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Can information and communication technology and institutional quality help mitigate climate change in E7 economies? An environmental Kuznets curve extension

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Abstract

Understanding the role of information communication and technology (ICT) in environmental issues stemming from extensive energy consumption and carbon dioxide emission in the process of economic development is worthwhile both from policy and scholarly fronts. Motivated on this premise, the study contributes to the rising studies associated with the roles of economic growth, institutional quality and information and communication technology (ICT) have on CO_2 emission in the framework of the 21st Conference of the Parties (COP21) on climate convention in Paris. Obtaining data from the emerging industrialized seven (E7) economies (China, India, Indonesia, Russia, Mexico, Brazil and Turkey) covering annual frequency from 1995 to 2016 for our analysis achieved significant outcome. From the empirical analysis, economic globalization and renewable energy consumption both reduce CO_2 emissions while ICT, institutional quality and fossil fuel contribute to the degradation of the environment. This study affirms the presence of an environmental Kuznets curve (EKC) phenomenon which shows an invented U-shaped curve within the E7 economies. On the causality front, both income and its square have a feedback causal relationship with carbon emissions while economic globalization, institutional quality, ICT and clean energy all have a one-way directional causal relationship with CO_2 emissions. Conclusively, the need to reduce environmental degradation activities should be pursued by the blocs such as tree planting activities to mitigate the effect of deforestation. Furthermore, the bloc should shift from the use of fossil-fuel and leverage on ICT to enhance the use of clean energy which is environmentally friendly.

Keywords: ICT, Environmental sustainability, Institutional quality, Renewable energy transition, Carbon reduction, Economic globalization, Panel econometrics, E7 economies

1 Introduction

Environmental degradation is an urgent threat that transcends the state boundaries (Benzie and Persson 2019). A number of countries have encountered problems with regard to natural disasters which over recent years have affected their economic well-being and quality of lives. One of the arguments for environmental degradation is that it is caused by CO_2 emission anthropogenic practices (Rogelj and Schleussner 2019). In particular, CO_2 emissions from energy utilized in the developing world surpassed that of developed nations after the 1990s (Kasman and Duman 2015). Environmental challenges require nations all over the globe to be more open to the risks of environmental warming because of the Paris Agreement of 2015 (COP21). About half a decade ago, the United Nations (UN) launched the Sustainable Development Goals (SDGs) to deal with essential challenges such as to achieve decreasing degradation (SDG 12 and 13) and growing economic and social prosperity, making harmony among countries, and coping with global ecological decline. Ecological pollution has hit a significant stage and hence, it has become essential to learn how ecological factors can influence economic development (Bakhsh et al. 2017).

Even when trade and industrial development are significant targets for all countries, advanced states are particularly anxious about the damage to the ecology (Raworth 2017). From a different point of view, emerging economies often disregarded these crucial problems in coping with economic development. As a consequence, the individuals who are the weakest and have no desire to get involved will struggle much. As a result, foreign collaboration on many of these problems will best be fulfilled as a gateway to industrialized economies and developing sustainably (Benzie and Persson 2019). In the current period, the effect of economic development on ecological deterioration has been investigated in various analyses and frequently linked to the theory of the EKC (Ozokcu et al. 2017; Adebayo and Kirikkaleli 2021; Adebayo et al. 2022).

Essentially, the EKC claims that economic development steadily leads to a certain ecological deterioration until a turning point threshold where the attendant economic development engenders an opposite tendency on ecological deterioration, also known as an inverted U-shaped curve (Grossman et al. 1991). Carbon emission in a country during its transition years is directly tied to economic development. In the long term, economic development of the economy would have a beneficial effect on climate until the nation hits a reasonable amount of real Gross Domestic Product (GDP) (Grossman et al. 1991; Shafik 1994; Bekun 2022). For example, a recent study found that CO_2 emission, energy intensity, and income are non-linearly connected among countries constituting the Association of Southeast Asian Nations (ASEAN) (Heidari et al. 2015). But these studies show that places with large income such as Singapore will reduce CO_2 emission. Different nations which have marginally higher income including Thailand, Indonesia as well as Philippines, usually experience slower economic development due to their higher CO_2 emission levels. Global trade is a channel that plays a crucial role in the development of nations' ecosystems. According to Shahbaz et al. (2018a, b, c), the advancement of the finance industry would improve economic development by growing aggregate demand to enterprises and companies and redistributing monetary capacity to more productive organizations, and thus raise energy use.

Investment from overseas and economic globalization are largely based on modern source of internet usage. The internet has become a central catalyst in the innovation turn for environmental sustainability and there is an evolving stream of literature maintaining that CO_2 emission can be minimized via the ICT sector (Elumban et al. 2016; Asongu et al. 2018). CO_2 emission deteriorates the available environment due to the emissions created during the manufacturing process. Moreover, advancement in ICT entails substantial energy usage. As ICT is associated with incremental innovative prospects, it is making use of great energy which contributes a lot in terms of CO_2 emission.

ICT is ruling in our modern world today and it plays an essential role in the quality of institutions. Information technology has been brought into a new paradigm. It is being used for social interaction and it is creating change in the quality of institutions. ICT facilitates trade openness especially when such ICT is very apparent in economic activities (Cortes et al. 2011).

Activities like trade openness or liberalization rely mostly on ICT which is modern in nature. Since the advent of the internet, internet use has played a crucial part in "international cooperation" finance, socio-economic growth, foreign exchange, organizational infrastructure and productivity. It has been imperative, inter alia, employment development, poverty reduction and energy consumption. Building on the evidence from the existing literature, it is reasonable to posit that with ICT, CO_2 emissions in other sectors of the economy would decrease. These include, inter alia, the: energy, agriculture, power, transportation, and financial sectors. Rendering the internet more efficient means reducing CO_2 emissions caused by associated energy consumption. Efficient measures need to be taken to control CO_2 emission which is consistent with engaging labor force that uses modern technology that has a negative impact on the economy.

Institutional quality has a significant impact on CO_2 emission. Inefficient financing from weak institutions in sectors which are private leads to, inter alia, corruption, protocols which are weak and a poor bureaucratic process. Institutional quality has currently drawn the attention of researchers and scientists with regard to the environment (Godil et al. 2020). In ensuring good cooperation among dealers, effective and impartial government institutions may play major roles. The rule of law, therefore, is currently a critical factor in addressing environmental problems. Consequently, a strong rule of law is vital to impose CO_2 emission control procedure as well as oversee how companies comply with attendant procedures. Relatively, if faults occur in institutional quality, by ignoring the externalities of the environment, companies are likely to disregard steps essential for the control of CO_2 emissions.

Two schools of thought have emerged from the literature on the linkage between CO_2 emission and ICT. While a strand of the literature argues that ICT increases CO_2 emissions, another group of extant researchers argues that ICT helps to reduce CO_2 emissions (Belhir et al. 2018). The internet has become the popular technological streaming for many different purposes. The way most people use and rely on the internet has become a huge energy and global warming threat. However, the internet has also become the fundamental medium by which people maintain their livelihoods every day (Islam et al. 2020). Financial industries should incorporate environmentally friendly technologies in order to minimize the environmental degradation that occurs during production (Amri et al. 2018).

The closest study in the literature to the present exposition is Asongu et al. (2018) which has assessed how enhancing ICT affects CO_2 emissions in sub-Saharan Africa (SSA) to conclude that CO_2 emissions can be reduced by ICT when certain critical thresholds of ICT penetration have been reached. Departing from the underlying study, this analysis explores the effect of ICT, institutional quality and income level on CO_2

emission. To make this assessment, we have used the Augmented Mean Group (AMG), Common Correlated Effect Mean Group (CCEMG) and Driscoll–Kraay (DK) OLS over the time stretching from 1995 to 2016, within the remit of E7.[1] In 2017, all of the countries highlighted in the E7 bloc were within the top 25 nations accounting for global CO_2 emissions. Chain was reported to have produced 9898.3 million metric tons, making it the first on the list.

In comparison to the other countries, India manufactured 2466.8 million metric tons of pollutant, which placed it third, whereas Russia produced 1692.8 million metric tons, placing it in fourth position. Mexico was 11th, having produced 490.3 million metric tons of pollutants, and Indonesia was 12th, having realized 486.8 million metric tons of pollutants. Additionally, Brazil was ranked 13th in terms of 476.1 million metric tons of pollutants. Meanwhile, in relation to greenhouse gas emissions, the Turkish Republic, which was the last of the E7 nations to be added to the list, was ranked at number 15th, with CO_2 emissions amounting to 447.9 million metric tons (see www.usato.com). With these E7 CO_2 emissions figures, we may infer that the E7 economies are responsible for generating a significant amount of CO_2 because of their commercial development.

Beyond the extension of Asongu et al. (2018) as clarified above, our analysis adds to the existing studies discussed, on the following fronts:

To our best of knowledge, this study examines the connection among ICT, economic globalization, institutional quality and CO_2 emissions for the emerging seven (E7) economies:

(i) Additionally, most previous studies on the association between internet usage and carbon dioxide emissions have been based on panel data models that have failed to consider the issue of cross-sectional dependence and heterogeneity which are relevant in providing robust findings [see Lu (2018) for 12 Asian countries, Amri (2018) for Tunisia and Nguyen et al. (2020) for G-20 economies]. The present analysis accounts for accurate and unbiased effects of cross-sectional dependence and heterogeneity which require the employment of a more advanced group of econometric tests.

(ii) We extend our analysis to examine if an EKC is apparent among E7 economies within the framework of an income-carbon emission relationship while accounting for combined effect of institutional quality and economic globalization in mitigating CO_2 emission that have received little or no documentation in the extant literature in the context of E7.

(iii) The authors employed the Augmented Mean Group (AMG) and Common Correlated Effect Mean Group (CCEMG) which provide more robust outcomes for policy recommendation.

The remainder of this study is organized as: this introduction is followed by a literature review in Sect.2. The analysis of the econometric methods and description are outlined in Sect. 3. Section 4 focuses on the empirical result and discussion. The final section presents the conclusion and recommendations.

[1] E7 Countries: Group of seven industrialized economies that comprise Brazil, Russia, India, China, Indonesia, Mexico and Turkey, which are all mostly emerging and newly industrialized nations.

2 Literature review

Economic influence of ICTs has been argued about throughout the 1960s. ICT has had a huge positive impact on economic and social issues around the globe. The relationship regarding ICT and economic development is considered optimistic (Engelbrecht and Xayavong 2007; Kretschmer 2012; Asongu et al. 2016, 2017; Sinha 2018; Sinha et al. 2020; Chien et al. 2021). In recent years, the controversy on climate conservation has escalated significantly. Several studies suggest that substantial reliance on ICT can affect the environment in the long term.

Emeri (2019) conducted a study in Tunisia using ICT, total factor efficiency and CO_2 variables. The study found that ICT had great impact on CO_2 emission used to proxy for pollution. Their study rejected the EKC assumption. Also, Nguyen (2020) conducted a study on the role of ICT and invention in deriving CO_2 emission and commercial progress in designated G-20 countries. In the first place, there were only five obstacles that hinder CO_2 emission including increasing oil costs, FDI, improved infrastructure, and spending on innovation. Secondly, ICT, financial sector progress, and economic development were all positive contributing forces for the economy. It appears that their observations show the invalidity of the omission of the EKC in their study. However, their research empirically shows that work to regulate use of oil and ecologically responsible refining, distribution, and steps like processing and manufacturing can mitigate emissions in these markets. Another study by Amri (2018) examined the linkage between CO_2 emission, income, ICT, and trade in Tunisia. The findings show that the EKC assumption was dismissed as higher long-term total factor productivity (TFP) coefficients were found opposed to the short TFP coefficients. Additionally, the analysis revealed that ICT has little or no effect on carbon emission as an indicator of pollutants. Tunisian decision-makers must ensure both a continuous improvement in their total factor efficiency as well as an expansion in ICT. A study by Godil et al. (2020) confirmed that CO_2 emission in the long run affects institutional quality and GDP positively impacted CO_2 emission. Relatively, FDI and ICT showed a negative impact on CO_2 emissions. Furthermore, the same study depicted that financial development and CO_2 negatively impacted CO_2 emission. Nonetheless, Magazzino (2021) tackled the connection among ICT, power ingestion air pollution and economic growth in EU countries. The study found that there was a unidirectional association between ICT and energy consumption. In addition, Park and Baloch (2018) found that electricity consumption had substantial effect on CO_2 emission and internet usage in EU countries. The study suggested that internet used is increasing the risk to ecological devolvement. Seemingly, Raheem et al. (2020) examined ICT and CO_2 emission. The result depict that ICT significantly impacts CO_2 emission in the long run and short run. Additionally, Zafar et al. (2022) investigated the potential long-term effects of information and communications technology (ICT) and education on environmental quality from 1990 to 2018. The results obtained by the continuously updated and fully modified (Cup-FM) test indicate that economic growth, education, and energy consumption stimulate carbon emission intensity in Asian countries.

In the wake of the above-mentioned studies, several empirical examinations have been done utilizing both total energy and energy consumption. Amidst the above assertion, two concepts have emerged, notably: green ICT and electricity for ICT.

Indeed, as indicated in Salahuddin et al. (2016), green ICT is defined as a state where production can be achieved via energy and environmental efficiency. This suggests that the introduction of new technologies into the energy system itself affects the sector and thus helps towards reaching alternative goals. In order to improve the environment, renewable energy could save cost.

Despite the importance of ICT in environmental outcomes, empirical studies have shown that some ICTs engender positive effects than others. The theoretical linkage between ICT, energy and the environment appeared of high interest as early as the 1990s. To see what is little known in the subject of EKC studies, it is significant that most investigations from extant studies have focused on country-specific or industrial sectors (Sadorsky 2012). Salahuddin et al. (2016) have conducted a very extensive study on this subject. Asongu (2018) assesses the effects of internet in 44 countries in Africa. The outcome indicated ICT use reduces CO_2 emissions. Majeed (2018) experientially tested the consequence of ICT know-how on emissions reduction in developing countries. The research analyzed 232 countries over the years 1980 to 2016. ICT favorably impacted developed countries; however, the impact did not favor developing countries.

Moreover**,** Cho et al. (2007) investigated the straight and knock-on influence of ICT investment on fuel consumption utilizing oil price and electricity as additional variables in South Korea. The study indicates that investment in ICT could decrease energy used under certain circumstances. Further, Salauddin et al. (2015) reiterated that internet usage ensures institutional quality. Similarly, a study by Abid (2017) on institutional quality in 41 European countries asserted that institutional quality reduces CO_2 emissions. Lau et al. (2014) stressed that institutional quality is crucial in minimizing CO_2 emissions. Lv et al. (2018) stressed that, better institutional quality strategies ensure environmental quality. Amri (2018) found causality amid CO_2 emissions, ICT, trade, wages, FDI and energy consumption in Tunisia. ARDL result gave no evidence in advocate of either enriching or controlling the effect of technology on environmental pollution. Lu (2018) also compared the effect of energy utilization, ICT and FDI on CO_2 emissions for distinct twelve Asian countries. Shabani et al. (2019) found unidirectional causation from energy intake, ICT to CO_2 emissions using a horizontal approach. Their finding was closely aligned with Arshad et al. (2020) who has analyzed the effect of trade, ICT, monetary progress, and energy consumption on greenhouse gases in fourteen Asia countries.

The research concluded that ICT may have an adverse and significant influence on pollution. Khan et al. (2018) asked if the rate of ICT investment matters when controlling for CO_2 emissions. Therefore, the authors selected the E7 countries they thought were important in the use of ICT in enhancing productivity of their economies as they constitute comparatively faster growing emerging countries. To authors' best of knowledge, this is the first study to examine the connection among ICT, monetary globalization, institutional quality and CO_2 emissions for the emerging seven (E7) economies. Subsequently, our analysis to examine if an EKC is apparent among E7 economies within the framework of an income–carbon emission relationship. Lastly, we employed the AMG and CCEMG which provide more robust outcomes for policy recommendation. The study indicated that ICT is linked with formation of waste and CO_2 emission.

Table 1 Description of variables

Name of indicators	Abbreviation	Proxies/scales of measurement	Sources
Carbon dioxide emissions per capita	CO_2	Measured in metric tonnes	WDI
Income	Y	It is proxied by the gross domestic product per capita (2010 Constant USD)	WDI
Square of income	Y^2	It measures the square of GDP per capita	WDI
ICT internet use	ICT	Internet users (per 100 people)	WDI
Renewable energy consumption	R	% of total final energy consumption	WDI
Fossil fuel	F	Fossil fuel energy consumption (% of total)	WDI
Economic globalization	EG	KOF globalization Index	Gygli et al. (2019) https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.htm
Institutional quality	INSQ	CPIA transparency, accountability, and corruption in the public sector rating	WDI

Source: Created by the authors

3 Data and methodology

This study adopts a battery of econometrics techniques to empirically analyze data on a group of seven emerging economies (E7) that comprises China, India, Brazil, Mexico, Russia, Indonesia, and Turkey. The data are sourced from the World Bank's development indicators from 1995 to 2016. The choice of these coefficients is in accordance with the 2030 Sustainable Development Goals (SDGs). These countries share some common economic traits with their fast-growing emerging status which has translated to substantial implications on energy-related developments alongside economic expansion in recent times. To assess the impacts of ICT, energy consumption and the current level of institutional quality in line with the level of economic globalization on their environmental quality, we provide a model specification for the empirical study in logarithm form in Eq. 1:

$$\begin{aligned} \mathrm{LnCO}_{2\mathrm{it}} =& \alpha_0 + \alpha_1 \mathrm{LnY}_{\mathrm{it}} + \alpha_2 \mathrm{Ln}Y^2{}_{\mathrm{it}} + \alpha_4\alpha_3 \mathrm{LnICT}_{\mathrm{it}} + \alpha_4 \mathrm{LnINSQ}_{\mathrm{it}} \\ &+ \alpha_5 \mathrm{LnEG}_{\mathrm{it}} + \alpha_6 \mathrm{LnR}_{\mathrm{it}} + \alpha_7 \mathrm{LnFF}_{\mathrm{it}} + \varepsilon_{\mathrm{it}}. \end{aligned} \tag{1}$$

Data spanning from 1995 through 2016 were gathered from the World Bank (WDI 2020), and KOF globalization index of Gygli et al. (2020). This study adopted the KOF globalization index of Gygli et al. (2019) as obtained from KOF Swiss Economic Institute to capture economic globalization. The KOF globalization index is gaining more popularity in empirical literature due to its broad scope of capturing globalization compared to other narrow well-known approaches like the trade openness proxy that mainly capitalizes on trade dynamics in contextualizing the globalization measurement (Shahbaz et al. 2018a; Wang et al. 2018; Le and Ozturk 2020). The full

Table 2 Descriptive statistics of the variables under review

	CO_2	*Y*	Y^2	ICT	INSQ	EG	*R*	FF
Mean	13.578	8.493	5.707	17.580	2.992	3.775	2.942	4.326
Median	13.105	8.952	4.551	18.044	3.000	3.873	3.065	4.424
Maximum	16.153	9.551	5.966	21.034	3.620	4.566	3.997	4.525
Minimum	12.055	6.514	1.980	11.247	2.230	2.749	1.171	3.938
Std. Dev	1.083	0.860	5.027	2.263	0.359	0.351	0.899	0.186
Skewness	0.774	− 0.753	0.481	− 0.732	− 0.335	− 0.9443	− 0.641	− 0.529
Kurtosis	2.627	2.210	2.257	2.847	2.855	3.313	2.205	1.724
Jarque–Bera	16.279a	18.568a	9.477	13.911a	3.028b	23.516a	14.608a	17.626a
Probability	(0.000)	(0.000)	0.008	(0.000)	(0.019)	(0.000)	(0.000)	(0.000)
Observations	154	154	154	154	154	154	154	154

[a] 0.01, [b]0.05 and [c]0.10 denotes statistical rejection level at 1%, 5% and 10%, respectively

description of variables in Eq. 1 is presented with measurement scales and symbols in Table 1.

There are other internet indicators like the penetration rate of mobile phones, computer investment inter alia. However, the present study utilized internet users (per 100 people) because, a study that was conducted at Carnegie Mellon University found that the primary reasons people use the Internet are to have fun and to learn more about the things that they are interested in. Internet marketing is another function that both public and private entities put the Internet to use for. After the introduction of the personal computer, the Internet rapidly evolved into a tool for widespread communication, despite the fact that its initial purpose was to improve communication among the armed forces. Since its inception, the Internet has developed from its esoteric beginnings into a mainstream mode of communication. This transformation took place since the internet's beginnings. According to Miniwatts Marketing Group, there are over two billion people connected to the Internet at any given moment, which accounts for 34.3% of the total population of the world.[2]

3.1 Data analysis

Varying degrees of relationship are expected among the variables in Eq. 1. Thus, we provide a simple descriptive statistics and correlation matrix to have a glimpse of what such relationships could exist between the variables under review as reported in Tables 2 and 3.

As can be seen in Table 2, ICT has the highest mean of 17.58 persons per year, minimum of 11.25 and a maximum of 21.03 persons per year. Next is CO_2 emission which has a mean of 13.58 metric tons per year, minimum of 12.1 and maximum of 16.15 metric tons per year. Income on the other hand has a mean of 8.5 million USD per year, minimum of 6.514 million USD per year and a maximum of 9.55 million USD per year while its square's mean is 5.71 million USD per year, minimum of 1.98 million USD per

[2] https://www.bing.com/ck/a?!&&p=b6b733b87fe5594bec376ff3d27906e19332c9ef44855ee59a6bf9b3bc87de7bJmltdHM9MTY1NTM3MzAxOSZpZ3VpZD01MDQ1YzI4Yy1jNDlhLTQ5YzctYTJlMS01NTlkYzJkOWIzMTkmaW5zaWQ9NTE1NA&ptn=3&fclid=bb071c97-ed59-11ec-8d25-20ce53457b3d&u=a1aHR0cHM6Ly9ibG9ncy53b3JsZGJhbmsub3JnL2VuZHBvdmVydHlpbnNvdXRoYXNpYS93aHktaWN0LWluZm9ybWF0aW9uLWFuZC1jb21tdW5pY2F0aW9uLXRlY2hub2xvZ2llcy1hbmQtd2h5LW5vdw&ntb=1.

Table 3 Correlation matrix

	CO_2	*Y*	ICT	INSQ	EG	*R*	FF
CO_2	1						
p-value	–						
Y	− 0.334a	1					
p-value	(0.000)	–					
ICT	0.134c	0.328a	1				
p-value	(0.096)	(0.000)	–				
INSQ	0.163b	− 0.276a	0.392a	1			
p-value	(0.042)	(0.000)	(0.000)	–			
EG	− 0.137c	− 0.305a	0.070	0.546a	1		
p-value	(0.089)	(0.000)	(0.382)	(0.000)	–		
R	0.425a	0.387a	− 0.060	− 0.307a	− 0.424a	1	
p-value	(0.000)	(0.000)	(0.456)	(0.000)	(0.000)	–	
FF	0.329a	0.325a	0.298a	− 0.152c	− 0.388a	0.667a	1
p-value	(0.000)	(0.000)	(0.000)	(0.059)	(0.000)	(0.000)	–

[a] 0.01, [b]0.05 and [c]0.10 denotes statistical rejection level at 1%, 5% and 10%, respectively

Table 4 Cross-sectional dependency (CD) test results

Model	Pesaran (2015) CD test	Pesaran (2015) LM test
$CO_2 = f(Y, Y^2$, ICT, INSQ, EG, R, FF)	− 4.409a	− 1.749c
p-value	(0.000)	(0.080)

[a] 0.01, [b]0.05 and [c]0.10 denotes statistical rejection level at 1%, 5% and 10%, respectively

year and a maximum of 5.97 million USD per year. Economic globalization has a mean of 3.8% per year, minimum of 2.75% per year and maximum of 4.57% per year. Clean energy has a mean of 2.94 metric tons per year, minimum of 1.2 metric tons per year and a maximum of 3.99 metric tons per year. While fossil fuel has a mean of 4.33 metric tons per year, minimum of 3.94 metric tons per year and a maximum of 4.52 metric tons per year. However, Table 3 also provides details of correlation metric which proofs that, income and economic globalization have positively significant relationships with CO_2 emission, but ICT, institution quality, clean energy and fossil fuel all have positive significant correlations with CO_2 emission. However, income has a positive correlation with ICT, clean energy, and fossil fuel but a negative correlated with institution quality and economic globalization. ICT on the other hand, has a positive correction with institution quality, economic globalization and fossil fuel but has a negative correlation with clean energy. Institution quality has positive correlation with economic globalization but a negative correlation with both clean energy and fossil fuel. Nevertheless, economic globalization has negative correlation with both clean energy and fossil-fuel, but clean energy has a positive correlation with fossil fuel. However, there may arise some level of concerns about possible cross-sectional dependency (CD) across individual unit of the panel model and it is highly imperative to carry out a test in this direction (De Hoyos and Sarafidis 2006; Dogan and Aslan 2017; Ozcan and Ozturk 2019). Hence, for confirmation purposes, we reported a cross-sectional dependency test results in Table 4

Table 5 Panel IPS and CIPS unit root test

Variables	CIPS				IPS			
	I(0)		*I*(1)		*I*(0)		*I*(1)	
	C	C&T	C	C&T	C	C&T	C	C&T
CO_2	−3.183	−2.682	−4.283a	−4.170a	−1.085	−2.214	−4.306a	−4.225a
Y	−0.806	−1.071	−2.582a	−3.008a	1.783	−1.239	−2.661a	−3.348a
Y^2	−0.816	−0.068	−3.482a	−2.571b	1.323	0.159	−3.896a	−3.193a
ICT	−2.064	−0.999	−2.452b	−3.345a	−0.829	−0.796	−3.869a	−2.801a
INSQ	−1.373	−1.380	−2.892a	−2.962b	−1.238	−2.261	−3.302a	−3.305a
EG	−2.302	−2.095	−5.015c	−5.242c	−2.334	−2.357	−4.362c	−4.651c
R	−0.592	−2.632	−5.034c	−4.958c	−2.657	−2.657	−4.672c	−4.794c
FF	−1.733	−2.197	−4.004a	−4.008a	−1.336	−2.620	−5.346a	−5.293a

[a] 0.01, [b]0.05 and [c]0.10 denotes statistical rejection level at 1%, 5% and 10%, respectively

following the application of Breusch and Pagan (1980) LM test and Pesaran (2015) LM test.

From Table 4, all the three tests affirm the presence of cross-sectional dependence following the statistical significance of the test statistics owing to the rejection of the null hypothesis of no cross-sectional dependence; thus, indicating the necessity to advance some level of caution in selecting appropriate methodologies for both the intending unit root test and cointegration techniques (Bilgili et al. 2017; Shahbaz et al. 2018b). Following these results, conventional panel unit root tests as seen in some extant studies could pave way for misleading conclusions on the unit root status of the variables and the true nature of cointegrating relationships for the panel study (Onifade et al. 2021b). Hence, to circumvent the associated methodological flaws in using conventional panel unit root test in the presence of cross-sectional dependence, we applied Panel IPS and CIPS test of Pesaran (2007) for the unit root analysis. The results of the unit root test from Table 4 show that the understudied variables are integrated of first order $I(1)$ (Table 5).

Having established the order of integration, we applied Westerlund (2007) cointegration technique that is founded on error correction mechanism (ECM) with the assumption that variables exist in their first order of integration to establish a cointegration relationship for the panel study. The error rectification method (ECM) of the estimation follows the expression in Eq. 2:

$$\Delta Y_{it} = \pi_i d_i + \theta_i \left(Y_{it-1} - \gamma_i^* X_{it-1} \right) + \sum\nolimits_{j=1}^{m} \theta_{ij} \Delta Y_{it-j} + \sum\nolimits_{j=0}^{m} \delta_{ij} \Delta X_{it-j} + \varepsilon_{it}. \quad (2)$$

From Eq. 2, $\pi_i^* = (\pi_{1i}, \pi_{2i})^*$, representing the vector of parameters, while $d_t = (1-t)^*$, and θ_i are, deterministic mechanisms, as well as the error correction parameter correspondingly. To identify cointegration existence, Westerlund (2007) approach produces four major statistics based on the least square estimation and corresponding significance of the adjustment term θ_i of the ECM model in Eq. 2 and these statistics can be categorized under two major subdivisions namely the group statistics and the panel statistics. The following are the test statistics for the Westerlund cointegration:

Table 6 Westerlund cointegration test

Statistics	Value	*p*-value
G_T	−2.120a	(0.001)
G_a	−1.651a	(0.000)
P_T	−4.172b	(0.015)
P_a	−2.443b	(0.026)

[a] 0.01, [b]0.05 and [c]0.10 denotes statistical rejection level at 1%, 5% and 10%, respectively

$$G_t = \frac{1}{N}\sum_{i-1}^{N}\frac{\acute{\alpha}_i}{\mathrm{SE}(\acute{\alpha}_i)}, \tag{3}$$

$$G_\alpha = \frac{1}{N}\sum_{i-1}^{N}\frac{T\acute{\alpha}_i}{\acute{\alpha}_i(1)}, \tag{4}$$

$$P_{\mathrm{T}} = \frac{\acute{\alpha}}{\mathrm{SE}(\acute{\alpha})}, \tag{5}$$

$$P_\alpha = T\acute{\alpha}_i. \tag{6}$$

The group means statistics, comprising G_{a} and G_{t}, are shown in Eqs. 3 and 4. Panel statistics, comprising P_a and P_t, are represented by Eqs. 5 and 6, where variables remained as earlier defined. The application of this test has been substantially reported in the literature as it is designed to accommodate cross-sectional dependency in a panel study (Shahbaz et al. 2018b; Le and Ozturk 2020; Alola et al. 2019; Nathaniel et al. 2020).

The Westerlund (2007) cointegration test outputs in Table 6 provide enough evidence of cointegration among the variables while taking into cognizance the concerns about cross-sectional dependence as the probability values for the rejection of a null of an absence of a cointegration relationship is significant at the 1% level for the group statistics and the 5% significance level for the panel statistics, respectively.

3.2 Panel estimations

Following the circumstances surrounding the results in Sect. 4.2, the panel estimators for the study should consequently take into cognizance the concerns on cross-sectional dependence. Hence, we applied three robust techniques that are designed to accommodate the latter concern for the study. The Augmented Mean Group (AMG) heterogeneous panel estimator of Eberhardt and Bond (2009) and Eberhardt and Teal (2010), and the advanced Common Correlated Effect Mean Group (CCEMG) panel estimator of Kapetanios et al. (2011) as initially developed by Pesaran (2006) were utilized in the study following Eqs. 7 and 8, respectively:

$$\Delta Y_{it} = \alpha_i + \beta_i \Delta X_{it} + \sum\nolimits_{t=1}^{T}\pi_t D_t + \varphi_i \mathrm{UCF}_t + \mu_{it}, \tag{7}$$

$$Y_{it} = \alpha_i + \beta_i X_{it} + \gamma_i Y^*{}_{it} + \delta_i X^*{}_{it} + \theta_i \mathrm{UCF}_t + \mu_{it}. \tag{8}$$

From the CCEMG expression in Eq. 8, Y^* and X^* represent the mean values of the variables Y_{it} and X_{it} alongside the unobserved common effects while D is a time variant dummy variable in Eq. 7. The OLS estimation of the differenced Eq. 7 is utilized to generate the AMG estimator as given in Eq. 9, where φ_i denotes the estimated slope parameters of the X_{it} variable in Eq. 7:

$$\mathrm{AMG} = \frac{1}{N}\sum_{i=1}^{N} \varphi_i. \tag{9}$$

We also reported the linear regression estimates with Driscoll–Kraay (DK) standard errors while conducting a robustness check for multicollinearity through the variance inflation factor (VIF) as reported in Table 9 in Appendix. A combination of these approaches has been noted to be very efficient in producing robust estimates especially when cross-sectional dependence issues have to be accommodated in a panel analysis (Hoechle 2007; Zhang and Lin 2012; Le and Ozturk 2020; Adedoyin et al. 2021; Appiah et al. 2022; Agboola et al. 2022; Bamidele et al. 2022). Table 7 presents the coefficients from the estimators.

From Table 7, the adopted estimators namely the AMG, the CCEMG, and the Driscoll–Kraay approach produced relatively close results on the average, with little difference that are only observed in terms of the magnitudes of estimated coefficients and their corresponding levels of statistical significance. Both economic globalization and renewable energy consumption (Table 7) were significant for achieving positive result on the quest for cleaner environment among the E7 economies as these two variables have a significant negative impact on the level of carbon emission in these economies. The current findings from this study complement the results from contemporary studies on the possible ameliorating impact of globalization on carbon emission among countries (Zaidi et al. 2019; Saud et al. 2020; Bekun et al. 2021a; Gyamfi et al. 2021a; Onifade et al. 2021a, b; Ohajionu et al. 2021; Steve et al. 2022). Increasing renewable energy consumption is a well-known propelling force for a quality environment and it is worthy to note that economic globalization is expected to be an influential driver of this force among the understudied E7 economies. In addition, in line with a priori expectation, the empirical results also provide evidence that the level of non-renewable energy consumption on the other hand has a positive and significant impact on CO_2 emission for the panel of the E7 economies.

However, the results in Table 7 again show that the level of institutional quality plays a significant role in exacerbating carbon emission among the E7 economies given that the institutional quality proxy (I) emerged with a positive significant coefficient. In a nutshell, this result calls for more attention on the crucial roles of transparency, accountability, and the fight against corruption in the public sector in attaining a desirable sustainable environment. It would require not just economic globalization alone, but also a better institutional quality level to push for an environmentally friendly agenda while enhancing sustainable income growth that can foster renewable energy consumption among the E7 economies.

Table 7 AMG, CCEMG and Driscoll–Kraay result

	Y	Y^2	ICT	INSQ	EG	*R*	FF	R^2	Wald test	No. group	No. Obs
AMG	0.735b	−7.750c	0.030c	0.043b	−0.064a	−0.001c	1.392b		19.58a	7	154
p-value	(0.045)	(0.062)	(0.091)	(0.020)	(0.006)	(0.088)	(0.012)		(0.006)		
CCEMG	0.690b	−1.270c	0.003c	0.054c	−0.039b	−0.082b	2.179a		45.43a	7	154
p-value	(0.011)	(0.074)	(0.052)	(0.076)	(0.033)	(0.038)	(0.000)		(0.000)		
Driscoll–Kraay	1.040a	−7.510b	0.245a	0.468b	−0.688a	−0.970a	0.787c	0.675	304.43a	7	154
p-value	(0.000)	(0.047)	(0.000)	(0.027)	(0.000)	(0.000)	(0.065)		(0.000)		

[a] 0.01, [b]0.05 and [c]0.10 denotes statistical rejection level at 1%, 5% and 10%, respectively

Furthermore, on the income aspects of the study presented in Table 7 above, the results reflect a cushioning role of income growth on carbon emission among the E7 economies. As the impacts of income level (Y), and growth in income level (Y^2) are positive and negative, respectively, the empirical findings support the inverted U-shape assumption that substantiates the validity of the environmental Kuznets curve (EKC) for the E7 economies. Economic expansion that translates to higher income levels among these nations is expected to assist in pushing these economies towards environmental sustainability. This affirms the findings of Gyamfi et al. 2021b, c and Bekun et al. 2021b, c.

Internet use is ideal for ecological analysis since it is a reliable predictor in environmental studies. According to this analysis, the utilization of internet might emit carbon dioxide in the environment as a rise in internet consumption increases CO_2 emission within the E7. This result is justifiable considering that there is a wide usage of web technology in E7 economies. This web of technological equipment used within the E7 nations consumes heavy energy which is largely not environmentally friendly. Another possible explanation is that E7 includes countries that primarily have most use of e-service and innovations. Owing to excessive usage of the internet, the resources used would be inappropriate. This result agrees with other research undertaken to shape policy guidelines of different studies related to economic and financial policies. Results are not in line with research conducted by Zhang and Liu (2015) for China, Salahuddin and Alam (2015) for Australia, Sarpong et al. (2020) for Southern Africa region and Gyamfi et al. (2021d) for E7 countries.

3.3 Granger causality

The estimates from the combined panel estimators that is applied in the study may not necessarily reflect the direction of causality among the variables, thus, we provide a causality test report for the variables in the present study following the importance of this test in various empirical studies (Saint Akadiri et al. 2019; Onifade et al. 2020; Alola and Kirikkaleli 2019; Çoban et al. 2020). We report the Dumitrescu and Hurlin (2012) Granger causality test for the study:

$$Y_{it} = \delta_i + \sum\nolimits_{k=1}^{p} \beta_{1ik} Y_{i,t-k} + \sum\nolimits_{k=1}^{p} \beta_{2ik} X_{i,t-k} + \varepsilon_{it}. \quad (10)$$

From Eq. 10, β_{2ik} and β_{1ik} denote the regression coefficients and the autoregressive parameters for individual panel variable i at time t, respectively. Following the assumption of a balance panel of observation for the variable Y_{it} and X_{it} in the study, the null hypothesis of absence of causality among variables was tested against the alternative hypothesis of heterogeneous causality in the panel observation. The Granger causality results is provided in Table 8 while an annotated diagrammatical representation of the overall empirical scheme, based on the adopted econometric outcomes is detailed out in Fig. 1 in Appendix.

Outcome from Table 8 shows that both income and its square have a feedback causal relationship with carbon emissions. Also, economic globalization, institutional quality, ICT and clean energy all have one-way directional causal relationship with carbon emission while there is no causal relationship between fossil fuel and carbon emission.

Table 8 Dumitrescu and Hurlin causality analysis

Null hypothesis:	*W*-Statistic	*p*-value	Causal remarks
$Y \rightarrow CO_2$	5.023b	(0.0265)	Feedback
$CO_2 \rightarrow Y$	25.475a	(1.E−06)	
$Y^2 \rightarrow CO_2$	1.226c	(0.0965)	Feedback
$CO_2 \rightarrow Y^2$	3.699b	(0.0273)	
$ICT \rightarrow CO_2$	0.015	(0.9002)	One-way
$CO_2 \rightarrow ICT$	0.003	(0.9543)	
$INSQ \rightarrow CO_2$	4.459b	(0.0364)	One-way
$CO_2 \rightarrow INSQ$	0.049	(0.8239)	
$EG \rightarrow CO_2$	6.587b	(0.0113)	One-way
$CO_2 \rightarrow EG$	2.221	(0.1383)	
$R \rightarrow CO_2$	1.819	(0.1795)	One-way
$CO_2 \rightarrow R$	5.072b	(0.0258)	
$FF \rightarrow CO_2$	2.051	(0.1543)	No causality
$CO_2 \rightarrow FF$	0.978	(0.3243)	

[a] 0.01, [b]0.05 and [c]0.10 denotes statistical rejection level at 1%, 5% and 10%, respectively

4 Conclusion

Following the UN-SDG-13 crusade to reduce climate change impact, this study explores this topical issue by investigating the effect of ICT, institutional quality, economic globalization and renewable energy consumption in the conventional EKC setting for E7 economies from 1995 to 2016. This study leverages on second-generational modeling methodology that corrects for cross-sectional dependence and heterogeneity to achieve the soundness of empirical findings. To this end, we used Augmented Mean Group, Common Correlated Effects Mean Group estimator; Driscoll–Kraay and Dumitrescu and Hurlin causality tests. The Westerlund cointegration analysis affirms the existence of a long-run bond between the studied highlighted variables. That is, jointly, income level and its quadratic form, economic globalization, and institutional quality explain the extent of environmental degradation in E7 economies.

This study result affirms the EKC phenomenon in E7. The plausible explanation for this finding resonates with the bloc as the emerging and industrialized economies where economic activities are operated without environmental sustainability in view. This suggests that emphasis is placed on economic expansion relative to the bloc quality of the environment. We also observed from the empirical results that fossil fuel-based energy also contributes to dampen the environment. Furthermore, the bloc shows that the institutional level is still not sufficient to spur a clean environment. The quality of intuitional and commitment in E7 economies are weak relative to her counterpart G7 economies where rule of law and other institutional apparatus are reinforced to maintain environmental sustainability. Interestingly, our study shows that economic globalization and renewable energy consumption improve the quality of the environment. This connotes that environmental consciousness is creeping into the blocs amidst a wave of global and economic interconnectedness. The need for a transition to renewables such as hydro energy, photovoltaic, biomass among others, which are known to be cleaner and ecosystem friendly, should be pursued in earnest. It was also found from the outcome that ICT usage contributes more to environmental degradation within the bloc.

5 Policy direction

This study further highlighted policy prescriptions in the light of the study's outcomes. The policy suggestion includes:

(i) The E7 economies are encouraged to pursue more commitment to build ICT infrastructure and technologies that engender clean production processes in the bloc. In order to accomplish clean-ICT development, E7 economies should concentrate on the most polluting industries such as travel, industry and buildings. In the field of manufacturing, ICT can be used to maximize capital usage in industrial development operations, conserve electricity, and boost efficiency. There should be a comprehensive plan for E7 to leverage on emerging technologies to improve quality of transportation. ICT could perhaps be utilized for economic and environmental purposes.

(ii) The implication of the EKC in E7 means that the bloc needs to minimize environmental degradation on its trajectory for an enhanced average income level. Given that this bloc is still very much emerging on its growth path, there is need to fortify the institutional apparatus needed to enact effective environmental strategies and regulations to achieve environmental sustainability without compromise for economic development.

(iii) The need for a transition to renewables is pertinent given the advantages of a cleaner environment. As such, there should be concerted efforts on the part of all stakeholders, government officials for a paradigm shift to clean energy technologies by substituting the bloc's share of her energy mix from conventional energy of fossil-fuel to clean energy sources.

(iv) Conclusively, the need to reduce environmental degradation activities should be pursued by the bloc. Measures such as tree planting in mitigating the effect of deforestation can be considered, inter alia.

5.1 Limitation and future recommendations

This study investigated the applicability of the EKC phenomenon and ICT for the E7. However, due to the lack of data available, it is not possible to incorporate governance actions and traditional indicators into the CO_2 emission equation for E7 currently. These variables may have varying degrees of influence on the environment and the economy. Cultural events and governance factors (as measured by political, socioeconomic, and economic data) have a great deal of potential to play a significant role in a country's total reserves, economic expansion, natural resources, financial deepening, technical development, and the effective operation of its human capital. As a suggestion for further studies, other scholars can extend the EKC argument by accounting for covariates such as population, urbanization in an asymmetric framework for other blocs like the Middle East and North Africa (MENA), sub-Saharan Africa, inter alia, using disaggregated data.

Appendix

See Table 9.

Table 9 VIF estimations table

Variables	VIF	1/VIF
Y	1.26	0.795
INSQ	1.49	0.672
EG	1.72	0.580
R	1.99	0.503
FF	1.87	0.534
ICT	1.93	0.548
Mean VIF	1.71	

The VIF estimation results confirm the absence of multi-collinearity problems as the values all fall below 10

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Many thanks in advance look forward to your favourable response
Yours truly,
Authors

Author contributions
The first authors BAG was responsible for the conceptual construction of the study's idea. Second author SAA handled the literature section while third authors FVB managed the data gathering. Also, ABA managed analysis and was responsible for proofreading and manuscript editing. All authors read and approved the final manuscript.

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Availability of data and materials
The data for this present study are sourced from WDI (World Bank Open Data|Data) as outlined in the data section.

Declarations

Competing interests
We wish to disclose here that there are no potential conflicts of interest at any level of this study.

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