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Exploring the Impact of Globalization, Economic Complexity, Urbanization, and Real Income on Environmental Degradation in E-7 Countries

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ABSTRACT

Current society has been centered on the edge of calamity induced by environmental degradation. Providing comprehensive scientific evidence and designing reliable and accurate policies have been irreparable initiatives to mitigate and reverse the effects of environmental degradation and harmonize the economy with nature. Within this addressed objective, the study explores the impact of globalization, economic complexity, urbanization, and real income on CO2 emissions, the ecological footprint, and the load capacity factor in 7 Emerging countries (E-7). The study provides comprehensive evidence regarding environmental degradation and environmental quality by handling three environmental-related indicators. The second-generation panel methods involving Durbin–Hausman panel cointegration LM Panel Bootstrap Cointegration Test AMG and CCEMG estimators and Dumitrescu and Hurlin Panel Causality Test are performed on the data spanning from 1995 to 2020. According to the investigation, the explanatory variables are cointegrated with three dependent variables. The study proves that renewable energy and globalization are pivotal factors in lessening environmental degradation and enriching environmental quality. However, urbanization and economic growth impair the environment of E-7 countries, while economic complexity is found to be a statistically significant factor for all environmental-related variables.

Keywords: Macroeconomics; Sustainable Development; Ecological Footprint; Economic Complexity Index; Load Capacity Factor; Globalization; Urbanization.

JEL Classification Codes: B22, C82, O11, O13, Q43, Q56

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INTRODUCTION

Environmental quality is essential in terms of human health, ecosystem equilibrium, and sustainable development. It emphasizes the critical need for sustainable utilization and conservation of natural resources, as well as access to clean air, water, and soil, alongside the protection of ecosystems and biodiversity. A healthy environment directly impacts individuals' quality of life and provides a foundational basis for sustainable economic activities (Estoque and Wu, 2024).

Global warming significantly and extensively impacts environmental quality. This phenomenon, driven by increased greenhouse gas levels in the atmosphere, disrupts ecosystems and natural processes globally, resulting in climate change. Effects such as glacier melting, rising sea levels, extreme weather events, and declining water resources pose serious threats to natural habitats and ecosystem services (Kumar et al. 2024). Climate change (hereafter, CC) adversely affects agricultural productivity, while events like droughts, floods, and erosion can disrupt economic and social systems. Therefore, it is crucial to mitigate global warming and its impacts to safeguard and enhance environmental quality (hereafter, EQ) (Rawat et al., 2024). The accumulation of greenhouse gases (hereafter, GHE) in the atmosphere, notably carbon dioxide, methane, and water vapor, causes global boiling. Deforestation, natural gas, coal, oil, human activities, elevate these gas concentrations in the atmosphere, thus triggering global warming. Figure 1 below illustrates the trend of global temperature change resulting from global warming (hereafter, GW) between 1990 and 2020.

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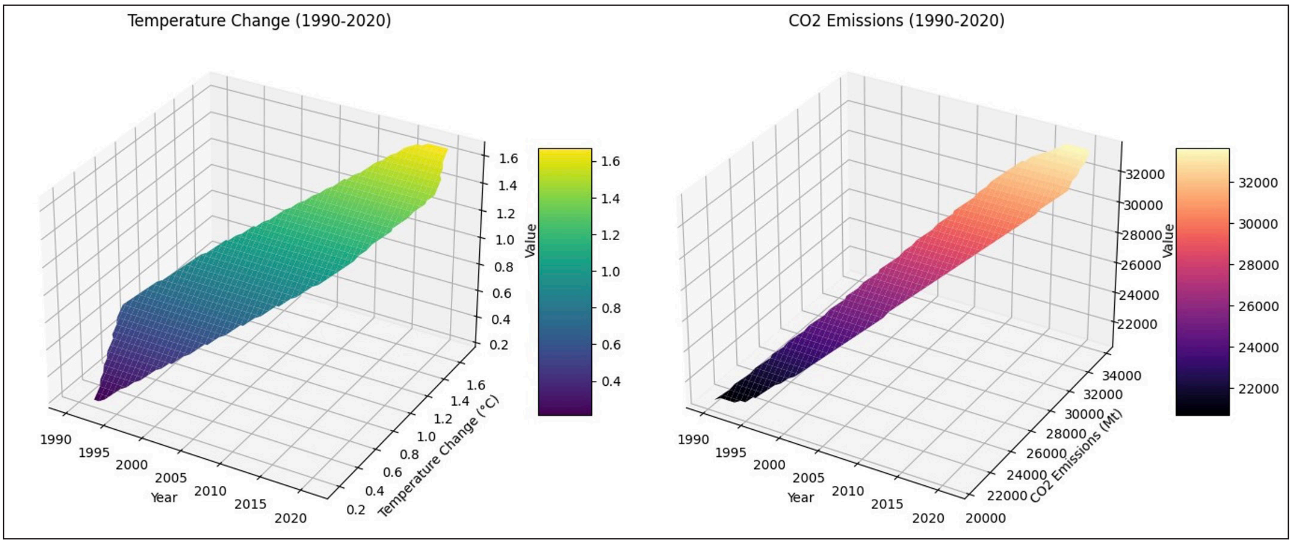

Figure 1. Global temperature change and CO_2 emissions (1990-2020).
Source: FAOSTAT (2024) and IEA (2024)

Upon analyzing Figure 1, it is clear that global temperature change and global CO_2 emissions exhibit a predominantly upward trajectory. The temperature change, which stood at 0.633 in 1990, rose to 1.682 by 2020. Hence, the approximately 166% increase in global temperature change from 1990 to 2020 indicates a heightened pace of GW (FAOSTAT, 2024). Moreover, the roughly 55% increase in global CO_2 emissions during the same period intensifies the frequency and severity of extreme weather events, elevates sea levels, and profoundly affects ecosystems (IEA, 2024). International actors have responded to these challenges, with international treaties playing a pivotal role.

Several international agreements have been established to tackle GW including the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, the Kyoto Protocol in 1997, and the Paris Agreement in 2015 (Pouikli, 2021). The Kyoto Protocol mandates industrialized nations to reduce GHE according to specified targets, while the Paris Agreement aims to limit global temperature rise to well below 2°C and ideally to 1.5°C (De Lassus St-Geniès 2024). These agreements incentivize countries to set emission reduction goals, transition to renewable energy (hereafter, RE) sources, and adopt sustainable development policies. Therefore, through international agreements, countries have committed to certain measures such as reducing emissions and investing in clean energy technologies.

In EQ literature, various variables are examined, with CO_2 emissions, the ecological footprint (hereafter, EF), and the load capacity factor (hereafter, LCF) being particularly important. This is because CO_2 emissions are a primary driver of GW. Fossil fuels (hereafter, FF), deforestation, and industrial processes emit considerable amounts of CO_2 into the atmosphere. According to the IPCC, CO_2 emissions account for 60% of global temperature increases, highlighting the critical need for their reduction (Nsabiyeze et al. 2024). EF quantifies the overall impact of human activities on nature; a larger footprint signifies greater environmental damage and higher greenhouse gas emissions. Reducing EF can be achieved through sustainable resource use and effective waste management. LCF denotes the maximum number of individuals an ecosystem can sustainably support. GW decreases the carrying capacity of ecosystems by depleting water resources, reducing agricultural productivity, and increasing the frequency of extreme weather events (Erdoğan and Pata 2024; Kumar et al., 2024). CO_2 emissions, LCF and EF are crucial determinants of GW , and managing these factors is vital in combating CC. Addressing these elements is essential for ensuring a sustainable future and maintaining climate equilibrium. Therefore, advances in these parameters are critical variables in E7 countries, as in the rest of the world.

Similar to other nations, E7 countries (Russia, China, India, Mexico, Brazil, Indonesia and Turkey) wield significant influence on GW and have made diverse commitments. These countries, driven by their rapid economic growth (hereafter, EG) and expanding populations, command substantial portions of global energy consumption and GHE. E7 nations have pledged to reduce carbon dioxide emissions and promote RE sources. EG, industrialization, and energy consumption (hereafter, EC) patterns in these countries influence carbon dioxide emissions, EF, and LCF.

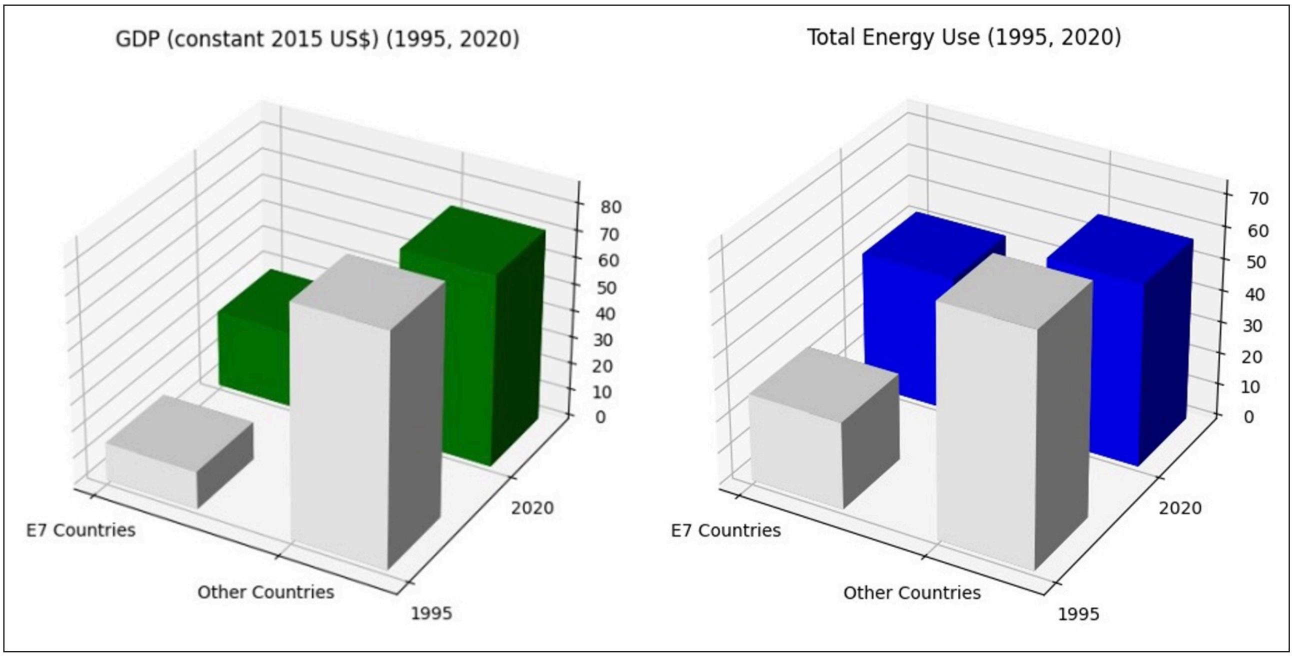

Figure 2. GDP and EC shares of E7 countries within the world (1995-2020).
Source: IEA (2024)

E7 countries constitute a substantial group based on their GDP and shares of global EC. Their GDP is utilized to offset the energy they consume. Figure 2 below illustrates the GDP and EC shares of E7 countries within the global context from 1995 to 2020.

In 1995, E7 countries accounted for 14.02% of the global GDP, a figure that significantly rose to 28.54% by 2020, more than doubling their share of the global GDP (World Bank 2024a). This expansion has resulted in increased levels of EC and GHE. Initially holding 27.32% of the world's total EC in 1995, E7 countries saw this figure climb to 42.66% by 2020. Moreover, FF comprised 78% of their total EC in 1995, increasing to 82.9% by 2020 (IEA, 2024). The use of high amounts of FF causes environmental issues such as air pollution (hereafter, AP), water pollution and CC (Arı, 2023). Conversely, RE accounted for 3% of their total EC in 1995, rising to 6.1% by 2020. Additionally, the shares of hydroelectric and other RE sources have also experienced significant increases (IEA, 2024). Figure 3 below illustrates the distribution of energy sources within the total EC of E7 countries from 1995 to 2020.

When analyzing Figure 3, it becomes evident that FF utilization in E7 countries rose from 78% of total EC in 1995 to 82.9% in 2020. Conversely, the proportion of RE increased from 3% in 1995 to 6.1% in 2020 (IEA, 2024). This indicates that E7 countries primarily generate their substantial income from FF, which constitute the largest share, while RE, crucial for EQ, has shown a significant but still inadequate increase. Therefore, it is crucial to focus on other critical factors alongside energy sources to enhance EQ in E7 countries.

EQ in E7 countries is influenced by several significant variables, including globalization (hereafter, KOF), economic complexity, and urbanization (hereafter, URB). KOF has multifaceted effects on GW in E7 countries: it boosts energy demand through EG and industrialization (hereafter, IND), yet it can also facilitate the adoption of clean energy technologies through technology transfer and heightened environmental awareness (Qing et al. 2024). This can be assessed within the framework of environmental economics theories, particularly those anticipating the dissemination of cleaner technologies through trade and investment.

The Economic Complexity Index (hereafter, ECI) gauges the knowledge and skill intensity of a nation's economic output. For E7 countries, a high ECI holds potential for diminishing the environmental impacts of intricate and technology-intensive production processes. Advanced economies can mitigate GW by embracing more efficient and eco-friendly technologies, aligning closely with theories of technological innovation and sustainable development (Ren et al. 2024).

URB, on the other hand, can yield both positive and negative repercussions on GW in E7 countries. Elevated rates of URB amplify energy demand and GHE, yet urban centers can contribute to sustainable development through enhanced energy efficiency and environmental regulations (Adebayo and Ullah 2024). This aligns closely

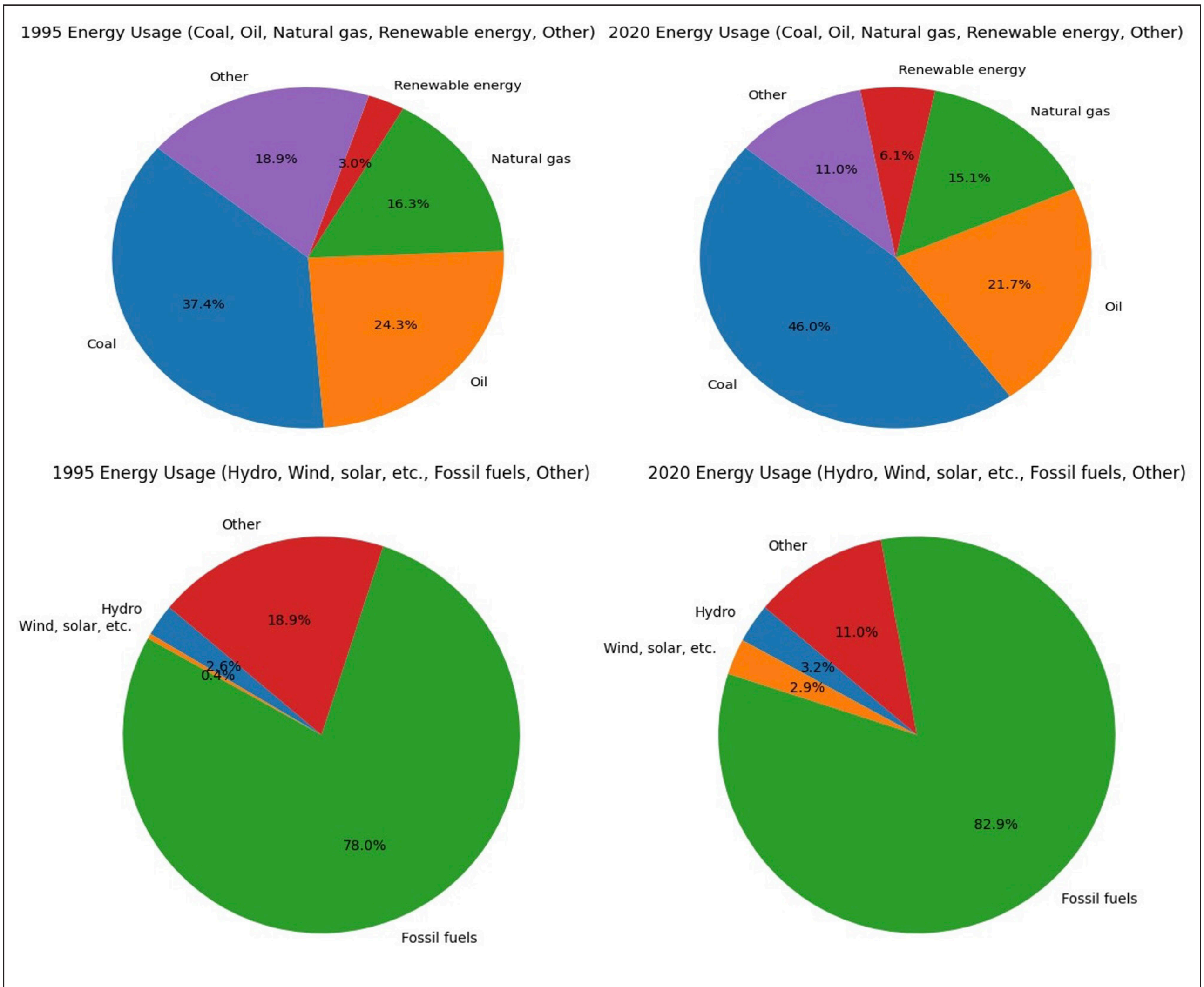

Figure 3. Energy source shares within total EC of E7 countries (1995-2020).
Source: IEA (2024)

with theories of urban environmental planning and sustainable urban development. Well-managed URB can augment energy efficiency and promote the adoption of RE sources, thereby alleviating the impacts of GW.

This research holds significant importance for multiple reasons. Firstly, the choice of sample is paramount. The E7 nations, characterized by their high income and substantial EC, are influential not only in terms of global EQ but also regarding country-specific environmental standards. Secondly, RE sources are of global importance and hold particular relevance for the E7 countries. However, the heavy reliance on FF within these nations and the insufficient growth in RE usage render it inadequate for ensuring EQ independently. Consequently, the models incorporate additional variables such as KOF, economic complexity, and URB, which are critical in influencing EQ. Thirdly, the study broadens the scope of EQ assessment for the E7 countries by including variables such as EF and LCF, in addition to AP measured through CO_2 emissions. Fourthly, the research employs second-generation panel data analysis techniques to effectively capture cross-sectional dependencies among the countries, reinforced by robustness tests. Lastly, causality tests are performed to evaluate not only the efficacy of economic policies and decisions but also the validity of economic models.

LITERATURE REVIEW

EG and development are among the most important macroeconomic goals for country economies. When the globalization period is examined, it is seen that many world countries have grown economically (Kihombo et al. 2022). However, it is seen that the environment-economy relationship increases with EG. In this context, studies on the relationship between EG and the environment (hereafter, ENV) have gained momentum. There is a significant literature on the connection between EG and environmental degradation (hereafter, ED) or EQ. Among the studies in the literature, undoubtedly the most intensive empirical studies are related to the Environmental Kuznets Curve (EKC) hypothesis. According to the EKC hypothesis, it is argued that ED will increase at the beginning of EG, and then ED will decrease and an inverted-U relationship will occur (Al-Mulali and Ozturk 2016; Bilgili et al. 2016; Apergis et al. 2017). The inverted-U relationship may be due to scale effect, composition effect or technical effect (Grossman and Krueger 1995). Often in the literature EKCs with cubic income and EKCs with quadratic income invaded. Studies have been conducted in many countries and periods to examine the hypotheses in question. In terms of empirical methods, it is determined that time series and panel data methods are frequently used. CO_2 emissions have often been used to determine ED in the EKC test. In this context, Holtz-Eakin and Selden (1995) is one of the pioneering studies on the quadratic form of the EKC. The authors tested the validity of the EKC hypothesis through 1951-1986 data from 130 countries. Empirically, the panel regression method was used. In the study where CO_2 was used as the environmental variable, the existence of an inverted-U connection was found. Shafik and Bandyopadhyay (1992) is the pioneer study regarding the cubic relationship regarding EKC. In this study, CO_2 was preferred as the environmental variable. In the study, which used data from 149 countries for the period 1960-1990, it was concluded that the shape of the EKC is monotonically increasing. In other words, it has been found that EG increases ED. When current studies using CO_2 in the EKC hypothesis are examined, the studies of Kostakis et al. (2023), Wang and Kim (2024), and Hassan et al. (2024) stand out.

It has been seen that EF variable has recently been used as an indicator of ED (Al-Mulali et al. 2015b; Ozturk et al. 2016; Yilanci and Pata 2020). Among the current studies examining the EKC hypothesis regarding the connection between EF and EG , Aydın et al. (2023) study examined the validity of the EKC hypothesis in G-7 countries. In the study, panel cointegration test and cointegration estimators that take cross-sectional dependence into consideration were used. In the study where CCEMG and DCCE methods were used, the results revealed that the EKC hypothesis is valid only in the USA. In other countries, it has been concluded that real GDP, which is an indicator of EG, reduces EF or causes statistically insignificant effects. In his study, Kamacı (2024) investigated the relationship between environmental variables and EG. The author also included KOF and hydroelectric energy variables in the model. Fractional Fourier ADL method was used in the study. FMOLS estimator was used in the long-term forecast. Fourier Toda-Yamamoto Causality test was used for causality analysis. In the study, the USA, which has high CO_2 emissions and EF, was examined. 1971-2014 was chosen as the sample period. Study findings revealed that EG increases EF and CO_2. In his study, Wang et al. (2024) tested the EKC hypothesis using CO_2 emissions and EF as environmental variables in 147 countries. Panel data methods were used in the study investigating the 1995-2018 sample period. Empirical findings emphasize that the EKC hypothesis is valid.

In terms of EQ, it is seen that LCF, which has become popular recently, is used in very few studies. In this context, Pata and Kartal (2023) tested the connection between EG and LCF using the LCF variable in their study. In the study, EKC and Load Capacity Curve (LCC) hypotheses were examined together. Various time series methods were used in the study investigating the period 1977-2018 in South Korea. Empirical findings have shown that both the EKC and LCC hypotheses are valid. In this study, similar findings were obtained by using the CO_2 variable to represent ED and the LCF variable to represent EQ. Raihan et al. (2023), who conducted similar research, examined the period 1971-2018 in Mexico. In the study using ARDL, FMOLS, DOLS and CCR methods, it was concluded that increases in EG reduce LCF. In other words, EG has increased ED. Among the current studies, Hakkak et al. (2023) examined the LCF-GDP relationship in the Russian example. 1992-2018 was used as the sample period. In the study where the ARDL method was used, it was concluded that EKC and LCC are valid together.

Globalization-Environment

With KOF process, important structural changes have occurred in country economies. Naturally, the interaction between ENV and KOF has also emerged. On the other hand, it has been proven that KOF increases EG (Dreher 2006; Usman et al. 2022). It is seen that subheadings (economic KOF, political KOF, social KOF) or the general KOF index are used in the use of the KOF variable. It is determined that CO_2 is frequently used as an environmental variable. It is observed that EF and LCF variables are used as alternatives to the environmental variable. Shahbaz et al. (2015) examined the connection between KOF and ENV through data from India for the period 1970-2012. ARDL limit test was used in the study, which focused on the effect of the general globalization index and sub-indices on carbon emissions. Empirical findings have shown that only increases in KOF reduce C02 emissions. It has been concluded that general, social and political KOF increases ED. Shahbaz et al. (2017) conducted a similar study for the period 1970-2012 and obtained the same result.

It is also seen that the Kyoto protocol is used in some studies as an indicator of political KOF. Grunewald and Martinez-Zarzoso (2016) found in their study in 170 economies between 1992 and 2009 that the Kyoto protocol increased ED. Bozkurt and Okumuş (2017), who conducted a similar study for 33 countries in the period 1980-2013, found similar results. Destek (2020) investigated the relationship between different components of KOF and ENV in Central and Eastern European countries. Empirical findings have shown that increases in political KOF reduce ED. It has been concluded that other KOF indicators increase ED.

Economic Complexity-Environment

Hausmann et al. (2014) that EG is driven by knowledge and that ECI is a fairly accurate predictor of growth. Based on this view, it is seen that ECI is used in many studies, especially the EKC hypothesis. Can and Gozgor (2017) are among the pioneering studies that use ECI in determining the validity of the EKC hypothesis. The authors tested the validity of the EKC in France in the period 1964-2014 with the DOLS method. Empirical findings have shown that higher ECI suppresses CO_2 levels. Neagu and Teodoru (2019) obtained the opposite result. More clearly, he found the existence of a positive connection between ECI and ENV. Doğan et al. (2019) investigated the connection between ECI and CO_2 in the economies of 55 countries in the period 1971-2014 within the scope of EKC. In the study using the panel quantile regression method, the findings showed that ECI has serious effects on ENV. According to the results, ECI reduced EQ in low- and high-middle-income country groups. In the high-income country group, ECI controlled CO_2 emissions. Therefore, the importance of production policies in low and middle-income countries targeting EG by taking environmental problems (hereafter, EP) into account has been emphasized. Aluko et al. (2023) investigated the connection between ECI and ED in 35 OECD countries in the period 1998-2017. EF, CO_2 emissions, N_2O emissions and GHE were used as environmental variables. In the study using Method of Moments quantile regression model methods, it was concluded that ECI leads to an increase in EF, CO_2 emissions, N_2O emissions and GHE at low income levels. On the other hand, it has been observed that these effects gradually decrease as income increases. Balsalobre-Lorente et al. (2024) investigated the relationship between ENV and ECI in the G-7 country group in the period 1991-2018. EF was used as the environmental variable. In the study using panel cointegration and panel causality methods, the results showed that ECI initially increases ED, and after a certain turning point, ED decreases. Similar results were found in Pata (2021), Ahmad et al. (2021) and Nguyen and Doytch (2022) also obtained.

Urbanization-Environment

It is known that URB also increases with the acceleration of IND Increasing URB causes significant effects on EG. On the other hand, the environmental effects of URB have become an important research area. Martinez-Zarzoso and Maruotti (2011) investigated the relationship between URB and ED in developing country economies. Panel data methods were used in the study examining the sample period of 1975-2003. CO_2 emission was used as the environmental variable. Empirical results have shown the existence of an inverted-U shape relationship between URB and CO_2 emissions. Sushinsky et al. (2013) and Al-Mulali et al. (2015a) argued that increasing URB increases ED. However, Al-Mulali et al. (2015b) emphasized the necessity of increasing trade openness (hereafter, TRO) to reduce ED. Liu et al. (2016), Ali et al. (2019), Khoshnevis-Yazdi and Golestani-Dariani (2019) proved the existence of a negative relationship between URB and CO_2 emissions. Researching the interaction between URB and ENV in SAARC countries, Kakar et al. (2024) used panel data methods. CO_2 emission was used as the environmental variable in the study. Findings showed the existence of bidirectional causality between CO_2 emissions and URB.

Renewable Energy-Environment

Energy is among the most important inputs of production. EG occurs with increasing production. Therefore, increasing EC is among the important determinants of EG. This situation creates the relationship between EC and ENV. When the types of energy are examined, the existence of RE and non-renewable energy (hereafter, NRE) is reached. It is seen that RE is encouraged on an international scale in terms of increasing EQ. Although investments and incentives for RE sources have increased, the use of NRE is higher. This situation requires measuring the relationship between RE and ENV. It is known that the increasing use of RE increases biodiversity. On the other hand, there is evidence that RE improves EQ. López-Menéndez et al. (2014) examined the connection between RE and ENV in 27 European Union countries. In the study using the panel data method, the period 1996-2010 was investigated. Empirical evidence has shown that increased use of RE reduces CO_2 emissions. Similar results were found by Bölük and Mert (2014), Apergis and Payne (2015), Bilgili et al. (2016) obtained. Kartal et al. (2023) study, the relationship

Table 1. Abbreviations and sources.

Variables	Abbrevation	Description	Log Transformation	Data Sources
Carbon Dioxide Emissions	CO_2	Metric tons per capita	lnCO2	The World Bank (2024b)
The Ecological Footprint	EF	Per capita	lnEF	The Global Footprint Network (2024)
The Load Capacity Factor	LCF	Biocapacity/ecological footprint	lnLCF	The Global Footprint Network (2024)
Globalization	KOF	An index includes economic, social, and political globalization	lnKOF	Gygli et al. (2019)
Economic Complexity Index	ECI	The index is estimated based on the variety of exports a country produces and their all-presence, or the number of countries able to create them.	-	OECD (2024)
Urbanization	URB	Urban population (% of total population)	lnURB	The World Bank (2024b)
Renewable Energy	REN	% of the total final energy consumption	lnREN	The World Bank (2024b)
Real Income	GDP	Constant 2015 US per capita	lnGDP	The World Bank (2024b)

between RE and ENV was examined with the Fourier Bootstrap Granger in quantiles approach. The period 1965–2018 is discussed. CO_2, EF and LCF variables were used as environmental indicators in the study. Empirical findings have shown that RE improves EQ according to all environmental indicators used. Raihan and Bari (2024) focused on the relationship between energy and ENV in the Chinese economy in their study. The period 1965-2022 was examined in the study in which CO_2 emissions were used as the environmental variable. ARDL method was used. NRE use and EG are included in the model. Empirical findings have shown that RE improves EQ in both the long and short term. It has been emphasized that recovery is higher in the long term.

DATA, METHODOLOGY AND EMPIRICAL RESULTS

In the study, we aim to address the evidence of the role of KOF, URB, REN, ECI, and GDP in EQ of Emerging seven (E-7) countries between 1995 and 2020. In the context of the countries' EQ, CO_2, EF, and LCF are considered, promoting insight into comprehensive evidence. CO_2 is a primary culprit of CC and GW, while the EF promotes knowledge on the pressure of anthropogenic activities such as air, soil, and marine pollution. The LCF is employed to simultaneously consider the supply and demand sides of ENV. However, E-7 countries, comprised of *Brazil, China, India, Indonesia, Mexico, Russia,* and *Türkiye,* are the seven biggest emerging countries in terms of EG. Table 1 presents some properties and knowledge of the considered variables.

This study executes three separate models shown in Equations 1-3-5 to examine the effects of the GDP, KOF, ECI, URB, and REN on CO_2, EF, and LCF.

$$CO2_{it} = f(GDP_{it}, KOF_{it}, URB_{it}, ECI_{it}); \quad (1)$$

$$lnCO2_{it}{=}c_0{+}\theta_1 lnGDP_{it}{+}\theta_2 lnKOF_{it}{+}\ \theta_3 lnURB_{it}{+}\ \theta_4 lnREN_{it}{+}\ \theta_3 ECI_{it}{+}\ \epsilon_{it} \quad (2)$$

$$EF_{it} = f(GDP_{it}, KOF_{it}, URB_{it}, ECI_{it}); \quad (3)$$

$$lnEF_{it}{=}a_0{+}\delta_1 lnGDP_{it}{+}\delta_2 lnKOF_{\text{it}}{+}\ \delta_3 lnURB_{it}{+}\ \delta_4 lnREN_{it}{+}\ \theta_3 ECI_{it}{+}\ \varepsilon_{it} \quad (4)$$

$$LCF_{it} = f(GDP_{it}, KOF_{it}, URB_{it}, ECI_{it}); \quad (5)$$

$$lnLCF_{it}{=}b_0{+}\varphi_1 lnGDP_{it}{+}\varphi_2 lnKOF_{\text{it}}{+}$$
$$\varphi_3 lnURB_{it}{+}\ \varphi_4 lnREN_{it}{+}\ \theta_3 ECI_{it}{+}\ \mu_{it} \quad (6)$$

The forms of the models with logarithmic series are disclosed in Equations 2, 4, and 6, respectively, to calculate the coefficient of elasticities. Only ECI is not used with logarithmic forms because negative values exist in the panel samples. In equations, the constant terms are presented by and . Moreoever, , and present the coefficient of the explanatory variables. Following the explanation of the performed models, Figure 4 discloses the flowchart of the estimations.

The study's first step of the empirical analysis is based on the descriptive analysis of all considered variables. The findings are shown in Table 2.

According to Table 2, there are 182 observations for each regarded variable, which confirms the balanced panel data in the empirical investigations. As a consequence of the descriptive analysis, it is revealed that lnKOF has the highest mean, followed by lnURB, lnREN, and lnCO2. Besides, lnURB has the maximum value, whereas lnLCF

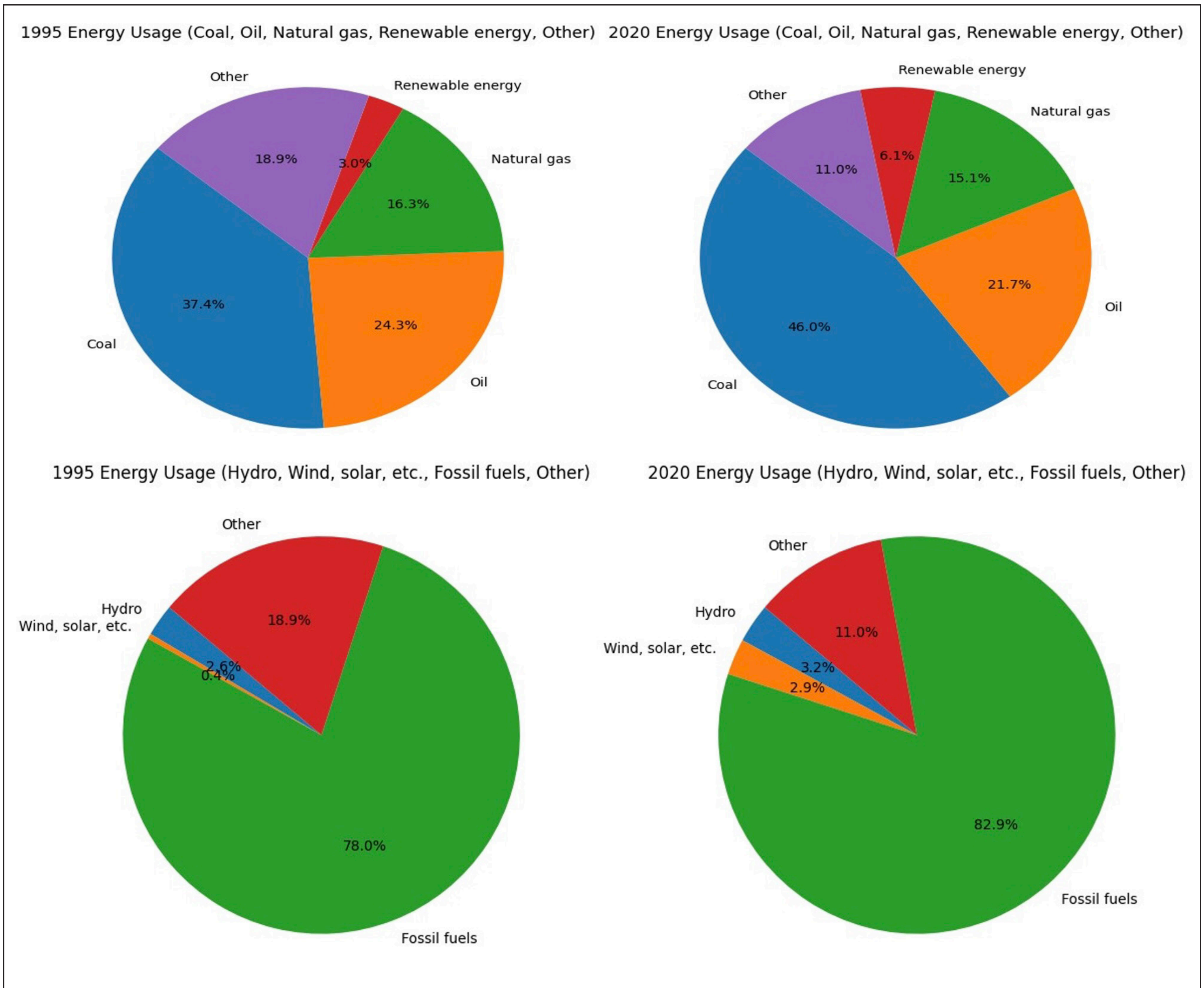

Figure 4. Flowchart of the estimation.

has the minimum value. Table 2 also points out that lnLCF has the highest standard deviation.

After examining the descriptive analysis, the study scrutinizes the prior analysis, which addresses which panel generation methods are applicable. The panel's primary analysis is to investigate the validity of the cross-section dependence (hereafter, CSD) and the slope coefficient heterogeneity. The Breusch-Pagan LM, Pesaran scaled LM, Bias-corrected scaled LM, and Pesaran CSD tests are applied to the series, and the findings of the mentioned CSD tests are tabulated in Table 3. The null hypothesis (hereafter of the tests indicates the absence of CSD in the series.

As a consequence of Table 3, of all tests is rejected in each series except ECI. As for ECI, the Pesaran CD denies the validity of CSD, while the reaming tests confirm the rejection of. Therefore, H_0 it can be claimed that CSD holds for all considered series, and any shocks in one country may dribble over to another country via the spillover impact. The first-generation panel methods (hereafter, FGPM), assuming the absence of CSD, do not promote consistent and accurate results. The panel unit root tests (hereafter, PURT) and cointegration analysis based on the second-generation panel methods (hereafter, SGPM) should be performed within this context. However, the second prior analysis in the panel approach is the delta tilde and delta tilde adjustment tests, which determine whether the slope coefficients are heterogeneous. In the study, the delta tilde (hereafter, and delta tilde adjustment (hereafter, Δ_{adj}) tests are performed for all three models, and the results of the tests are shown in Table 4. As a consequence of Table 4, it is revealed that the presence of the heterogeneous slope coefficient is detected for all considered models. Therefore, it is indicated that the second-generation panel unit root tests (hereafter, SGPURT), cointegration analysis, and long-run estimators are applicable to the study.

Table 2. Descriptive statistics

	LNCO2	LNEF	LNLCF	LNKOF	LNREN	LNURB	ECI
Mean	1.175921	0.872361	-0.297382	4.109728	2.894238	4.051937	0.481446
Median	1.217945	1.024093	-0.582039	4.131613	3.011578	4.239186	0.384815
Maximum	2.471893	1.852293	1.351057	4.277038	3.925531	4.466747	1.393506
Minimum	-0.237455	-0.328619	-1.483105	3.668977	1.156881	3.281174	-0.351723
Std. Dev.	0.727229	0.573305	0.779191	0.120312	0.871496	0.361469	0.444059
Skewness	0.165176	-0.405748	0.714479	-1.102386	-0.634284	-0.763949	0.553895
Kurtosis	2.176771	2.405087	2.589461	4.442427	2.306705	2.165483	2.262688
Jarque-Bera	5.966858	7.677722	16.76269	52.64056	15.84856	22.98424	13.42879
Probability	0.050619	0.021518	0.000229	0.000000	0.000362	0.000010	0.001213
Sum	214.0177	158.7698	-54.12353	747.9704	526.7513	737.4525	87.62316
Sum Sq. Dev.	95.72400	59.49091	109.8920	2.619961	137.4703	23.64949	35.69105
Observations	182	182	182	182	182	182	182

Source: Authors' calculation.

Table 3. Outcomes of CSD tests.

Variables	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
LnCO2	300.8918***	43.18823***	43.04823***	14.44411***
lnEF	202.2702***	27.97059***	27.83059***	5.798017***
lnLCF	243.8532***	34.38699***	34.24699***	13.67439***
lnGDP	425.9286***	62.48184***	62.34184***	20.48857***
lnKOF	480.4347***	70.89231***	70.75231***	21.90262***
ECI	156.2842***	20.87481***	20.73481***	0.562746
lnURB	505.2600***	74.72294***	74.58294***	22.44627***
lnREN	237.0024***	33.32990***	33.18990***	11.09874***

Note: *,**, and *** are significance level at the 10%,5%, and 1% level, respectively.
Source: Authors' calculation.

Table 4. Outcomes of slope heterogeneity test.

Dependent Variable	Test value		p-value	
	Delta tilde	Delta tilde adjusted	Delta tilde	Delta tilde adjusted
LnCO2	9.956***	11.937 ***	0.000	0.000
lnEF	5.122***	6.142***	0.000	0.000
lnLCF	6.643***	7.964***	0.000	0.000

Note: *** ise significance level at the 1% level.
Source: Authors' calculation.

Table 5. Outcomes of CIPS PURT.

Variables	Level		Δ	
	C	C+T	C	C+T
LnCO2				
	-2.17726	-1.7882	-4.326***	-4.467***
lnEF	-1.20576	-2.185*	-4.986***	-5.046***
lnLCF	-2.05318	-2.2366	-5.210***	-5.303***
lnGDP	-1.44559	-0.99466	-2.753***	-3.039***
lnKOF	-2.31002	-1.83166	-4.469***	-4.354***
lnECI	-2.127	-2.162	-5.396***	-5.422***
lnURB	-2.192	0.15930	-2.892***	-2.292
lnREN	-1.95875	-0.59803	-3.869***	-4.082***

Note: *,**, and *** are significance level at the 10%,5%, and 1% level, respectively.
Source: Authors' calculation.

Table 6. Durbin–Hausman panel cointegration test.

Tests	CO		EF		LCF	
	Test statistic	**p-value**	**Test statistic**	**p-value**	**Test statistic**	**p-value**
Durbin-H panel statistics	0.243	0.404	8.251***	0.000	4.344***	**0.000**
Durbin-H group statistics	-0.081	0.532	4.519***	0.000	5.333***	**0.000**

Note: *,**, and *** are significance level at the 10%,5%, and 1% level, respectively.
Source: Authors' calculation.

The CIPS PURTs are performed to examine the series' stationaryness, and the outcome of the PURTs is presented in Table 5. When interpreting the CIPS PURT with constant and constant&trend terms, it is concluded that all series contain a unit root at the level while the first difference values of all series are stationary at the 1% significance level.

When scrutinizing the outcome of the CIPS PURT, each series is integrated at *I (1)*, and the panel cointegration tests are performed to determine whether the series are cointegrated. In the study, as the influence of the explanatory variables on three environmental indicators comprising CO_2, EF, and LCF, the panel cointegration tests are applied for three models. Within this context, The Durbin-Hausan and the LM panel bootstrap cointegration proposed by Westerlund and Edgerton (2007) analysis are executed. The Durbin-Hausman panel cointegration (hereafter, PHPO) analysis involved in the second-generation panel techniques, allowing for considering the cross-section dependence, is the first employed cointegration test in the study, and this test is also applicable when the inclusion of a stationary independent variable in the panel exists. PHPO analysis reveals two different statistics. The Durbin-H panel statistic is the first statistic assuming the presence of slope homogeneity. The Durbin-H group statistics is the second one, allowing for considering slope heterogeneity. The null hypothesis of the Durbin-Hausman panel cointegration analysis shows the absence of cointegration. The findings of the tests are disclosed in Table 6. The Durbin-H panel and group statistics on model 1 promote the exception of, H_0 which means that there is no long-run connection between lnCO2, lnGDP, ECI, lnKOF, lnREN, and lnURB. In contrast, the validity of the long-run movement holds for the variables employed in Model 2 and Model 3.

The LM bootstrap panel cointegration analysis is the second applied method. The null hypothesis of the analysis argues that a long-run movement holds for the variables. The findings of the LM bootstrap panel cointegration analysis with constant (C) and constant & trend (C&T) terms are shown in Table 7. When the test statistics of C and C&T and the corresponding bootstrap p-values for lnCO2, lnEF, and lnLCF are examined, the rejection of the null hypothesis does not hold for all three models. In another explanation, the long-run relationship between the variables involved in all three models is verified according to the findings of The LM bootstrap panel cointegration analysis.

Table 7. LM panel bootstrap cointegration test results.

DependentVariable				DependentVariable				DependentVariable			
LnCO2				lnEF				lnLCF			
Statistics		**Boostrapped p-values**		**Statistics**		**Boostrapped p-values**		**Statistics**		**Boostrapped p-values**	
C	**C&T**	**C**	**C&T**	**C**	**C&T**	**C**	**C&T**	**C**	**C&T**	**C**	**C&T**
5.411	13.281	1.000	0.984	9.367	17.648	0.727	0.676	7.329	15.348	0.989	0.929

Source: Authors' calculation.

Table 8. Outcomes of AMG and CCEMG for the model 1.

Variables	AMG			CCEMG		
	Coefficients	**Std. err.**	**p-values**	**Coefficients**	**Std. err.**	**p-values**
Lngdp	0.2814052	0.1720815	0.102	0.38667***	0.0643093	0.000
LnURB	0.098752*	0.5094147	0.053	-1.394994	2.599609	0.592
LnREN	-0.54869***	0.1082357	0.000	-0.59800***	0.1156829	0.000
LnKOF	-0.476537**	0.1744812	0.006	-.2181291	0.184838	0.238
ECI	0.039426	0.0247282	0.111	0.0237335	0.0530554	0.655
Cons	-1.54396	1.781935	0.386	3.820116	5.263923	0.468

Note: *,**, and *** are significance level at the 10%,5%, and 1% level, respectively.
Source: Authors' calculation.

Table 9. Outcomes of AMG and CCEMG for the model 2.

Variables	AMG			CCEMG		
	Coefficients	**Std. err.**	**p-values**	**Coefficients**	**Std. err.**	**p-values**
Lngdp	0.47968***	0.1501184	0.001	0.5871056	0.31764*	0.065
LnURB	1.11017*	0.662743	0.094	2.063982	1.17738*	0.080
LnREN	-0.26956**	0.1148384	0.019	-0.4613818	0.20933**	0.028
LnKOF	-0.63903***	0.1784822	0.000	-0.6359731	0.29169**	0.029
ECI	0.0289698	0.018348	0.114	0.0419256	0.0276184	0.129
Cons	-4.523819	3.130269	0.148	2.855519	10.99798	0.795

Note: *,**, and *** are significance level at the 10%,5%, and 1% level, respectivelly.
Source: Authors' calculation.

The next path of the econometric process followed in the study is estimating the long-run effect of the explanatory variables on lnCO2, InEF, and lnLCF. The AMG and CCEMG estimators are performed within this objective for three models. The finding of the AMG and CCEMG estimators for lnCO2 is presented in Table 8.

As accompanying the validity of the cointegration connection in the variables of Model 1, the AMG and CCEMG estimators are applied to find the magnitude and direction of the explanatory variables on lnCO2. The finding of the estimators on Model 1 is documented in Table 8. When considering the evidence obtained from the estimators, all explanatory variables promote a statistically significant influence on lnCO2 at the 10% significance level, except ECI. The coefficient of InGDP in AMG and CCEMG estimators is found to be 0.281 and 0.386, respectively, which shows that an increase in lnGDP impairs the air quality (hereafter AQ) of the considered countries. Moreover, the evidence of the AMG and CCEMG estimators on the nexus between lnURB is controversial. According to the AMG estimator, a 1% increase in lnURB impairs AQ by 0.987%, whereas lnURB enriches AQ in the CCEMG estimators by 1.394%.

Table 10. Outcomes of AMG and CCEMG for the model 3.

Variables	AMG			CCEMG		
	Coefficients	Std. err.	p-values	Coefficients	Std. err.	p-values
Lngdp	-0.44711***	0.1381567	0.001	0.24414	0.819197	0.766
LnURB	-0.00446	0.5884291	0.994	-0.32292	4.384502	0.941
LnREN	0.25506**	0.1027444	0.013	0.11410	0.1555246	0.463
LnKOF	0.64001**	0.2395693	0.008	-0.04681	0.7467854	0.950
ECI	-0.03488	0.021369	0.103	-0.03845	0.0356308	0.280
Cons	0.31765	2.728132	0.907	-6.3792	7.943553	0.422

Note: *,**, and *** are significance level at the 10%,5%, and 1% level, respectivelly.
Source: Authors' calculation.

A 1% increase in lnREN mitigates lNCO2 by 0.548 in the AMG estimations, while a 1% rise in lnREN lessens lNCO2 by 0.598% in the CCEMG estimations. The finding of the estimators for the coefficient of lnKOF is statistically significant and negative, and AQ is improved by lnKOF, calculated as approximately 0.476% in the AMG estimator and 0.218% in the CCEMG estimator.

In the study, lnEF is concentrated as another dependent variable, which presents a comprehensive knowledge of the demand side of ENV, reflecting air, soil, and marine degradations. Table 9 poses the findings of the AMG and CCEMG estimators. When examining the statistics on ECI, ECI is also found to be statistically insignificant in Model 2. As a result of the AMG and CCEMG estimators on lngdp, ED are increased by a 1% increase in lngdp measured as 0.479% and 0.587%, respectively. Table 10 shows that lnURB is a pivotal factor harming EQ, and the magnitude of lnurb on lnEF in the AMG and CCEMG estimator is calculated as 1.11% and 2.063%, respectively. However, the finding of Table 9 verifies that lnREN and lnKOF have a favorable influence in mitigating ED.

Scrutinizing the effects of the explanatory variables on lnLCF is the last long-run estimation; the estimators' results are shown in Table 10. When interpreting the evidence obtained from the CCEMG estimators, lnLCF is not statistically associated with all explanatory variables. As for the finding of the AMG estimator, lnURB and ECI do not matter for sustainability in E-7 countries. Furthermore, the favorable role of lnREN and lnKOF in sustainability is verified by the result of the AMG estimator, and a 1% increase in lnREN leads to a 0.255% increase in lnLCF while a 0.64% improvement in lnLCF is accompanied by a 1% increase in lnKOF.However, the result of the AMG on lnGDP shows that an increase in lnGDP promotes a diminishing effect on sustainability, measured as 0.447%.

The last path of the empirical analysis is to perform the Dumitrescu and Hurlin (D-H) panel causality (hereafter, DHPC) analysis to determine the causality connection between the explanatory variables and environmental-related indicators. DHPC analysis outcome is presented in Table 11. Firstly, the causality connection between the explanatory variables and lnCO2 is interpreted. As a result of Table 11, it is shown that a one-way causality link operated from lnGDP to lnCO2 and a one-way connection running from lnCO2 to lnURB are verified. Besides, a mutual causality relationship between lnKOF and lnCO2 holds for the E-7 countries. When focusing on the nexus between the explanatory variables and lnEF, it is concluded that a two-way causality link between three variables comprising lnURB, lnKOF, and ECI and lnEF is confirmed while lnEF is induced by lnREN. The finding of DHPC for Model 3 is the last examining evidence in the study, and it is underlined that lnLCF causes all explanatory variables.

DISCUSSION and CONCLUSION

In recent times, society has encountered severe challenges such as CC, GW, rapidly annihilating natural resources, and various forms of ED. The policymakers, intergovernmental organizations, and each global, regional, and local meeting and trace have currently addressed the urgent actions aimed at mitigating and reversing EP and establishing the economic and social structure based upon sustainability. Within this scope, outstanding agendas, traces, and goals such as the Kyoto Protocol, the Paris Conference, and SDGs have been introduced for the policymakers to protect the recent welfare and provide a liveable world for future generations. However, comprehensive scientific research is pivotal and contributes to policy actions. Within this scope, this study scrutinizes the impact of EG, URB, RE, KOF, and ECI on three environmental indicators in E-7 countries. CO_2 emissions are one of the concentrated

Table 11. Dumitrescu and hurlin panel causality test.

Null Hypothesis	W-stat	Zbar-Stat	p-value	Decision
lnGDP -/-> lnCO	7.5625	7.3585	0.0418	lnGDP --> lnCO
lnCO-/-> lnGDP	2.7169	3.2121	0.2142	-
lnURB-/-> lnCO	14.4834	6.4793	0.2902	-
lnCO-/-> lnURB	19.3159	10.1702	0.0266	lnCO--> lnURB
lnREN -/-> lnCO	2.8676	3.4940	0.2205	-
lnCO-/-> lnREN	6.8580	2.6735	0.3764	-
lnKOF -/-> lnCO	29.6375	18.0535	0.0025	lnKOF --> lnCO
lnCO-/-> lnKOF	3.5316	4.7362	0.0925	lnCO--> lnKOF
ECI -/-> lnCO	1.6598	-0.4500	0.8441	-
lnCO-/-> ECI	3.2512	4.2116	0.1698	-
lnGDP -/-> lnEF	2.7804	3.3308	0.3422	-
lnEF-/-> lnGDP	2.0686	0.0907	0.9683	-
lnURB-/-> lnEF	23.0976	13.0585	0.0253	lnURB--> lnEF
lnEF-/-> lnURB	29.3616	17.8427	0.0038	lnEF--> lnURB
lnREN -/-> lnEF	3.9153	5.4540	0.0583	lnREN --> lnEF
lnEF-/-> lnREN	4.2015	2.9124	0.2966	-
lnKOF -/-> lnEF	23.4635	13.3380	0.0051	lnKOF --> lnEF
lnEF-/-> lnKOF	4.6547	6.8373	0.0127	lnEF--> lnKOF
lnECI -/-> lnEF	4.1754	5.9407	0.0279	lnECI --> lnEF
lnEF-/-> lnECI	3.4476	4.5791	0.0545	lnEF--> lnECI
lnGDP -/-> lnLCF	14.2885	6.3304	0.2129	-
lnLCF-/-> lnGDP	4.4707	6.4931	0.0215	lnLCF--> lnGDP
lnURB-/-> lnLCF	17.9572	9.1325	0.1381	-
lnLCF-/-> lnURB	28.7469	17.3732	0.0063	lnLCF--> lnURB
lnREN -/-> lnLCF	0.9475	-0.0981	0.9531	-
lnLCF-/-> lnREN	1.5796	-0.5561	0.8378	-
lnKOF -/-> lnLCF	12.6895	5.1092	0.2193	-
lnLCF-/-> lnKOF	3.2577	4.2238	0.0963	lnLCF-/-> lnKOF
lnECI -/-> lnLCF	0.7053	-0.5514	0.7947	-
lnLCF-/-> lnECI	14.5381	6.5210	0.0735	lnLCF-/-> lnECI

Source: Authors' calculation.

variables because GW and CC driven by GHE, especially CO_2 emissions, are severe threats faced by the world, and they are also major culprits of the observed ED such as floods, droughts, deforestation, and melting glaciers. The study also employs EF as another dependent variable because air degradations are not only forms of pollution, and the pressure of human activities harms all ecosystems, such as marine, soil, and air. Employing EF provides comprehensive insights that examine the role of the explanatory variables of ENV. Moreover, neglecting the supply side of ENV and just focusing on the demand side of ENV does not promote sufficient knowledge, decreasing the performance of the policy action because the policy aimed at addressing improving reproductive nature plays a vital role in sustainability. LCF is used as the third dependent variable within this context. Moreover, focusing on E-7 countries is an important example because of their social, economic, and political properties.

In performing to achieve more resilient and concrete evidence harmonized with utilizing all variables, the Durbin-Hausman panel cointegration analysis and LM panel Bootstrap Cointegration analysis, AMG and CCEMG estimators based upon the second-generation panel techniques are executed because of detecting the presence of CSD and slope heterogeneity for three models. At the same time, the Dumitrescu and Hurlin Panel Causality Test is also employed to find the causality direction among the variables. The panel cointegration tests confirm the presence of the cointegrated connection between the variables for all models. Late, the long-run estimations are processed. When the evidence on the CO_2 emissions is considered, RE is detected as an essential solution for lessening the CO_2 emissions. Like RE, KOF also promotes a supportive role in mitigating air degradation. However, EG and URB impair AQ, whereas ECI does not matter for AQ.

When examining the influence of explanatory variables on EF, it is observed that the results concerning EF support the evidence on CO_2 emissions. In another explanation, RE and KOF are also found to be pivotal factors in lessening the pressure of anthropogenic activities on ENV, whereas higher URB and economic welfare are achieved at the cost of comprehensive ED. However, EF is not influenced by ECI. The LCF is regarded as the final dependent variable within this context. As a consequence of the outcome of the nexus between the explanatory variables and the LCF, EG of the E-7 countries impairs sustainability, whereas RE plays a vital role in sustainability. The EQ of the countries considered is not associated with URB or ECI. KOF decreases the pressure of the anthropogenic activities mentioned in Models 1 and 2, At the same time, The model 3 also proves that KOF enriches sustainability.

Following the explanation for the empirical evidence, this study reveals significant macro and micro-based policy insights, which hopefully contribute to the objectives and targets based upon the sustainability of the E-7 countries. The role of RE in lessening ED and enriching EQ is highlighted as a consequence of the investigation in the study. Although RE promotes a comprehensive supportive effect on ENV of the E-7 countries, more committed and urgent actions seem to be required because the share of E-7 countries' global EC is almost 42%, and these countries are liable for 46% of the world's carbon emissions. However, the economies of E-7 countries dominantly rely on fossil energy resources, and they are ranked as the top fossil energy consumers and producers in the world. Despite the detrimental effects of fossil energy resources on ENV, disturbance in the global fossil energy supply, highly volatile fossil energy prices, the reliance on fossil energy imports and the dominant share of fossil energy export in total income, and the fact that NRE resources will soon run out are pushing factors for the E-7countries to implement urgent actions for the renewable energy transition. Within this scope, the expansion of public-private partnerships and regional collaboration portfolios play a vital role in expanding green energy funds. The Joint actions and commitment of the E-7 countries on Feed-in tariffs, tax subsidies, and long-term loans with low interest rates stimulate private enterprises to adopt, invest, and develop new energy technologies. However, installing solar panels and energy efficiency-based technologies can be further promoted across the existing energy-intensity sectors.

The study also confirms that KOF has improved environmental impact, decreasing CO_2 and EF and increasing the LCF of the E-7 countries. Day by day, the E-7 countries have dramatically integrated into the global economy. The social, political, and economic structures have been reshaped and transformed due to KOF. However, inflows of advanced and greener technologies, know-how, and management knowledge have become available for the countries. In contrast, social awareness of ED and polluting production and consumption patterns have become more visible worldwide. In order to mature the supportive role of KOF in ENV, the E-7 countries may promote the exchange of goods and services by providing cleaner technologies and investing in green, energy-efficient technologies and high-tech industries. The leap forward in the mentioned fields will create dynamic comparative advantages that help the E-7 countries to lift the highest-income group. Another implication from the study is that economic expansion and economic complexity do not improve sustainability. Policymakers should determine and implement urgent efforts and initiatives because E-7 countries have the highest economic performance among developing countries, and these countries' economic objectives increase the pressure on the regional and worldwide ENV. The results of the ECI and EG confirmed the current properties of the E-7 countries. These countries' heavy industry process still relies on fossil energy resources. Some countries in the group are ranked the most fossil energy exporter, while the rest are the most fossil energy importers. At the same time, the current ECI in the E-7 countries does not encourage environmentally friendly technologies. Within this scope, the current polluted economic structure should be evolved into energy efficiency, less natural resources reliance, and the required energy fulfilled by RE. URB process is another detected impaired factor of EQ. Governments, urban planning agencies, and metropolitan officials should take more efficient steps to reduce the influence of urbanization on EQ. As the population grows in urban areas in the E-7 countries, infrastructure, transit emissions, traffic jams, domestic solid and water waste, employing fertile soils, and deforestation have been some challenges and polluted factors in these countries. Within this scope, intelligent urban planning, energy-efficient and green methods and materials utilized in infrastructure, renewable energy sources, and fuel-efficient and hybrid cars in the big cities are essential policies to reduce the rising trends in contamination.

All in all, this study also provides some recommendations based on the limitations of the study for further research. Although the concentration on the E-7 countries is an essential example in terms of the nexus between the regarded explanatory and three environmental-related indicators, other economic and future research can be performed for political classifications such as BRICS, OECD, European Unions, Next-11 countries with the same methods used in the study. However, different explanatory variables such as R&D expenditures, investment in RE, financial development, and natural resources rents can be employed for the E-7 countries or other mentioned countries. Moreover, types of globalization comprise political, social, and economic sub-components of ecological footprints, and their LCF can be executed by novel research. The final offer of new research is that the quantile approach or the wavelet techniques may be used for the same variables.

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