegrated regression in panel data. In: Baltagi, B.H., Fomby, T.B., Carter Hill, R. (Eds.), Nonstationary Panels, Panel Cointegration, and Dynamic Panels, Advances in Econometrics, vol. 15. Emerald Group Publishing Limited, Bingley, pp. 179–222. https://doi.org/10.1016/S0731-9053(00)15007-8.

Kearsley, A., Riddel, M., 2010. A further inquiry into the pollution haven hypothesis and the environmental Kuznets curve. Ecol. Econ. 69, 905–919. https://doi:10.1016/j.ecolecon.2009.11.014.

Kellemberg, D.K., 2009. An empirical investigation of the pollution haven effect with strategic environment and trade policy. J. Int. Econ. 78, 242–255. https://doi:10.1016/j.jinteco.2009.04.004.

Kentor, J., 1998. The long-term effects of foreign investment dependence on economic growth,1940-1990. Am. J. Sociol. 103 (4), 1024–1046. https://doi.org/10.1086/231295.

Khan, D., Ullah, A., 2019. Testing the relationship between globalization and carbon dioxide emissions in Pakistan: does environmental Kuznets curve exist? Environ. Sci. Pollut. Res. 26, 15194–15208. https://doi.org/10.1007/s11356-019-04913-9.

Khezri, M., Heshmati, A., Khodel, M., 2022. Environmental implications of economic complexity and its role in determining how renewable energies affect CO2 emissions. Appl. Energy 306, 117948. https://doi.org/10.1016/j.apenergy.2021.117948.

Koc, S., Bulus, G.C., 2020. Testing validity of the EKC Hypothesis in South Korea: role of renewable energy and trade openness. Environ. Sci. Pollut. Control Ser. 27, 29043–29054. https://doi.org/10.1007/s11356-020-09172-7.

Laverde-Rojas, H., Guevara-Fletcher, D., Camacho-Murillo, A., 2021. Economic growth, economic complexity, and carbon dioxide emissions: the case of Columbia. Hellyon 7, e07188. https://doi.org/10.1016/j.heliyon.2021.e07188.

Le, H.P., Ozturk, I., 2020. The impacts of globalization, financial development, government expenditures, and institutional quality on CO2 emissions in the presence of environmental Kuznets curve. Environ. Sci. Pollut. Control Ser. 27, 22680–22697. https://doi.org/10.1007/s11356-020-08812-2.

Lean, H.H., Smyth, R., 2010. Multivariate Granger causality between electricity generation, exports and GDP in Malaysia. Energy 35, 3640–3648.

Lean, H., Tan, B., 2011. Linkages between foreign direct investment, domestic investment and economic growth in Malaysia. J. Econ. Cooperation Dev. 32 (4), 75–96.

Li, H.S., Geng, Y.C., Shinwari, R., Yangjie, W., Rjoub, H., 2021. Does renewable energy electricity and economic complexity index help to achieve carbon neutrality target of top exporting countries? J. Environ. Manag. 299, 113386 https://doi.org/10.1016/j.jenvman.2021.113386.

Liu, J., Qu, J., Zhao, K., 2019. Is China's development conforms to the Environmental Kuznets Curve hypothesis and the pollution haven hypothesis? J. Clean. Prod. 234, 787–796. https://doi.org/10.1016/j.jclepro.2019.06.234.

Lv, Z., Xu, T., 2018. Is economic globalization good or bad for the environmental quality? New evidence from dynamic heterogeneous panel models. Technol. Forecast. Soc. Change 137, 340–343. https://doi.org/10.1016/j.techfore.2018.08.004.

Ma, Q., Murshed, M., Khan, Z., 2021. The nexuses between energy investments, technological innovations, emission taxes, and carbon emissions in China. Energy Pol. 155, 112345 https://doi.org/10.1016/j.enpol.2021.112345.

Ma, M., Feng, W., Huo, J., Xiang, X., 2022a. Operational carbon transition in the megalopolises' commercial buildings. Build. Environ. 226, 109705 https://doi.org/10.1016/j.buildenv.2022.109705.

Ma, M.-D., Chen, M.-X., Feng, W., Huo, J.-W., 2022b. What decarbonized the residential building operation worldwide since the 2000s. Petrol. Sci. 19 (6), 3194–3208. https://doi.org/10.1016/j.petsci.2022.10.016.

Mabey, N., McNally, R., 1999. Foreign Direct Investment and the Environment: from Pollution Havens to Sustainable Development. A WWF-UK Report.

MacKinnon, J., Haug, A., Michelis, L., 1999. Numerical Distribution Functions of Likelihood Ratio Tests for Cointegration. J. Appl. Econometr. 14 (5), 563–577.

Mair, S., Druckman, A., Jackson, T., 2016. Global inequities and emissions in Western European textiles and clothing consumption. J. Clean. Prod. 132 (132), 57e69. https://doi.org/10.1016/j.jclepro.2015.08.082.

Mani, M., Wheeler, D., 1998. In search of pollution havens? Dirty industry in the world economy, 1960 to 1995. J. Environ. Dev. 7, 215. https://doi.org/10.1177/107049659800700302.

Martins, J.M., Adebayo, T.S., Mata, M.N., Oladipupo, S.D., Adeshola, I., Ahmed, Z., Correia, A.B., 2021. Modeling the relationship between economic complexity and environmental degradation: evidence from top seven economic complexity countries. Front. Environ. Sci. 398 https://doi.org/10.3389/fenvs.2021.744781.

Mirziyoyeva, Z., Salahodjaev, R., 2022. Renewable energy and CO2 emissions intensity in the top carbon intense countries. Renew. Energy 192, 507–512. https://doi.org/10.1016/j.renene.2022.04.137.

Murshed, M., Apergis, N., Alam, M.S., Khan, U., Mahmud, S., 2022. The impacts of renewable energy, financial inclusivity, globalization, economic growth, and urbanization on carbon productivity: evidence from net moderation and mediation effects of energy efficiency gains. Renew. Energy 196, 824–838. https://doi.org/10.1016/j.renene.2022.07.012.

Murshed, M., Ahmed, R., Khudoykulov, K., Kumpamool, C., Alrwashdeh, N.N.F., Mahmood, H., 2023. Can enhancing financial inclusivity lower climate risks by inhibiting carbon emissions? Contextual evidence from emerging economies. Res. Int. Bus. Finance 65, 101902. https://doi.org/10.1016/j.ribaf.2023.101902.

Noailly, J., Smeets, R., 2015. Directing technical change from fossil-fuel to renewable energy innovation: An application using firm-level patent data. J. Environ. Econ. Manag. 72, 15–37. https://doi.org/10.1016/j.jeem.2015.03.004.

Nuţă, F.M., Nuţă, A.C., Zamfir, C.G., Petrea, S.-M., Munteanu, D., Cristea, D.S., 2021. National carbon accounting—analyzing the impact of urbanization and energy-related factors upon CO2 emissions in central–eastern European countries by using machine learning algorithms and panel data analysis. Energies 14 (10), 2775. https://doi.org/10.3390/en14102775.

Nwaogu, U.G., Ryan, M.J., 2015. FDI, foreign aid, remittance and economic growth in developing countries. Rev. Dev. Econ. 19 (1), 100–115. https://doi.org/10.1111/rode.12130.

Onwachukwu, C.I., Yan, I., K, M., Tu, K., 2021. The causal effect of trade liberalization on the environment. J. Clean. Prod. 318, 128615 https://doi.org/10.1016/j.jclepro.2021.128615.

Padhan, H., Padhang, P.C., Tiwari, A.K., Ahmed, R., Hammoudeh, S., 2020. Renewable energy consumption and robust globalization (s) in OECD countries: do oil, carbon emissions and economic activity matter? Energy Strategy Rev. 32, 100535 https://doi.org/10.1016/j.esr.2020.100535.

Pedroni, P., 2001. Fully modified OLS for heterogeneous cointegrated panels. In: Baltagi, B.H., Fomby, T.B., Carter, H.R. (Eds.), Nonstationary Panels, Panel Cointegration, and Dynamic Panels, Advances in Econometrics, vol. 15. Emerald Group Publishing Limited, Bingley, pp. 93–130. https://doi.org/10.1016/S0731-9053(00)15004-2.

Pereira, P., Basic, F., Bogunovic, I., Barcelo, D., 2022. Russian-Ukrainian war impacts the total environment. Sci. Total Environ. 837, 155865 https://doi.org/10.1016/j.scitotenv.2022.155865.

Phillips, P.C.B., 1995. Fully Modified Least Squares and Vector Autoregression. Econometrica 63 (5), 1023–1078. https://doi.org/10.2307/2171721.

Phillips, P.C., Hansen, B.E., 1990. Statistical inference in instrumental variables regression with I (1) processes. Rev. Econ. Stud. 57 (1), 99–125. https://doi.org/10.2307/2297545.

Poncet, S., de Waldemar, 2013. Export Upgrading and Growth: The Prerequisite of Domestic Embeddedness. World Dev. 51, 104–118. https://doi.org/10.1016/j.worlddev.2013.05.010.

Rafindadi, A.A., Muye, I.M., Kaita, R.A., 2018. The effects of FDI and energy consumption on environmental pollution in predominantly resource-based economies of the GCC. Sustain. Energy Technol. Assessments 25, 126–137. https://doi.org/10.1016/j.seta.2017.12.008.

Rehman, A., Alam, M.M., Ozturk, I., Alvarado, R., Murshed, M., Işık, C., Ma, H., 2023. Globalization and renewable energy use: how are they contributing to upsurge the CO2 emissions? A global perspective. Environ. Sci. Pollut. Control Ser. 30 (4), 9699–9712. https://doi.org/10.1007/s11356-022-22775-6.

Romero, J.P., Gramkow, C., 2021. Economic complexity and greenhouse gas emissions. World Dev. 139, 105317 https://doi.org/10.1016/j.worlddev.2020.105317.

Saikkonen, P., 1991. Asymptotically Efficient Estimation of Cointegration Regressions. Econometr. Theor. 7 (1), 1–21. https://www.jstor.org/stable/3532106.

Santos, A., Forte, R., 2021. Environmental regulation and FDI attraction: a bibliometric analysis of the literature. Environ. Sci. Pollut. Control Ser. 28 (7), 8873–8888. https://doi.org/10.1007/s11356-020-11091-6.

Sarkodie, S.A., Strezov, V., 2019. Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. Sci. Total Environ. 646, 862–871. https://doi.org/10.1016/j.scitotenv.2018.07.365.

Saud, S., Chen, S., Haseeb, A., Khan, K., Imran, M., 2019. The nexus between financial development, income level, and environment in central and eastern European countries: a perspective on belt and road initiative. Environ. Sci. Pollut. Res. 26, 16053–16075. https://doi.org/10.1007/s11356-019-05004-5.

Shahbaz, M., Mutascu, M., Azim, P., 2013. Environmental Kuznets curve in Romania and the role of energy consumption. Renew. Sustain. Energy Rev. 18, 165–173. https://doi.org/10.1016/j.rser.2012.10.012.

Shahbaz, M., Mallick, H., Mahalik, M.K., Loganathan, N., 2015. Does globalization impede environmental quality in India? Ecol. Indicat. 52, 379–393. https://doi.org/10.1016/j.ecolind.2014.12.025.

Shahbaz, M., Solarin, S.A., Ozturk, I., 2016. Environmental Kuznets Curve hypothesis and the role of globalization in selected African countries. Ecol. Indicat. 67, 623–636. https://doi.org/10.1016/j.ecolind.2016.03.024.

Shahbaz, M., Khan, S., Ali, A., Bhattacharya, M., 2017a. The impact of globalization on CO2 emissions in China. Singapore Econ. Rev. 62, 929–957. https://doi.org/10.1142/S0217590817400331.

Shahbaz, M., Nasreen, S., Ahmed, K., Hammoudeh, S., 2017b. Trade openness–carbon emissions nexus: the importance of turning points of trade openness for country panels. Energy Econ. 61, 221–232. https://doi.org/10.1016/j.eneco.2016.11.008.

Shahbaz, M., Shahzad, S.J.H., Mahalik, M.K., Hammoudeh, S., 2018. Does globalization worsen environmental quality in developed economies? Environ. Model. Assess. 23, 141–156. https://doi.org/10.1007/s10666-017-9574-2.

Shahbaz, M., Mahalik, M.K., Shahzad, S.J.H., Hammoudeh, S., 2019. Testing the globalization-driven carbon emissions hypothesis: international evidence. Int. Econ. 158, 25–38. https://doi.org/10.1016/j.inteco.2019.02.002.

Shahzad, U., Dogan, B., Sinha, A., Fareed, Z., 2021a. Does Export product diversification help to reduce energy demand: exploring the contextual evidences from the newly industrialized countries. Energy 214, 118881. https://doi.org/10.1016/j.energy.2020.118881.

Shahzad, U., Fareed, Z., Shahza, F., Shahzad, K., 2021b. Investigating the nexus between economic complexity, energy consumption and ecological footprint for the United States: new insights from quantile methods. J. Clean. Prod. 279, 123806 https://doi.org/10.1016/j.jclepro.2020.123806.

Shen, J., Wang, S., Liu, W., Chu, J., 2019. Does migration of pollution-intensive industries impact environmental efficiency? Evidence supporting "Pollution Haven Hypothesis. J. Environ. Manag. 242, 142–152. https://doi.org/10.1016/j.jenvman.2019.04.072.

Singhania, M., Saini, N., 2021. Demystifying pollution haven hypothesis: the role of FDI. J. Bus. Res. 123, 516–528. https://doi.org/10.1016/j.jbusres.2020.10.007.

Stock, J.H., Watson, M.W., 1993. A simple estimator of cointegrating vectors in higher order integrated systems. Econometrica 61 (4), 783–820. https://doi.org/10.2307/2951763.

Suki, N.M., Sharif, A., Afshan, S., Suki, N.M., 2020. Revisiting the Environmental Kuznets Curve in Malaysia: the role of globalization in sustainable environment. J. Clean. Prod. 264, 121669 https://doi.org/10.1016/j.jclepro.2020.121669.

Sweet, C.M., Maggio, D.S.E., 2015. Do Stronger Intellectual Property Rights Increase Innovation? World Dev. 66, 665–677. https://doi.org/10.1016/j.worlddev.2014.08.025.

The Economist, 2022. Why the War in Ukraine Is Driving up Europe's Use of Coal – and its Price. https://www.economist.com/the-economist-explains/2022/05/09/why-the-war-in-ukraine-is-driving-up-europes-use-of-coal-and-its-price.

Tsurumi, T., Managi, S., 2010. Decomposition of the Environmental Kuznets Curve: Scale, Technique, and Composition Effects. Environ. Econ. Pol. Stud. 11, 19–36. https://doi.org/10.1007/s10018-009-0159-4.

Ullah, S., Luo, R., Ali, K., Irfan, M., 2022. How Does the Sectoral Composition of FDI Induce Economic Growth in Developing Countries? the Key Role of Business Regulations. Economic Research-Ekonomska Istraživanja. https://doi.org/10.1080/1331677X.2022.2129406.

Ulucak, Z.S., Ilkay, S.C., Ozcan, B., Gedikli, A., 2020. Financial globalization and environmental degradation nexus: evidence from emerging economies. Resour. Pol. 67, 101698 https://doi.org/10.1016/j.resourpol.2020.101698.

Verhorn, C.L., Vasarevici, A., 2011. FDI and macroeconomic policies, central and EasternEuropeanCountries. Zagreb Int. Rev. Econ. Bus. 14 (1), 23–34.

Vongpraseuth, T., Choi, C.G., 2015. Globalization, foreign direct investment, and urban growth management: policies and conflicts in Vientiane, Laos. Land Use Pol. 42, 790–799. https://doi.org/10.1016/j.landusepol.2014.10.003.

Vučković, M., Bobek, V., Maček, A., Skoko, H., Horvat, T., 2020. Business environment and foreign direct investments: the case of selected European emerging economies. Econ. Res.-Ekonomska Istraživanja 33 (1), 243–266. https://doi.org/10.1080/1331677X.2019.1710228.

Wang, M., Yao, M., Wang, S., Qian, H., Zhang, P., Wang, Y., Sun, Y., Wei, W., 2021a. Study of the emissions and spatial distributions of various power-generation technologies in China. J. Environ. Manag. 278, 111401 https://doi.org/10.1016/j.jenvman.2020.111401.

Wang, S., He, Y., Song, M., 2021b. Global value chains, technological progress, and environmental pollution: inequality towards developing countries. J. Environ. Manag. 277, 110999 https://doi.org/10.1016/j.jenvman.2020.110999.

Wang, Z., Jebli, M.B., Madaleno, M., Doğan, B., Shahzad, U., 2021c. Does export product quality and renewable energy induce carbon dioxide emissions: evidence from leading complex and renewable energy economies. Renew. Energy 171, 360–370. https://doi.org/10.1016/j.renene.2021.02.066.

Wang, Z., Zhao, N., Wei, W., Zhang, Q., 2021d. A differentiated energy Kuznets curve: evidence from mainland China. Energy 214, 118942. https://doi.org/10.1016/j.energy.2020.118942.

Xia, W., Apergis, N., Bashir, M.F., Ghosh, S., Doğan, B., Shahzad, U., 2021. Investigating the role of globalization, and energy consumption for environmental externalities: empirical evidence from developed and developing economies. Renew. Energy 183, 219–228. https://doi.org/10.1016/j.renene.2021.10.084.

Xiang, X., Ma, M., Ma, X., Chen, L., Cai, W., Feng, W., Ma, Z., 2022. Historical decarbonization of global commercial building operations in the 21st century. Appl. Energy 322, 119401. https://doi.org/10.1016/j.apenergy.2022.119401.

Yan, D., Hong, T., Li, C., Zhang, Q., An, J., Hu, S., 2017. A thorough assessment of China's standard for energy consumption of buildings. Energy Build. 143, 114–128. https://doi.org/10.1016/j.enbuild.2017.03.019.

Yang, J., Tan, Y., Xue, D., 2019. The impacts of globalization on city environments in developing countries: a case study of 21 cities in Guangdong Province, China. J. Clean. Prod. 240, 118273 https://doi.org/10.1016/j.jclepro.2019.118273.

Yilanci, V., Bozoklu, S., Gorus, M.S., 2020. Are BRICS countries pollution havens? Evidence from a bootstrap ARDL bounds testing approach with a Fourier function. Sustain. Cities Soc. 55, 102035 https://doi.org/10.1016/j.scs.2020.102035.

Yildirim, D.C., Esen, O., Yildirim, S., 2022. The non-linear effects of environmental innovation on energy sector-based carbon emissions in OECD countries. Technol. Forecast. Soc. Change 182, 121800. https://doi.org/10.1016/j.techfore.2022.121800.

Yin, X., Chen, W., Eom, J., Clarke, L., Kim, S., Patel, P., Yu, S., Kyle, G.P., 2015. China's transportation energy consumption and CO2 emissions from a global perspective. Energy Pol. 82, 233–248. https://doi.org/10.1016/j.enpol.2015.03.021.

Yunzhao, L., 2022. Modelling the role of eco innovation, renewable energy, and environmental taxes in carbon emissions reduction in E-7 economies: evidence from advance panel estimations. Renew. Energy 190, 309–318. https://doi.org/10.1016/j.renene.2022.03.119.

Zafar, M.W., Saud, S., Hou, F., 2019. The impact of globalization and financial development on environmental quality: evidence from selected countries in the Organization for Economic cooperation and Development (OECD). Environ. Sci. Pollut. Res. 26, 13246–13262. https://doi.org/10.1007/s11356-019-04761-7.

Zhang, C., Zhou, X., 2016. Does foreign direct investment lead to lower CO2 emissions? Evidence from a regional analysis in China. Renew. Sustain. Energy Rev. 58, 943–951. https://doi.org/10.1016/j.rser.2015.12.226.

Zhang, Z., Zhu, K., Hewings, G.J.D., 2017. A multi-regional input-output analysis of the pollution haven hypothesis from the perspective of global production fragmentation. Energy Econ. 64, 13–23. https://doi.org/10.1016/j.eneco.2017.03.007.

Zhao, Y., Su, Q., Li, B., Zhang, Y., Wang, X., Zhao, H., Guo, S., 2022. Have those countries declaring "zero carbon" or "carbon neutrality" climate goals achieved carbon emissions-economic growth decoupling? J. Clean. Prod. 363, 132450 https://doi.org/10.1016/j.jclepro.2022.132450.

Zheng, F., Zhou, X., Rahat, B., Rubbaniy, G., 2021. Carbon neutrality target for leading exporting countries: on the role of economic complexity index and renewable energy electricity. J. Environ. Manag. 299, 113558 https://doi.org/10.1016/j.jenvman.2021.113558.

Zheng, Y., Wei, W., Murshed, M., Khan, S., Mahmood, H., Das, N., 2022. Repercussions of hydroelectricity use on carbon emissions in Bangladesh: evidence using novel Fourier-bootstrapped ARDL and Fourier-Gradual shift causality analyses. Eval. Rev. https://doi.org/10.1177/0193841X221135674.