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Modeling the Relationship Between Economic Complexity and Environmental Degradation: Evidence From Top Seven Economic Complexity Countries

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The continuous growth in CO_2 emissions of nations around the globe has made achieving the aim of sustainable development extremely challenging. Therefore, the current research assesses the connection between CO_2 emissions and economic complexity in the top 7 economic complexity countries while taking into account the role of economic growth, renewable energy consumption, and globalization for the period between 1993 and 2018. The research aims to answer the following questions: 1) What is the association between CO_2 and the regressors in the long-run? 2) What are the effects of renewable energy consumption, economic growth, economic complexity, and globalization on CO_2 emissions? The research utilized the CS-ARDL, CCEMG and panel causality approaches to investigate these interconnections. The empirical outcomes revealed that economic growth and economic complexity increase CO_2 emissions while renewable energy consumption and globalization mitigate CO_2 emissions. The outcomes of the causality test revealed a feedback causal connection between economic growth and CO_2, while a unidirectional causality was established from economic complexity, globalization and renewable energy consumption to CO_2 emissions in the top 7 economic complexity countries.

Keywords: CO_2 emissions, economic complexity, globalization, renewable energy consumption, economic growth

INTRODUCTION

Environmental quality and pollution concerns have become a subject of discussion for economist's ecologists, policymakers, and researchers over the past two decades. Human demand for natural resources puts strain on the environment, resulting in a slew of environmental concerns such as climate change, soil degradation, pollution, and biodiversity loss (Adebayo and Kirikkaleli, 2021; Soylu et al., 2021). Humanity's unrestricted exploitation of natural resources produces irreparable harm to the biosphere, which has a detrimental impact on the globe's sustainable social development and economic goals (Shahbaz et al., 2021). Excessive exploitation and use of natural resources, as well as growing pollution and waste emissions, pose a danger to national economies. Carbon emissions (CO_2) are now causing serious environmental issues such as global warming, climate change, and biodiversity loss. As a result, nations have taken steps to reduce CO_2 at international gatherings, including the Stockholm Conference, the Montreal and Kyoto Protocols, and the Paris Agreement. Notwithstanding all attempts, CO_2 keeps rising globally. The level of economic growth is a critical component influencing environmental deterioration. The environmental and ecological cost of economic progress, in particular, is a source of worry (Ozturk and Acaravci, 2016; Adebola Solarin et al., 2017; Rjoub et al., 2021). The study of Grossman and Krueger (1991) was the first to examine the inverted U-shaped connection between numerous environmental degradation indices and economic development. This connection demonstrates that as the degree of development increases, degradation of the environment rises initially, and then when a specific limit is reached, economic growth lowers the environmental deterioration.

Furthermore, several academics have recently added the economic complexity index as a measure of economic progress in their study (Ahmad et al., 2021; Pata, 2021). Dreher (2006) constructing the economic complexity index (ECI) to calculate a nation's technology-intensive exports. ECI is an indication of a country's economic progress in terms of export since this data only covers exported items. ECI is described in the international trade literature as the technological level and understanding of the production process (Abbasi et al., 2021; Pata, 2021). In other words, a nation's productive output necessitates a high degree of ingrained skills and knowledge (Hidalgo and Hausmann, 2009). ECI varies according to the diversity and sophistication of each nation's exports (Doğan et al., 2019). On the one hand, as the economy's complexity grows, so does product diversity, and more output contributes to higher emissions. Moreover, ECI can have a beneficial impact on the quality of the environment since it involves research and development activities as well as the ability to promote eco-friendly goods and clean technology (Neagu, 2020). As Hidalgo and Hausmann (2009) stated, ECI remains at the center of the rationale for the disparity in per capita income between nations. As a result, ECI is closely related to a nation's per capita income and wellbeing (Abbasi et al., 2021).

Energy is also critical to economic progress and environmental degradation. Economic activities that consume a lot of energy result in increased CO_2 emissions (Adebola Solarin et al., 2017). Excessive usage of fossil fuels in the industrial production process raises CO_2 and inhibits sustainable growth by creating climate change and ecological problems. With the population of the globe growing, the continued usage of fossil fuel sources including oil, coal, and gas resulted in military and geopolitical conflicts, an increase in environmental concerns, and oil price instability (Orhan et al., 2021). Renewable energy sources, as opposed to fossil fuels, are clean, limitless, and ecologically beneficial. Since the massive growth in fossil fuel consumption has resulted in catastrophes and severe ecological harm, renewable energy should be utilized in place of fossil fuels to improve the sustainability of the environment while also providing energy diversity and security (Sarkodie and Strezov, 2019).

Globalization is another element that contributes to environmental deterioration. Globalization influences human demand on the environment by facilitating economic, technical, and cultural progress. (Dreher, 2006) (KOF) index can be used to gauge globalization. This indicator is divided into three complementary components: political, social, and economic. Globalization, which has gained traction during the 1990s, has resulted in significant economic developments such as capital flows and international trade liberalization. Globalization boosts total factor productivity, opens up new investment options, and strengthens financial markets (Kirikkaleli et al., 2021). To sum up, globalization can affect environmental pollution positively or negatively. Most economists believe that globalization has a positive net impact on the degradation of the environment (Dreher, 2006). Since globalization does not give an exact impact (positive or negative), its influence on the degradation of the environment should be investigated (Pata, 2021).

Over the years, several studies have been done to inform the public on the influence of economic complexity, economic growth, globalization, and renewable energy consumption on CO_2 emissions; however, findings mixed. For instance, some studies (Dogan and Seker, 2016; Pata, 2021; Rafique et al., 2021) found CO_2-ECI positive connections while some studies (Can and Gozgor, 2016; Doğan et al., 2019; Boleti et al., 2021) established negative CO_2-ECI association. Moreover, the studies of Koengkan et al. (2020), Pata (2021), and Khan et al. (2019) disclosed CO_2-GLO positive interrelation whereas the studies of He et al. (2021) and Koengkan et al. (2020) confirmed negative CO_2-GLO association. Additionally, the majority of the studies found that economic expansion triggers emissions of CO_2 (Adebayo, 2020; Coelho et al., 2021; Kirikkaleli and Adebayo, 2021).

In this regard, our study attempts to overcome the gap in the literature by focusing on the top seven economic complexity nations (Japan, Switzerland, South Korea, Germany, Singapore, Australia and Czech) (see **Figure 1**)[1] which are ranked as developed nations. This research adds to the current literature in the following ways: First, we assess not only the influence of economic complexity but also the influence of REC, economic growth, and globalization on environmental deterioration. Second, this research introduces the interaction term to assess the influence of renewable energy and economic complexity on CO_2 emissions to capture whether globalization among these nations has any implications on renewable energy utilization and economic complexity and, as a result, for CO_2. To the authors' understanding, this is the first study to explore these associations using the interaction term. Therefore, the present research fills the gap in the ongoing literature. Third, the current study adds by employing a unique CS-ARDL to address the concerns of heterogeneity and CSD in panel data, which have been

[1]https://oec.world/en/rankings/country/eci/ (Accessed: January, 2021).

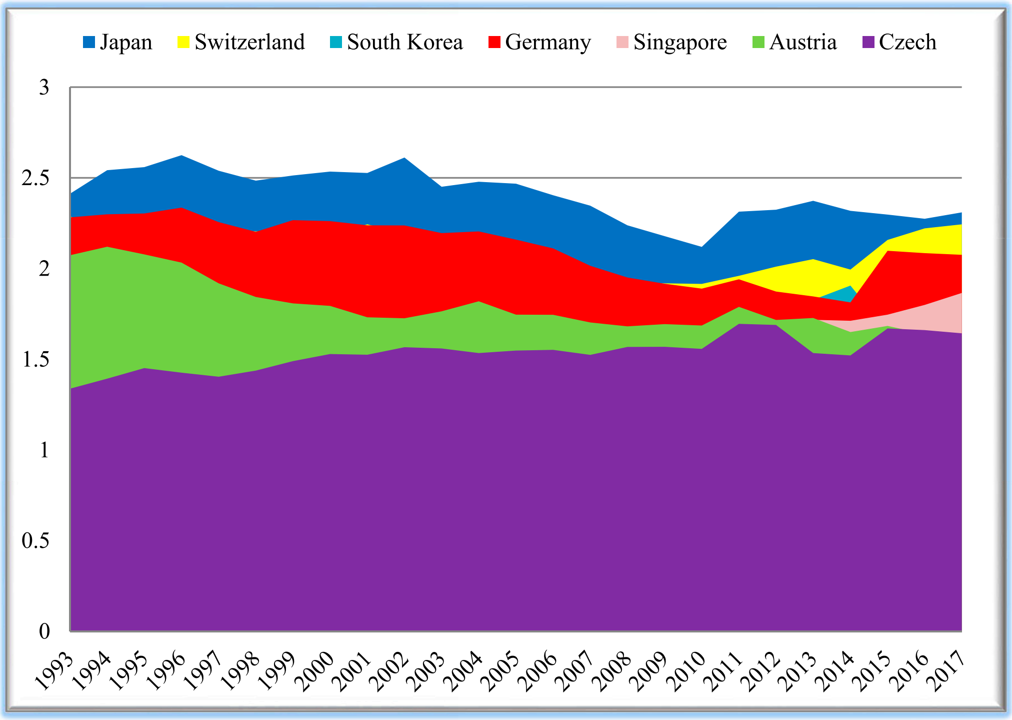

FIGURE 1 | Top 7 economic complexity nations trends from 1993 to 2017.

overlooked in earlier studies. This approach is resistant to misspecification bias endogeneity cross-sectional dependence, nonstationarity, and heterogeneity (Lin et al., 2021). Thirdly, we applied the CCEMG approach as a robustness check.

The remaining sections of this research are compiled as follows: *Literature Review* present the data and methods. *Findings and Discussion* illustrates the findings and discussion and the conclusion is presented in *Conclusion and Policy Path.*

LITERATURE REVIEW

This section of the study presents a summary of the studies conducted regarding the connection between carbon emissions (CO_2) and economic growth (GDP), globalization (GLO), economic complexity (ECI), and renewable energy utilization (REC). Regarding the interrelationship between CO_2 and economic growth, several studies have been conducted; however, mixed findings are reported. For instance, Using G7 countries and data from 1970 to 2015, (Cai et al., 2018) assessed the GDP-CO_2 interrelationship. The investigators applied Granger Causality based on bootstrap ARDL and the study outcomes unveiled that GDP dampens the quality of the environment. Furthermore, there is proof of unidirectional causal linkage from GDP to CO_2. Similarly, Wang and Ye (2017) using the BRICS Nations assessed the GDP-CO_2 interrelationship using PLS and the study outcome disclosed positive GDP-CO_2 interrelationship. Moreover, Ahmad et al. (2021) study on the GDP-CO_2 association in 30 Chinese provinces and cities using the panel method disclosed that an upsurge in GDP mitigates CO_2. Also, the EKC hypothesis is validated. Moreover, the study of Leitão (2021a) in Portugal using FMOLS disclosed that an increase in GDP contributes to the degradation of the environment. Using the ARDL approach, Khan et al. (2019) assessed the connection between GDP and CO_2 from 1965 to 2015 and their outcome disclosed a positive GDP-CO_2 interrelationship. Using Brazil as a case study, Hdom and Fuinhas (2020) investigated the EKC hypothesis using data from 1975 to 2016 and DOLS, FMOLS, and Causality approaches. The study affirmed the EKC hypothesis also, there is unidirectional causality from GDP to CO_2. Furthermore, the study of Salari et al. (2021) in the United States from 1997 to 2016 disclosed positive CO_2-GDP interconnection.

Globalization boosts total factor productivity (TFP) by increasing trade. Foreign direct investment (FDI) and the transfer of sophisticated technologies between industrialized and developing nations stimulate economic growth. Furthermore, globalization creates investment possibilities *via* FDI and strengthens financial markets *via* financial deregulation. Certainly, this process improves trade, economic growth, and financial markets as well as the consumption of energy which increases CO_2 emissions. On the association between globalization and CO_2 emissions, several studies have been done with mixed findings. For instance, Muhammad and Khan (2021) research on the globalization-emissions association using 31 developed and 155 developing countries disclosed that in both developed and developing nations an upsurge in globalization triggers emissions levels. Moreover, the study of Leal and Marques (2021) using 23 African countries from 1999 to 2017 disclosed a positive globalization-emissions association. On the contrary, the study of He et al. (2021) in Mexico established a negative globalization-emissions association interrelationship. The negative globalization-emissions association is also supported by the study of Koengkan et al. (2020) for Latin America and Caribbean Countries between 1975 and 2016. Using South Asian countries, the study of Khan et al. (2019) confirmed a negative GLO-CO_2 interrelationship.

Renewable energy sources, as opposed to fossil fuels, are clean, limitless, and ecologically beneficial. Since the massive growth in fossil fuel consumption has resulted in catastrophes and severe ecological harm, renewable energy should be utilized in place of fossil fuels to improve the sustainability of the environment while also providing energy diversity and security (Sarkodie and Strezov, 2019). On this note, several studies have been done on renewable energy use and CO_2 emissions association. For example, using 25 selected African countries, the study of Zoundi (2017) on the REC-CO_2 interrelationship and Panel FMOLS from 1980 to 2012 disclosed negative CO_2-REC association. Moreover, using Portugal, Italy, Greece, and Spain as a case study, the study of Balsalobre-Lorente et al. (2021) established that renewable energy usage helps to abate CO_2 emissions. Likewise, using European nations as a case study, the study of Leitão and Lorente (2020) established that renewable energy utilization plays a significant role in decreasing emissions of CO_2. In India, Kirikkaleli and Adebayo (2021) assessed the CO_2-REC connection using frequency domain causality test and their outcome disclose that an upsurge REC contributes to the degradation of the environment. Similarly, the study of Leitão (2021b) on the REC-GDP connection using FMOLS disclosed that an upsurge in REC mitigates CO_2 emissions. Furthermore, REC can predict CO_2. Moreover, the study of Cherni and Essaber Jouini (2017) on the REC-CO_2 interrelationship unveiled that an upsurge in REC mitigates CO_2 pollution. This outcome is also validated by the studies of Adams and Nsiah (2019) for 28 Sub-Sahara African countries and Haseeb et al. (2018) for BRICS countries.

Furthermore, several academics have recently added the economic complexity index as a measure of economic progress in their study (Ahmad et al., 2021; Pata, 2021). ECI is an indication of a country's economic progress in terms of export since this data only covers exported items. ECI is described in the international trade literature as the technological level and understanding of the production process (Abbasi et al., 2021; Pata, 2021). In other words, a nation's productive output necessitates a high degree of ingrained skills and knowledge (Hidalgo and Hausmann, 2009). ECI varies according to the diversity and sophistication of each nation's exports (Doğan et al., 2019). Several studies have been done on renewable energy use and CO_2 emissions association. For example, using 55 countries and data from 1971 to 2014, the study of Dogan and Seker (2016) established positive ECI-CO_2 interrelationship. Similarly, the study of Neagu (2020) on the ECI-CO_2 interrelationship using European Union countries from 1990 to 2018, and DOLS, FMOLS, and Panel Causality approaches disclosed that an upsurge in ECI triggers CO_2 emissions. Contrarily, the study of Doğan et al. (2019) established negative ECI-CO_2 interrelationship in 28 OECD countries from 1990 to 2014 using Panel ARDL. Likewise, the study of Boleti et al. (2021) using 88 developed and developing countries an data from 2002 to 2012 revealed negative ECI-CO_2 interrelationship. **Table 1** presents the summary of discussed studies.

METHODOLOGY

Theoretical Underpinning and Data

The theoretical foundation of this research is centered on the EKC theory. Economic growth can have three separate effects on environmental degradation. CO_2 is impacted by economic growth in three dissimilar ways namely scale, composition, and technique effects. According to the scale effect, economic development leads to environmental pollution at first because it requires more energy and resources, culminating in more waste and pollution (Alola, 2019; Shan et al., 2021). The structure of a country, on the other hand, influences the degree of emissions and materials required in the production process. Additionally, the composition effect predicts that structural changes from the industrial to service sectors would minimize the negative environmental consequences of economic development. Finally, the technique effect shows that when a country's wealth grows, it adopts new and enhanced technology that boosts productivity while lowering emissions.

Economic complexity (ECI) is another major factor that may impact environmental quality. Economic complexity is a broader assessment of a country's size, structural changes, and technological progress (Mealy and Teytelboym, 2020). Nonetheless, the complexity of an economy may assist governments in managing research, information, skills, and technical advancement, all of which support greener goods and ecologically friendly technologies, culminating in less ecological destruction (Abbasi et al., 2021). On the flipside, simple economies lack the means to manage efficient knowledge; as a result, goods are produced utilizing conventional technologies and nonrenewable energy sources. As a result, nonrenewable energy and old technology have a negative impact on the environment (Kirikkaleli and Adebayo, 2021).

Renewable energy is the cleanest kind of energy available, with no pollution or resource depletion, thus its use improves the environment. The most ecologically friendly sources of energy are solar and wind. Unlike fossil fuels, renewables are limitless. On the other hand, nonrenewable resources are limited and unsustainable, and their extensive usage amplifies climate change and global warming by increasing GHGs emissions (Ozturk and Acaravci, 2016). This implies that using nonrenewable energy produces more CO_2, but using renewable energy reduces emissions.

Globalization boosts trade and economic expansion, which has an impact on energy consumption and the environment. While globalization has exacerbated the climate issue, it can also help to mitigate it. Moreover, globalization hastens the spread of eco-friendly technology *via* worldwide networks of industry flows of capital, and R&D (Ramzan et al., 2021). Furthermore, the proliferation of new technologies will make monitoring and openness on climate action easier. The present study is centered on the studies of Abbasi et al. (2021) and Ahmad

TABLE 1 | Summary of studies.

Authors	Nation (s)	Period	Method(s)	Findings
	Impact of GDP on CO_2 Emissions			
Cai et al. (2018)	G7 countries	1970–2015	Granger Causality	GDP → CO_2
Wang and Ye (2017)	BRICS Nations	1996–2015	PLS	GDP → CO_2 (+)
Ahmad et al. (2021)	30 Chinese provinces and cities	2000–2016	Panel Technique	GDP → CO_2 (+)
Muhammad (2019)	MENA nations	2001–2017	GMM	GDP → CO_2 (–)
Khan et al. (2019)	Pakistan	1965–2015	ARDL	GDP → CO_2 (+)
Hdom and Fuinhas (2020)	Brazil	1975–2016	DOLS, FMOLS, Causality	GDP → CO_2 (+)
Salari et al. (2021)	States in USA	1997–2016	Panel Techniques	GDP → CO_2 (+)
Gao and Zhang (2021)	13 Asian developing countries	1980–2010	Panel FMOLS, DH Causality	GDP → CO_2 (+)
Kılavuz and Doğan (2021)	Turkey	1961–2018	ARDL	GDP → CO_2 (+)
(Awosusi et al. 2021)	South Korea	1965–2019	ARDL	GDP → CO_2 (+)
(Vaseer et al. 2021)	WAME nations	1990–2017	Panel Techniques	GDP → CO_2 (+)
	Impact of globalization on CO_2 Emissions			
Muhammad and Khan (2021)	31 developed and 155 developing countries	1991–2018	GMM	GLO → CO_2 (+)
Leal and Marques (2021)	23 African countries	1999–2017	ARDL	GLO → CO_2 (+)
He et al. (2021)	Mexico	1990-2018	Dual-adjustment approach, ARDL	GLO → CO_2 (–)
Koengkan et al. (2020)	Latin America and Caribbean Countries	1975–2016	Panel Quantile	GLO → CO_2 (-)
Pata (2021)	Brazil and China	1971–2016	Fourier ADL cointegration	GLO → CO_2 (+)
Khan et al. (2019)	South Asian countries	1972–2017	Panel FMOLS	GLO → CO_2 (+)
Ramzan et al. (2021)	Latin America	1980–2017	FMOLS, DOLS	GLO → CO_2 (+)
	Impact of Renewable energy on CO_2 Emissions			
Zoundi (2017)	25 selected African countries	1980–2012	Panel FMOLS	REC → CO_2 (–)
Namahoro et al. (2021)	seven East African countries (EACs)	1980–2016	CCEMG, NARDL	REC → CO_2 (–)
Haseeb et al. (2018)	BRICS countries	1990–2015	AMG	REC → CO_2 (–)
Cherni and Essaber Jouini (2017)	Tunisia	1990–2016	ARDL, Granger Causality	REC → CO_2 (–)
Charfeddine and Kahia (2019)	MENA)	1980–2015	PVAR	REC → CO_2 (–)
Adams and Nsiah (2019)	28 Sub-Sahara African countries	1980–2014	FMOLS, GMM	REC → CO_2 (–)
(Udemba et al. 2021)	Chile	1990–2018	NARDL	REC → CO_2 (–)
	Impact of Economic Complexity on CO_2 Emissions			
Dogan and Seker (2016)	55 countries	1971–2014	Quantile Regression	ECI → CO_2 (+)
Neagu (2020)	European Union countries		DOLS, FMOLS, Panel Causality	ECI → CO_2 (+) ECI ≠ CO_2
Pata (2021)	USA	1980–2016	VECM, FMOLS	ECI → CO_2 (+)
Doğan et al. (2019)	28 OECD countries	1990–2014	AMG	ECI → CO_2 (–)
Rafique et al. (2021)	top 10 ECI economies	1980–2017	FMOLS, DOLS, GMM	ECI → EF (+)
Boleti et al. (2021)	88 developed and developing countries	2002–2012	FE-OLS	ECI → CO_2 (–)

et al. (2021) by incorporating renewable energy consumption into the model as follows:

$$C0_{2i,t} = \alpha_0 + \theta_1 GDP_{i,t} + \theta_2 REC_{i,t} + \theta_3 GLO_{i,t} + \theta_4 ECI_{i,t} + \varepsilon_{i,t} \tag{1}$$

Where "i," denotes the cross-section, i.e., the top economic complexity economy. The period which is from 1993 to 2018 is depicted by t and α denotes the intercept term. The error term and parameters are illustrated by ε and $\theta' s$, respectively. CO_2 stands for carbon emissions which is calculated as metric tonnes per Capita, GDP is calculated as GDP per capita and is utilized to denote economic growth. REC stands for renewable energy and it is measured as renewables consumption per capita (Kwh). ECI stands for economic complexity which is a good proxy for a productive economic structure since it assesses the productive structure of nations and reflects the amount of sophistication and differences in industrial structure. GLO represents globalization and it is measured as an index based on FDI, trade, and portfolio investment. CO_2 and REC are gathered from the British Petroleum database, globalization data is obtained from Gygli et al. (2019), GDP is gathered from the World Bank dataset and ECI data is collected from OEC_World database.

Estimation Strategy

Cross-Sectional Dependence Test

This study commenced by examining cross-sectional dependency (CD) because nations are linked *via* numerous economic, social, and cultural networks that may produce spillover effects. Consequently, the present research utilized CD tests to ascertain the cross-sectional dependence. The CSD test equation is stipulated as follows:

$$CSD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho}_{ij}\right) \tag{2}$$

Where pairwise correlation is illustrated by ρij.

The null and alternative hypotheses are "there is no CD in the data" and "CD is present" respectively.

Slope Homogeneity Test

The next phase assesses the existence of slope heterogeneity amongst the cross-section units. The issue of heterogeneity must be determined because, due to differences in developing nation's economic and demographic structure, there is a possibility of slope heterogeneity, which could potentially affect the consistency of panel estimators. For this reason, this study utilized the slope homogeneity method. The Hashem Pesaran and Yamagata (2008) test is illustrated below;

$$\widetilde{\Delta}_{SH} = (N)^{\frac{1}{2}}(2k)^{-\frac{1}{2}}\left(\frac{1}{N}\widetilde{S} - k\right) \quad (3)$$

$$\widetilde{\Delta}_{ASH} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1)}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\widetilde{S} - 2k\right) \quad (4)$$

Where $\widetilde{\Delta}_{ASH}$ and $\widetilde{\Delta}_{SH}$, stand for adjusted delta tilde and delta tilde, respectively.

The null and alternative hypotheses are "there is homogeneity" and "there is no homogeneity" respectively.

Stationarity Test

In the empirical analysis, it is essential to understand the stationarity features of series. Thus, we applied cross-sectionally augmented IPS (CIPS) to capture the series stationarity features. This approach is effective, specifically for heterogeneous slope and CD. The equations for these tests are as follows:

$$\Delta Y_{i,t} = \gamma_i + \gamma_i Y_{i,t-1} + \gamma_i \overline{X}_{t-1} + \sum_{l=0}^{p}\gamma_{il}\Delta\overline{Y_{t-l}} + \sum_{l=1}^{p}\gamma_{il}\Delta Y_{i,t-l} + \varepsilon_{it} \quad (5)$$

Where the first difference between averages and the lagged are illustrated by $\Delta\overline{Y_{t-l}}$ and $\overline{Y}_{t-1}$, respectively. Moreover, by taking the average of each CADF, the CIPS is obtained as illustrated by **Equation 6**.

$$\widehat{\mathrm{CIPS}} = \frac{1}{\mathrm{N}}\sum_{\mathrm{i=1}}^{\mathrm{n}}\mathrm{CADF_i} \quad (6)$$

The null and alternative hypotheses are "there is unit root" and "there is no unit root".

Cointegration Test

It is essential to capture the long-run association among the variables of interest. Thus, the present research applied the Westerlund (2007) cointegration test to capture the long-run association between CO_2 and regressors. Unlike the traditional cointegration tests (e.g., Kao and Pedroni), this test offers impartial outcomes in the presence of CD and heterogeneity. The cointegration test is presented as follows:

$$\alpha i(L)\Delta y_{it} = y2_{it} + \beta_i\left(y_{it} - 1 - \acute{\alpha}_i \mathrm{x_{it}}\right) + \lambda_\mathrm{i}(\mathrm{L})\mathrm{v_{it}} + \eta_\mathrm{i} \quad (7)$$

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

The Westerlund cointegration statistics are presented as follows:

$$G_t = \frac{1}{N}\sum_{i-1}^{N}\frac{\acute{\alpha}_i}{SE(\acute{\alpha}_i)} \quad (8)$$

$$G_\alpha = \frac{1}{N}\sum_{i-1}^{N}\frac{\mathrm{T}\acute{\alpha}_i}{\acute{\alpha}_i(1)} \quad (9)$$

$$P_T = \frac{\acute{\alpha}}{SE(\acute{\alpha})} \quad (10)$$

$$P_\alpha = \mathrm{T}\acute{\alpha} \quad (11)$$

Where G_a and G_t stands for group means statistics, while P_a and P_t stand for panel statistics. The null and alternative hypotheses are "no cointegration" and "there is cointegration".

Cross-Sectionally Augmented ARDL

Next, we used the cross-sectional augmented ARDL (CS-ARDL) model established by Chudik and Pesaran (2015) to evaluate the long-run and short-run effects of economic development, economic complexity, globalization, and renewable energy use on CO_2 emissions. The CS-ARDL yields trustworthy results since it is resistant to endogeneity and non-stationarity issues, and it also overcomes cross-sectional dependency and heterogeneity challenges (Wang et al., 2021). The CS-ARDL Equations are presented as follows:

$$Y_{it} = \sum_{i=1}^{py}\pi_{it}Y_{i,t} + \sum_{i=0}^{pz}\theta_{i1}^{\iota}Z_{i,t-1} + \sum_{i=0}^{pT}\phi_{i1}^{\iota}Z_{i,t-1} + e_{it} \quad (12)$$

Where $X_{t-1}^{-} = (Y_{t-1}^{-}, Z_{t-1}^{-})\iota$, The $\overline{Y_t}$ and $\overline{Z_t}$ illustrates average cross-sections. Moreover, X_{t-1}^{-} illustrates the averages of both dependent and regressors:

$$\widehat{\vartheta}_{CS-ARDL,i} = \frac{\sum_{i=0}^{pz}\widehat{\theta}_{iI}^{\iota}}{1 - \sum_{I=1}^{py}\widehat{\pi}_{iI}} \quad (13)$$

$$\widehat{\vartheta}_{meangroup(MG)} = \frac{1}{N}\sum_{i=1}^{N}\widehat{\vartheta}_i \quad (14)$$

Panel Causality

After verifying the connection between the independent and dependent variables, policymakers must understand the causal connection between the series under investigation. Therefore, the present research applied the Dumitrescu and Hurlin (2012) causality test to assess the variables causal association. As heterogeneity existed in the panels, the present study applied this test. In comparison with other panel causality tests, the DH causality test offers various benefits: 1) It regulates the panel data's unobserved heterogeneity. 2) In the presence of heterogeneity and CSD, the test is appropriate. 3) It regulates the regression model's heterogeneity as well as the causal relationship's heterogeneity. 4) There are no requirements for the test in terms of cross-sectional unit size or time dimension. 5) In the event of imbalanced panels, the test is equally effective (Tufail

TABLE 2 | Descriptive statistics.

	CO_2	ECI	GDP	GLO	REC
Mean	9.628900	1.772849	39914.13	79.52386	4.936359
Median	9.800719	1.770030	41187.51	81.87234	2.119721
Std. Dev.	2.381198	0.520993	17947.88	8.262817	5.704039
Skewness	0.161958	−1.208584	0.461411	−0.850665	0.867438
Kurtosis	3.842608	5.404474	2.729053	2.994575	1.976097

et al., 2021). The panel DH causality equation is illustrated as follows:

$$z_{\mathrm{i,t}} = \alpha_{\mathrm{i}} + \sum_{j=1}^{p} \overset{j}{\underset{i}{\beta}} z_{\mathrm{i,t-j}} + \sum_{j=1}^{p} \overset{j}{\underset{i}{\gamma}} T_{\mathrm{i,t-j}} \quad (15)$$

The null and alternative hypotheses are "no causality" and "there is causality".

FINDINGS AND DISCUSSION

The empirical analyses commenced by taking a look at the descriptive statistics of CO_2, ECI, GLO, REC, and GDP, which is reported in **Table 2**. GDP (39914.13) has the highest mean value, followed by GLO (79.52386), CO_2 (9.628900), REC (4.936359), and ECI (1.772849). ECI (0.520993) has a more consistent score which is followed by CO_2 (2.381198), REC (5.704039), GLO (8.262817), and GDP (17947.880) as revealed by the standard deviation. Furthermore, the skewness value disclosed that ECI and GLO are negatively skewed while CO_2, GDP, and REC are skewed positively. The kurtosis value uncovered that all the series (GDP, REC, and GLO) are platykurtic (less than 3) whilst ECI and CO_2 are leptokurtic (greater than 3).

The study proceeds by examining the cross-section dependence (CSD) and Slope heterogeneity which are reported in **Tables 3**, **4** respectively. The CSD results reported in **Table 3** unveiled the issue of CSD as revealed by Breusch-Pagan LM, Pesaran scaled LM, Bias-corrected scaled LM, and Pesaran CD tests. Therefore, we fail to accept the null hypothesis. The CSD's significance originates from the reality that advanced economies are interconnected in today's globalized world. This indicates that any disturbance in the underlying variables of a nation might extend to other economies. As a result of the spillover effects, the variables are cross-sectionally dependent. **Table 4** shows that the panel of the top seven economic complexity countries exhibit varying levels of technological advancement and growth. As a consequence, the findings suggest the occurrence of variation in slope coefficients. The study further applied the CIPS unit root test which is a second-generation test to detect the stationarity features of series and the outcomes are reported in **Table 5**. The outcomes of the test revealed that all the series are stationary at first difference.

To identify the cointegration between CO_2 and the regressors, we applied the Westerlund cointegration test which is reported in **Table 6**. The outcomes from the test unveiled that in the long-run, the series are cointegrated. Therefore, the null hypothesis of "no cointegration" is refuted in this study. Therefore, the outcomes uncovered that there is longrun association between CO_2 and REC, GDP, ECI, and GLO.

After the long-run association between CO_2 and ECI, GDP, REC, and GLO has been confirmed, we continued by assessing the long-run and short-run influence of ECI, GDP, REC and GLO *via* the CS-ARDL. The outcomes of the CS-ARDL are presented in **Table 7** and the outcomes disclosed the followings:

The influence of GDP on CO_2 emissions is positive and significant which implies that a 1% upsurge in GDP will trigger CO_2 by 0.3012% in Model-1, 0.5196% in Model-2, and 0.3286 in Model-3 keeping other indicators constant. This implies that an upsurge in growth contributes to emissions in these nations. Similar results are also observed in the short-run. The findings show that in these nations, the scale impact outweighed the composition and technique effects, implying that economic expansion is driving environmental degradation by consuming more energy and producing more pollutants. This further indicates that these countries prioritize economic growth over environmental degradation. As a result, the environmental quality of these nations has degraded in the course of obtaining higher economic expansion. This outcome is in line with the study of Usman et al. (2020) in the United States who established negative and significant CO_2-GDP connections. Furthermore, the study of Abbasi et al. (2021) corroborates this finding. However, this outcome is not consistent with the studies of Coelho et al. (2021) for South Korea, Akinsola et al. (2021) for Indonesia, Zhang et al. (2021) for Malaysia and Su et al. (2021) for Brazil and Yuping et al. 2021) for Argentina.

Moreover, the CO_2-GDP^2 interrelationship is negative which infers that a 1% upsurge in GDP^2 mitigates CO_2 by 0.5604% (model-1), 0.7580% (model-2), and 0.5211% (model-3) when other factors are kept constant. The negative CO_2-GDP^2 interrelationship was also confirmed by the short-run coefficients. As a result, in these countries, there is an inverted U-shaped link between economic expansion and environmental degradation. It demonstrates that after achieving a certain level of income, ecological problems can be mitigated with improved environmental law, technical advancements, sustainable manufacturing, and consumption habits. It also shows that these nation's present policies are on the correct track, as their economies steadily transition away from polluting sectors and technology and toward green technologies and low-carbon clean industries. The inverted U-shaped growth-CO_2 emissions nexus is verified in the long term by the negative and statistically significant CO_2-GDP^2 connection. As a result, economic expansion can be considered to damage the environment at first before benefiting it afterward. This result is consistent with the work of Lin and Zhu (2019) for Chinese province analysis and (Kihombo et al., 2021) WAME nations.

Furthermore, the outcomes from the Table disclosed that in the three models, the influence of economic complexity (ECI) on CO_2 is positive and significant. This outcome demonstrates that an upsurge in ECI contributes to the degradation of the ecosystem. Therefore, ECI does not play a vital role in mitigating emissions in the selected countries. The possible

TABLE 3 | CSD tests.

Tests	GDP	REC	ECI	GLO	CO_2
Breusch-Pagan LM	510.49*	247.96*	248.27*	501.81*	206.69*
Pesaran scaled LM	75.531*	35.020*	35.069*	74.191*	28.653*
Bias-corrected scaled LM	75.391*	34.880*	34.929*	74.051*	28.513*
Pesaran CD	22.590*	8.0697*	11.801*	22.392*	4.6026*

Note: *p < 0.01.

TABLE 4 | slope Homogeneity Outcomes.

Test	Model-1		Model-2		Model-3	
	Value	*p* Value	Value	*p* Value	Value	*p* Value
$\hat{\Delta}$	6.980*	0.000	8.651*	0.000	6.224*	0.000
$\hat{\Delta}_{adjusted}$	7.822*	0.000	9.361*	0.000	7.864*	0.000

Note: *p < 0.01.

TABLE 5 | CIPS.

Variables	Level	First difference
CO_2	−2.041	−5.058*
GDP	−1.947	−4.039*
REC	−2.351	−5.318*
ECI	−1.838	−3.880*
GLO	−2.695	−5.710*

Note: *p < 0.01.

TABLE 6 | cointegration test.

	Model-1		Model-2		Model-3	
	Value	*p*-Value	Value	*p*-Value	Value	*p*-Value
Gt	−2.414	0.031**	−3.565*	0.000	−3.821*	0.000
Ga	−8.440	0.264	−11.715*	0.000	−12.409*	0.000
Pt	−8.908	0.000*	−14.246*	0.000	−15.791*	0.000
Pa	−14.923	0.000*	−13.562*	0.000	−14.729*	0.000

Note: *p < 0.01, ** p < 0.05.

explanation for this association is ascribed to the fact that product complexity and structural changes (production activities) are detrimental to the environment. More precisely, the study finds that diversifying export items increases CO_2 emissions. The study outcome aligns with the studies of Abbasi et al. (2021) and Ahmad et al. (2021) who established that ECI harms the quality of the environment Nevertheless, this outcome refutes the finding of and Neagu (2020) (1) who found ECI-CO_2 negative interrelation.

Moreover, in the three models, the renewable energy usage (REN) influence on CO_2 is negative and significant which implies that REN can play a vital role in combating the degradation of the environment. This demonstrates that cleaner and greener energy sources lower emission levels in the atmosphere. These findings corroborate the theoretical expectation that renewable energy is environmentally friendly. The findings show that renewable energy is an effective instrument for achieving environmental and economic sustainability by reducing the negative consequences of human activities, such as land usage and water and commodities utilization. This outcome is anticipated and it concurs with the works of Apergis and Payne (2014) for sub-Saharan Africa nations, Adebayo and Kirikkaleli (2021) for Japan, and Tufail et al. (2021) for highly decentralized economies.

There effect of globalization on CO_2 is negative which implies that 1% upsurge in GLO caused CO_2 to decrease by 0.0278 (Model-1), 0.011 (Model-2), and 0.0223 (Model-3) respectively, keeping other factors constant. This infers that GLO helps in abating degradation of the environment in the top 7 economic complexity nations. Given that the globalization index and CO_2 emissions levels have both increased over the years, this research contradicts the premise that globalization causes higher CO_2 emissions. This research outcome complies with the study of Yuping et al. (2021) for Argentina who established that globalization helps in mitigating emissions levels in Argentina. The study of He et al. (2021) for Mexico between 1990 and 2018 also validates this outcome by establishing a negative connection between globalization and CO_2. Nonetheless, this result is not consistent with the findings of Kirikkaleli et al. (2021) who discovered that the globalization process produces a significant increase in CO_2 emissions due to the widespread use of energy in production and consumption activities in advanced and developing economies.

We examine the combined effects of globalization and renewable energy use to better understand the explanation for such a puzzling outcome. In the context of Model-2, it is observed that renewable energy consumption and globalization jointly mitigate the emissions level in the long run and short-run. Moreover, in model 3, globalization and economic complexity are found to jointly mitigate emissions of CO_2 which implies that globalization plays a vital role in mitigating CO_2 emissions.

The present study applied the CCEMG long-run estimator to check the consistency of the panel quantile regression outcomes in the top seven economic complexity countries (Japan, Germany, South Korea, Singapore, Czech, Austria, and Switzerland). The CS-ARDL estimator has been chastised for imposing a homogeneity constraint on long-run parameters when countries differ in socioeconomic structure and size. therefore, we utilized the Common Correlated Effect Mean Group (CCEMG) initiated (Pesaran, 2006) which allows the parameters to be heterogeneous in the long run as a robustness check. **Table 8** presents the outcomes of the CCEMG. The CCEMG findings reinforce the reliability of the

TABLE 7 | CS-ARDL short and long-run outcomes.

	Model-1	Model-2	Model-3
Short-Run Outcomes			
Regressors	Coefficient (std.Error)	Coefficient (std.Error)	Coefficient (std.Error]
GDP	0.4181** (0.3822)	0.6372* (0.4128)	0.5901*** (0.3411)
GDP^2	−0.0553*** (0.1985)	−0.0811 (0.0761)	−0.0579** (0.1169)
ECI	0.0158* (0.0561)	0.3478 (0.0468)	0.3481** (0.1288)
REN	−0.1766* (0.0862)	−0.3145** (0.0145)	−0.2075** (0.0678)
GLO	−0.0856*** (0.2812)	−0.0712* (0.1962)	−0.0572* (0.1734)
GLO*REN		−0.0104*** (0.0751)	
GLO*ECI			−0.0692*** (0.1287)
ECM(-1)	−0.6522* (0.0883)	-0.7418* (0.0761)	−0.5814* (0.0543)
Long-run Outcomes			
GDP	0.3012* (0.1452)	0.5196* (0.1245)	0.3286* (0.0914)
GDP^2	−0.5604* (0.085)	−0.7580** (0.0193)	−0.5211* (0.1154)
ECI	0.8921* (0.0136)	0.2812** (0.1922)	0.1382** (0.0298)
REN	−0.7259*** (0.2189)	−0.5440** (0.2972)	−0.4157* (0.1282)
GLO	−0.0278* (0.0672)	−0.011*** (0.0871)	−0.0223* (0.0821)
GLO*REN		−0.4218* (0.0129)	
GLO*ECI			−0.0961* (0.0651)

*Note: The symbols *, **, and *** signify the significance levels at 1, 5, and 10%, respectively.*

TABLE 8 | Robustness check (CCEMG) outcomes.

	Model-1	Model-2	Model-3
Regressors	Coefficient (std.Error)	Coefficient (std.Error)	Coefficient (std.Error)
GDP	0.382** (0.3822)	0.5612* (0.1821)	0.4612*** (0.0913)
GDP^2	−0.0854*** (0.0181)	−0.0354*** (0.0076)	−0.0579** (0.1169)
ECI	0.1108*** (0.0162)	0.6129* (0.0859)	0.5497* (0.0719)
REN	−0.0186* (0.0194)	−0.0179*** (0.0546)	−0.0141** (0.0226)
GLO	−0.0922*** (0.1001)	−0.0512* (0.1962)	−0.0243* (0.0375)
GLO*REN		−0.0104*** (0.0751)	
GLO*ECI			−0.0938* (0.0913)
Constant	1.02591 (0.8501)	1.6510 (0.6718)	1.2837 (0.4684)

*Note: The symbols *, **, and *** signify the significance levels at 1, 5, and 10%, respectively.*

TABLE 9 | Panel causality test.

	W-Stat	Zbar-Stat	Prob	Decision
ECI →CO_2	6.36713*	8.37155	0.0000	Unidirectional Causality
CO_2→ECI	0.67537	−0.47251	0.5953	
GDP →CO_2	7.98288	6.04461	0.0000*	Feedback Causality
CO_2 →GDP	4.76869	2.66432	0.0077*	
GLO→CO_2	2.78598**	2.54193	0.0110	Unidirectional Causality
CO_2 →GLO	0.81241	−0.40790	0.6833	
REC →CO_2	4.85375	2.75378	0.0059*	Unidirectional Causality
CO_2 →REC	2.12745	−0.11341	0.9097	

Note: * $p < 0.01$.

CS-ARDL outcomes since these other techniques provided outcomes that were identical with the CS-ARDL results.

The study assesses the causal interrelation between CO_2 and GDP, ECI, GLO, and REC by applying the Dumitrescu and Hurlin panel causality test. The outcomes of the causality test are presented in **Table 9** and the outcomes unveiled unidirectional causality from economic complexity to CO_2. Furthermore, there is a feedback causal linkage between CO_2 and GDP which suggests that GDP can predict CO_2 and vice-versa. Moreover, one-way causality was observed from GLO to CO_2 emissions. Lastly, there is proof of unidirectional causal interrelation from REC to CO_2 which illustrates that REC can predict CO_2 in the top seven economic complexity nations.

CONCLUSION AND POLICY PATH

Conclusion

The present research investigates the influence of economic growth (GDP), renewable energy consumption (REC), economic complexity index (ECI), and globalization (GLO) on CO_2 emissions (CO_2) utilizing the top 7 economic complexity economies. The study utilized panel data stretching from 1993 to 2018 to assess these connections. The present research utilized second-generation techniques to investigate these dynamics. The slope heterogeneity and Pesaran CD testing findings indicate a cross-sectional and slope heterogeneity across countries, allowing us to progress with the 2^{nd} generation cointegration and unit root approaches. The CIPS unit root test outcomes unveiled that the variables are I(1). Furthermore, the outcomes of the cointegration tests (Westerlund and Pedroni) disclosed that the series have long-run association, i.e., CO_2, and ECI, GLO, REC, and GDP cointegrated in the long run. Moreover, we applied CS-ARDL and CCEMG to identify the influence of ECI, GLO, REC, and GDP on CO_2. The outcomes of the CS-ARDL and CCEMG unveiled that GDP and ECI contribute to the degradation of the environment, while REC and GLO mitigate CO_2 emissions. Furthermore, the interaction between globalization and renewable energy utilization helps in abating CO_2. In addition, the interaction between globalization and economic complexity helps in curbing CO_2. The outcomes of CCEMG also validate the CS-ARDL outcomes. Furthermore, we applied the panel causality test to identify the causal impact of ECI, GLO, REC, and GDP on CO_2, and the outcomes disclosed feedback causal linkage between CO_2 and GDP while unidirectional causal linkage was found from REC, ECI and GLO to CO_2. This outcome illustrates that any policy that will influence ECI, GLO and REC will have a significant impact on environmental sustainability. Additionally, any policy that will promote economic growth will impact CO_2 and vice versa.

Policy Recommendation

In reaction to the ECI outcome, we recommend that the top seven economic complexity nations develop more sophisticated environmental quality modification goods. Furthermore, if nations accelerate their transition from a primary structure to a higher technological structure, they may have a positive ecological effect. Furthermore, authorities should delegate responsibility to lower authorities to modify the environment. A decentralizing state is more keen to encourage carbon-emitting operations by upholding high-quality standards and establishing a freeloader program to sell its polluting industries to nearby areas. Smaller state entities, on the other hand, are more inclined to track heavily polluting businesses and improve environmental efficiency.

In addition, government officials and policymakers should improve programs that encourage successful renewable energy usage policies. This would reduce the degree of ecological damage while increasing the real output and ensuring the sustainability of the environment. Furthermore, the significance of renewable energy consumption indicates that these economies are on the correct track towards decarbonization and sustainable growth. Nonetheless, policymakers must take proactive steps to diversify sources of energy to reduce reliance on fossil fuels and increase the use of greener energy.

Although globalization has been proven to contribute to environmental sustainability in these nations, it is critical to guarantee that the increase in energy demand caused by globalization is matched by renewable energy supplies. In this sense, policymakers in these countries can aim to trade REC from neighboring nations, therefore enhancing the beneficial environmental results connected with trade globalization. Likewise, policymakers in these countries should consider soliciting FDI to help expand their renewable energy sectors. It is reasonable to assume that financial globalization-induced FDI inflows can culminate into technical spillover, which will alleviate the technological restrictions that have hampered renewable energy adoption in these countries.

Moreover, economic efforts aimed at creating a low-carbon ecosystem will encourage long-term investment in clean technologies, preventing further carbonization of the top 7 economic complexity countries structures. If the necessary actions are taken, the economic system will gradually decarbonize.

In the future, researchers may examine the influence of economic complexity on the environment by employing alternative time series and panel techniques for dissimilar nations or groups of nations. Nation groupings may also be evaluated as emerging and advanced economies. These efforts would aid in our understanding of the influence of economic complexity on ecological damage.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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REFERENCES

Abbasi, K. R., Lv, K., Radulescu, M., and Shaikh, P. A. (2021). Economic Complexity, Tourism, Energy Prices, and Environmental Degradation in the Top Economic Complexity Countries: Fresh Panel Evidence. *Environ. Sci. Pollut. Res.* doi:10.1007/s11356-021-15312-4

Adams, S., and Nsiah, C. (2019). Reducing Carbon Dioxide Emissions; Does Renewable Energy Matter? *Sci. Total Environ.* 693, 133288. doi:10.1016/j.scitotenv.2019.07.094

Adebayo, T. S., Akinsola, G. D., Kirikkaleli, D., Bekun, F. V., Umarbeyli, S., and Osemeahon, O. S. (2021). Economic Performance of Indonesia amidst CO_2 Emissions and Agriculture: A Time Series Analysis. *Environ. Sci. Pollut. Res.* 28, 47942–47956. doi:10.1007/s11356-021-13992-6

Adebayo, T. S., Coelho, M. F., Onbaşıoğlu, D. Ç., Rjoub, H., Mata, M. N., Carvalho, P. V., et al. (2021). Modeling the Dynamic Linkage between Renewable Energy Consumption, Globalization, and Environmental Degradation in South Korea: Does Technological Innovation Matter? *Energies* 14 (14), 4265. doi:10.3390/en14144265

Adebayo, T. S., and Kirikkaleli, D. (2021). Impact of Renewable Energy Consumption, Globalization, and Technological Innovation on Environmental Degradation in Japan: Application of Wavelet Tools. *Environ. Dev. Sustain.* doi:10.1007/s10668-021-01322-2

Adebayo, T. S., Ramzan, M., Iqbal, H. A., Awosusi, A. A., and Akinsola, G. D. (2021). The Environmental Sustainability Effects of Financial Development and

Urbanization in Latin American Countries. *Environ. Sci. Pollut. Res.* doi:10.1007/s11356-021-14580-4

Adebayo, T. S. (2020). Revisiting the EKC Hypothesis in an Emerging Market: An Application of ARDL-Based Bounds and Wavelet Coherence Approaches. *SN Appl. Sci.* 2 (12), 1945. doi:10.1007/s42452-020-03705-y

Adebayo, T. S., Rjoub, H., Akinsola, G. D., and Oladipupo, S. D. (2021). The Asymmetric Effects of Renewable Energy Consumption and Trade Openness on Carbon Emissions in Sweden: New Evidence from Quantile-On-Quantile Regression Approach. *Environ. Sci. Pollut. Res.*, 1–12. doi:10.1007/s11356-021-15706-4

Adebola Solarin, S., Al-Mulali, U., and Ozturk, I. (2017). Validating the Environmental Kuznets Curve Hypothesis in India and China: The Role of Hydroelectricity Consumption. *Renew. Sustain. Energ. Rev.* 80, 1578–1587. doi:10.1016/j.rser.2017.07.028

Ahmad, M., Ahmed, Z., Majeed, A., and Huang, B. (2021). An Environmental Impact Assessment of Economic Complexity and Energy Consumption: Does Institutional Quality Make a Difference? *Environ. Impact Assess. Rev.* 89, 106603. doi:10.1016/j.eiar.2021.106603

Alola, A. A. (2019). The Trilemma of Trade, Monetary and Immigration Policies in the United States: Accounting for Environmental Sustainability. *Sci. Total Environ.* 658, 260–267. doi:10.1016/j.scitotenv.2018.12.212

Apergis, N., and Payne, J. E. (2014). Renewable Energy, Output, CO_2 Emissions, and Fossil Fuel Prices in Central America: Evidence from a Nonlinear Panel Smooth Transition Vector Error Correction Model. *Energ. Econ.* 42, 226–232. doi:10.1016/j.eneco.2014.01.003

Awosusi, A. A., Kirikkaleli, D., Akinsola, G. D., Adebayo, T. S., and Mwamba, M. N. (2021). Can CO_2 emissions and energy consumption determine the economic performance of South Korea? A time series analysis. *Environ. Sci. Pollut. Res.* 1–16.

Balsalobre-Lorente, D., Leitão, N. C., and Bekun, F. V. (2021). Fresh Validation of the Low Carbon Development Hypothesis under the EKC Scheme in Portugal, Italy, Greece and Spain. *Energies* 14 (1), 250. doi:10.3390/en14010250

Boleti, E., Garas, A., Kyriakou, A., and Lapatinas, A. (2021). Economic Complexity and Environmental Performance: Evidence from a World Sample. *Environ. Model. Assess.* 26 (3), 251–270. doi:10.1007/s10666-021-09750-0

Cai, Y., Sam, C. Y., and Chang, T. (2018). Nexus between Clean Energy Consumption, Economic Growth and CO_2 Emissions. *J. Clean. Prod.* 182, 1001–1011. doi:10.1016/j.jclepro.2018.02.035

Can, M., and Gozgor, G. (2016). Dynamic Relationships Among CO_2 Emissions, Energy Consumption, Economic Growth, and Economic Complexity in France. *SSRN J.* doi:10.2139/ssrn.2756638

Charfeddine, L., and Kahia, M. (2019). Impact of Renewable Energy Consumption and Financial Development on CO_2 Emissions and Economic Growth in the MENA Region: A Panel Vector Autoregressive (PVAR) Analysis. *Renew. Energ.* 139, 198–213. doi:10.1016/j.renene.2019.01.010

Cherni, A., and Essaber Jouini, S. (2017). An ARDL Approach to the CO_2 Emissions, Renewable Energy and Economic Growth Nexus: Tunisian Evidence. *Int. J. Hydrogen Energ.* 42 (48), 29056–29066. doi:10.1016/j.ijhydene.2017.08.072

Chudik, A., and Pesaran, M. H. (2015). Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. *J. Econ.* 188 (2), 393–420.

Dogan, E., and Seker, F. (2016). Determinants of CO_2 Emissions in the European Union: The Role of Renewable and Non-renewable Energy. *Renew. Energ.* 94, 429–439. doi:10.1016/j.renene.2016.03.078

Doğan, B., Saboori, B., and Can, M. (2019). Does Economic Complexity Matter for Environmental Degradation? an Empirical Analysis for Different Stages of Development. *Environ. Sci. Pollut. Res.* 26 (31), 31900–31912. doi:10.1007/s11356-019-06333-1

Dreher, A. (2006). Does Globalization Affect Growth? Evidence from a New index of Globalization. *Appl. Econ.* 38 (10), 1091–1110. doi:10.1080/00036840500392078

Dumitrescu, E.-I., and Hurlin, C. (2012). Testing for Granger Non-causality in Heterogeneous Panels. *Econ. Model.* 29 (4), 1450–1460. doi:10.1016/j.econmod.2012.02.014

Gao, J., and Zhang, L. (2021). Does Biomass Energy Consumption Mitigate CO_2 Emissions? the Role of Economic Growth and Urbanization: Evidence from Developing Asia. *J. Asia Pac. Economy* 26 (1), 96–115. doi:10.1080/13547860.2020.1717902

Grossman, G. M., and Krueger, A. B. (1991). "Environmental Impacts of a North American Free Trade Agreement," in *Papers (No. 158; Papers)* (Princeton: Woodrow Wilson School - Public and International Affairs). doi:10.3386/w3914Available at: https://ideas.repec.org/p/fth/priwpu/158.html

Gygli, S., Haelg, F., Potrafke, N., and Sturm, J. E. (2019). The KOF Globalisation Index–Revisited. *Rev. Int. Org.* 14 (3), 543–574.

Haseeb, A., Xia, E., Baloch, M. A., and Abbas, K. (2018). Financial Development, Globalization, and CO_2 Emission in the Presence of EKC: Evidence from BRICS Countries. *Environ. Sci. Pollut. Res.* 25 (31), 31283–31296. doi:10.1007/s11356-018-3034-7

Hashem Pesaran, M., and Yamagata, T. (2008). Testing Slope Homogeneity in Large Panels. *J. Econom.* 142 (1), 50–93. doi:10.1016/j.jeconom.2007.05.010

Hdom, H. A. D., and Fuinhas, J. A. (2020). Energy Production and Trade Openness: Assessing Economic Growth, CO_2 Emissions and the Applicability of the Cointegration Analysis. *Energ. Strategy Rev.* 30, 100488. doi:10.1016/j.esr.2020.100488

He, X., Adebayo, T. S., Kirikkaleli, D., and Umar, M. (2021). Consumption-based Carbon Emissions in Mexico: An Analysis Using the Dual Adjustment Approach. *Sustainable Prod. Consumption* 27, 947–957. doi:10.1016/j.spc.2021.02.020

Hidalgo, C. A., and Hausmann, R. (2009). The Building Blocks of Economic Complexity. *Proc. Natl. Acad. Sci.* 106 (26), 10570–10575. doi:10.1073/pnas.0900943106

Khan, M. K., Teng, J.-Z., Khan, M. I., and Khan, M. O. (2019). Impact of Globalization, Economic Factors and Energy Consumption on CO_2 Emissions in Pakistan. *Sci. Total Environ.* 688, 424–436. doi:10.1016/j.scitotenv.2019.06.065

Kihombo, S., Vaseer, A. I., Ahmed, Z., Chen, S., Kirikkaleli, D., and Adebayo, T. S. (2021). Is There a Tradeoff between Financial Globalization, Economic Growth, and Environmental Sustainability? an Advanced Panel Analysis. *Environ. Sci. Pollut. Res.*. doi:10.1007/s11356-021-15878-z

Kirikkaleli, D., and Adebayo, T. S. (2021). Do public-private Partnerships in Energy and Renewable Energy Consumption Matter for Consumption-Based Carbon Dioxide Emissions in India?. *Environ. Sci. Pollut. Res.* 28 (23), 30139–30152. doi:10.1007/s11356-021-12692-5

Kirikkaleli, D., Adebayo, T. S., Khan, Z., and Ali, S. (2021). Does Globalization Matter for Ecological Footprint in Turkey? Evidence from Dual Adjustment Approach. *Environ. Sci. Pollut. Res.* 28 (11), 14009–14017. doi:10.1007/s11356-020-11654-7

Koengkan, M., Fuinhas, J. A., and Santiago, R. (2020). Asymmetric Impacts of Globalisation on CO_2 Emissions of Countries in Latin America and the Caribbean. *Environ. Syst. Decis.* 40 (1), 135–147. doi:10.1007/s10669-019-09752-0

Kılavuz, E., and Doğan, İ. (2021). Economic Growth, Openness, Industry and CO_2 Modelling: Are Regulatory Policies Important in Turkish Economies? *Int. J. Low-Carbon Tech.* 16 (2), 476–487. doi:10.1093/ijlct/ctaa070

Leal, P. H., and Marques, A. C. (2021). The Environmental Impacts of Globalisation and Corruption: Evidence from a Set of African Countries. *Environ. Sci. Pol.* 115, 116–124. doi:10.1016/j.envsci.2020.10.013

Leitão, N. C., and Lorente, D. B. (2020). The Linkage between Economic Growth, Renewable Energy, Tourism, CO_2 Emissions, and International Trade: The Evidence for the European Union. *Energies* 13 (18), 4838. doi:10.3390/en13184838

Leitão, N. C. (2021a). Testing the Role of Trade on Carbon Dioxide Emissions in Portugal. *Economies* 9 (1), 22. doi:10.3390/economies9010022

Leitão, N. C. (2021b). The Effects of Corruption, Renewable Energy, Trade and CO_2 Emissions. *Economies* 9 (2), 62. doi:10.3390/economies9020062

Lin, B., and Zhu, J. (2019). Determinants of Renewable Energy Technological Innovation in China under CO_2 Emissions Constraint. *J. Environ. Manage.* 247, 662–671. doi:10.1016/j.jenvman.2019.06.121

Lin, X., Zhao, Y., Ahmad, M., Ahmed, Z., Rjoub, H., and Adebayo, T. S. (2021). Linking Innovative Human Capital, Economic Growth, and CO_2 Emissions: An Empirical Study Based on Chinese Provincial Panel Data. *Int. J. Environ. Res. Public Health* 18 (16), 8503. doi:10.3390/ijerph18168503

Mealy, P., and Teytelboym, A. (2020). Economic Complexity and the green Economy. *Res. Pol.* 2020, 103948. doi:10.1016/j.respol.2020.103948

Muhammad, B. (2019). Energy Consumption, CO_2 Emissions and Economic Growth in Developed, Emerging and Middle East and North Africa Countries. *Energy* 179, 232–245. doi:10.1016/j.energy.2019.03.126

Muhammad, B., and Khan, S. (2021). Understanding the Relationship between Natural Resources, Renewable Energy Consumption, Economic Factors, Globalization and CO 2 Emissions in Developed and Developing Countries. *Nat. Resour. Forum* 45 (2), 138–156. doi:10.1111/1477-8947.12220

Namahoro, J. P., Wu, Q., Xiao, H., and Zhou, N. (2021). The Impact of Renewable Energy, Economic and Population Growth on CO_2 Emissions in the East African Region: Evidence from Common Correlated Effect Means Group and Asymmetric Analysis. *Energies* 14 (2), 312. doi:10.3390/en14020312

Neagu, O. (2020). Economic Complexity and Ecological Footprint: Evidence from the Most Complex Economies in the World. *Sustainability* 12 (21), 9031. doi:10.3390/su12219031

Orhan, A., Adebayo, T. S., Genç, S. Y., and Kirikkaleli, D. (2021). Investigating the Linkage between Economic Growth and Environmental Sustainability in India: Do Agriculture and Trade Openness Matter? *Sustainability* 13 (9), 4753. doi:10.3390/su13094753

Ozturk, I., and Acaravci, A. (2016). Energy Consumption, CO_2 emissions, Economic Growth, and Foreign Trade Relationship in Cyprus and Malta. *Energ. Sourc. B: Econ. Plann. Pol.* 11 (4), 321–327. doi:10.1080/15567249.2011.617353

Pata, U. K. (2021). Renewable and Non-renewable Energy Consumption, Economic Complexity, CO_2 Emissions, and Ecological Footprint in the USA: Testing the EKC Hypothesis with a Structural Break. *Environ. Sci. Pollut. Res.* 28 (1), 846–861. doi:10.1007/s11356-020-10446-3

Pesaran, M. H. (2006). Estimation and Inference in Large Heterogeneous Panels with a Multifactor Error Structure. *Econometrica* 74 (4), 967–1012. doi:10.1111/j.1468-0262.2006.00692.x

Rafique, M. Z., Nadeem, A. M., Xia, W., Ikram, M., Shoaib, H. M., and Shahzad, U. (2021). Does Economic Complexity Matter for Environmental Sustainability? Using Ecological Footprint as an Indicator. *Environ. Dev. Sustain.*. doi:10.1007/s10668-021-01625-4

Salari, M., Javid, R. J., and Noghanibehambari, H. (2021). The Nexus between CO_2 Emissions, Energy Consumption, and Economic Growth in the U.S. *Econ. Anal. Pol.* 69, 182–194. doi:10.1016/j.eap.2020.12.007

Sarkodie, S. A., and 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. doi:10.1016/j.scitotenv.2018.07.365

Shahbaz, M., Sharma, R., Sinha, A., and Jiao, Z. (2021). Analyzing Nonlinear Impact of Economic Growth Drivers on CO_2 Emissions: Designing an SDG Framework for India. *Energy Policy* 148, 111965. doi:10.1016/j.enpol.2020.111965

Shan, S., Ahmad, M., Tan, Z., Adebayo, T. S., Man Li, R. Y., and Kirikkaleli, D. (2021). The Role of Energy Prices and Non-linear Fiscal Decentralization in Limiting Carbon Emissions: Tracking Environmental Sustainability. *Energy* 234, 121243. doi:10.1016/j.energy.2021.121243

Soylu, Ö. B., Adebayo, T. S., and Kirikkaleli, D. (2021). The Imperativeness of Environmental Quality in China amidst Renewable Energy Consumption and Trade Openness. *Sustainability* 13 (9), 5054. doi:10.3390/su13095054

Su, Z.-W., Umar, M., Kirikkaleli, D., and Adebayo, T. S. (2021). Role of Political Risk to Achieve Carbon Neutrality: Evidence from Brazil. *J. Environ. Manage.* 298, 113463. doi:10.1016/j.jenvman.2021.113463

Tufail, M., Song, L., Adebayo, T. S., Kirikkaleli, D., and Khan, S. (2021). Do fiscal Decentralization and Natural Resources Rent Curb Carbon Emissions? Evidence from Developed Countries. *Environ. Sci. Pollut. Res.* 28, 49179–49190. doi:10.1007/s11356-021-13865-y

Udemba, E. N., Ahmed, Z., Adebayo, T. S., and Kirikkaleli, D. (2021). Determinants of consumption-based carbon emissions in Chile: an application of non-linear ARDL. *Environ. Sci. Pollut. Res.* 1–15.

Usman, O., Iortile, I. B., and Ike, G. N. (2020). Enhancing Sustainable Electricity Consumption in a Large Ecological reserve-based Country: the Role of Democracy, Ecological Footprint, Economic Growth, and Globalisation in Brazil. *Environ. Sci. Pollut. Res.* 27 (12), 13370–13383. doi:10.1007/s11356-020-07815-3

Vaseer, A. I., Ahmed, Z., Chen, S., Kihombo, S., Kirikkaleli, D., and Adebayo, T. S. (2021). Is there a tradeoff between financial globalization, economic growth, and environmental sustainability? An advanced panel analysis. *Environ. Sci. Pollut. Res.* 1–11.

Wang, Z., and Ye, X. (2017). Re-examining Environmental Kuznets Curve for China's City-Level Carbon Dioxide (CO_2) Emissions. *Spat. Stat.* 21, 377–389. doi:10.1016/j.spasta.2016.09.005

Westerlund, J. (2007). Testing for Error Correction in Panel Data. *Oxford Bull. Econ. Stats* 69 (6), 709–748. doi:10.1111/j.1468-0084.2007.00477.x

Yuping, L., Ramzan, M., Xincheng, L., Murshed, M., Awosusi, A. A., Bah, S. I., et al. (2021). Determinants of Carbon Emissions in Argentina: The Roles of Renewable Energy Consumption and Globalization. *Energ. Rep.* 7, 4747–4760. doi:10.1016/j.egyr.2021.07.065

Zhang, L., Li, Z., Kirikkaleli, D., Adebayo, T. S., Adeshola, I., and Akinsola, G. D. (2021). Modeling CO_2 Emissions in Malaysia: An Application of Maki Cointegration and Wavelet Coherence Tests. *Environ. Sci. Pollut. Res.* 28 (20), 26030–26044. doi:10.1007/s11356-021-12430-x

Zoundi, Z. (2017). CO_2 Emissions, Renewable Energy and the Environmental Kuznets Curve, a Panel Cointegration Approach. *Renew. Sustain. Energ. Rev.* 72, 1067–1075. doi:10.1016/j.rser.2016.10.018

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