

A G D I Working Paper

WP/22/052

Can Information and Communication Technology and Institutional Quality help mitigate climate change in E7 economies? An Environmental Kuznets Curve extension

Forthcoming: Journal of Economic Structures

Bright A. Gyamfi

Faculty of Economics and Administrative Sciences,
Cyprus International University
Nicosia, North Cyprus, Via Mersin 10, Turkey.
Email: brightgyamfi1987@gmail.com

Asiedu B. Ampomah

Faculty of Economics and Administrative Sciences
Cyprus International University
Nicosia, North Cyprus, via Mersin 10, Turkey
Email: asieduampomab@gmail.com

Festus V. Bekun¹

Faculty of Economics Administrative and Social sciences,
Istanbul Gelisim University, Istanbul, Turkey
&
Adnan Kassar School of Business, Department of Economics
Lebanese American University, Beirut, Lebanon
&
Faculty of Economics and commerce,
The Superior University Lahore, Pakistan
Email: fbekun@gelisim.edu.tr

Simplice A. Asongu

School of Economics, University of Johannesburg,
Johannesburg, South Africa
E-mails: asongusimplice@yahoo.com, asongus@afridev.org

¹Corresponding authors: Festus Victor Bekun; fbekun@gelisim.edu.tr

Research Department

Can Information and Communication Technology and Institutional Quality help mitigate climate change in E7 economies? An Environmental Kuznets Curve extension**Bright A. Gyamfi, Asiedu B. Ampomah, Asiedu B. Ampomah, Festus V. Bekun & Simplicie A. Asongu****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 economic growth, institutional quality and information and communication technology (ICT) have on CO₂ 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 –2016 for our analysis achieved significant outcome. From the empirical analysis, economic globalization and renewable energy consumption both reduce CO₂ 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 inverted 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 CO₂ 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 CO₂ emission anthropogenic practices (Rogelj and Schleussner, 2019). In particular, CO₂ 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 & 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 CO₂ pollution, 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 CO₂ pollution. Different nations which have marginally higher income including Thailand, Indonesia as well as Philippines, usually experience slower economic development due to their higher CO₂ emission levels. Global trade is a channel that plays a crucial role in the development of nations' ecosystems. According to Shahbaz et al. (2018), 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.

Investments 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 CO₂ emission can be minimized via the ICT sector (Elumbanet al., 2016; Asongu et al., 2018). CO₂ 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 CO₂ 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, CO₂ 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 CO₂ emissions caused by associated energy consumption. Efficient measures need to be taken to control CO₂ emission which is consistent with engaging labour force that uses modern technology that has a negative impact on the economy.

Institutional quality has a significant impact on CO₂ 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 regards 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 CO₂ emission control procedure as well as oversees 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 CO₂ emissions.

Two schools of thought have emerged from the literature on the linkage between CO₂ emission and ICT. While a strand of the literature argues that ICT increases CO₂ emissions, another group of extant researchers argues that ICT helps to reduce CO₂ 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 (Coroma et al., 2014). Financial industries should incorporate environmentally friendly technologies in order to minimize the environmental degradation that occurs during production (Amri et al., 2019).

The closest study in the literature to the present exposition is Asongu et al. (2018) which has assessed how enhancing ICT affects CO₂ emissions in Sub-Saharan Africa (SSA) to conclude that CO₂ 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 CO₂ 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 E7². In 2017, all of the countries highlighted in the E7 bloc were within the top 25 nations accounting for global CO₂ emissions. China 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 3rd, whereas Russia produced 1692.8 million metric tons, placing it in 4th position. Mexico was eleventh, 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 CO₂ emissions amounting to 447.9 million metric tons (see www.usato.com). With these E7 CO₂ emissions figures, we may infer that the E7 economies are responsible for generating a significant amount of CO₂ 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 amongst ICT, economic globalization, institutional quality and CO₂ 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

²E7 Countries: Group of seven industrialised economies that comprise Brazil, Russia, India, China, Indonesia, Mexico and Turkey, which are all mostly emerging and newly industrialized nations.

institutional quality and economic globalization in mitigating CO₂ 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 Section 2. The analysis of the econometric methods and description are outlined in Section 3. Section 4 focuses on the empirical result and discussion. The final section presents the conclusion and recommendations.

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; Asongu et al., 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.

Emri (2019) conducted a study in Tunisia using ICT, total factor efficiency and CO₂ variables. The study found that ICT had great impact on CO₂ discharges 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 CO₂ and commercial progress in designated G-20 countries. In the first place, there were only five obstacles that hinder CO₂ 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 Emri (2018) examined the linkage between CO₂ 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 CO₂ in the long run affects institutional quality and GDP positively impacted CO₂. Relatively, FDI and ICT showed a negative impact on CO₂ emissions. Furthermore, the same study depicted that financial development and CO₂ negatively impacted CO₂. 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 CO₂ 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 CO₂. The result depict that ICT significantly impacts CO₂ 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 forty-four countries in Africa. The outcome indicated ICT use reduces CO₂ emissions. Majeed (2018) experientially tested the consequence of ICT know-how on emissions reduction in developing countries. The research analyzed two hundred and thirty-two 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 CO₂ emissions. Lau et al. (2014) stressed that institutional quality is crucial in minimizing CO₂ emissions. Lv et al. (2018) stressed that, better institutional quality strategies ensure environmental quality. Amri (2018) found causality amid CO₂emissions, 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 CO₂emissions for distinct twelve Asian countries. Shabani et al. (2019) found unidirectional causation from energy intake, ICT to CO₂ emissions using a horizontal approach. Their finding was closely aligned with Arhad (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 CO₂ 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 amongst ICT, monetary globalization, institutional quality and CO₂emissions 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 CO₂.

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 of China, India, Brazil, Mexico, Russia, Indonesia, and Turkey. The data are sourced from the World Bank's development indicators from 1995- 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 equation 1;

$$\begin{aligned} LnCO_{2it} = & \alpha_0 + \alpha_1 LnY_{it} + \alpha_2 LnY^2_{it} + \alpha_4 \alpha_3 LnICT_{it} + \alpha_4 LnINSQ_{it} + \alpha_5 LnEG_{it} + \alpha_6 LnR_{it} \\ & + \alpha_7 LnFF_{it} + \varepsilon_{it} \quad (1) \end{aligned}$$

Data spanning from 1995 through 2016 was 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 description of variables in Eq. 1 is presented with measurement scales and symbols in Table 1.

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

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 world³.

3.2 Data Analysis

Varying degrees of relationship are expected among the variables in Equation 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.

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	16.279 a	18.568 a	9.477	13.911 a	3.028b	23.516 a	14.608 a	17.626 a
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

Note a=0.01, b=0.05 and c=0.01

³<https://www.bing.com/ck/a?!&&p=b6b733b87fe5594bec376ff3d27906e19332c9ef44855ee59a6bf9b3bc87de7bJmltdHM9MTY1NTM3MzAxOSZpZ3VpZD01MDQ1YzI4Yy1jNDIhLTQ5YzctYTJIMS01NTIkYzJkOWIzMTkmaW5zaWQ9NTE1NA&pntn=3&fclid=bb071c97-ed59-11ec-8d25-20ce53457b3d&u=a1aHR0cHM6Ly9ibG9ncy53b3JsZGJhbmsub3JnL2VuZHBvdmdVydHlpbmNvdXRoYXNpYS93aHktaWN0LWluZm9ybWF0aW9uLWFuZC1jb21tdW5pY2F0aW9uLXRlY2hub2xvZ2llcy1hbmQtd2h5LW5vdw&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)	-

Note a=0.01, b=0.05 and c=0.01

As it can be seen from 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 CO₂emission 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 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 proves that, income and economic globalization have positively significant relationships with CO₂ emission, but ICT, institution quality, clean energy and fossil fuel all have positive significant correlations with CO₂ 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 following the application of Breusch and Pagan (1980) LM Test and Pesaran (2015) LM Test.

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)

Note a=0.01, b=0.05 and c=0.01

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 (Gyamfi et al. 2020; 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: 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

Note a=0.01, b=0.05 and c=0.01

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:

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

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 group mean statistics $G\tau$ and $G\alpha$ follows the derivations from the expressions in Eq. 3 and Eq.4;

$$G\tau = \frac{1}{N} \sum_{i=1}^N \frac{\hat{\alpha}_i}{SE(\hat{\alpha}_i)} \quad (3)$$

$$G\alpha = \frac{1}{N} \sum_{i=1}^N \frac{T^{\wedge} \alpha i}{\wedge \alpha i(1)} \quad (4)$$

Where, $\wedge \alpha i$ is denoted by $SE(\wedge \alpha i)$ as the standard error. The semiparametric kernel technique of $\alpha i(1)$ is $\wedge \alpha i(1)$.

$$P_T = \frac{\hat{\alpha}}{SE(\hat{\alpha})} \quad (5)$$

$$P_{\alpha} = T\hat{\alpha} \quad (6)$$

The two remaining panel mean estimations which prove that the entire panel is co-integrated are shown in Eq. 5 and Eq. 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).

Table 6: Westerlund Cointegration Test

Statistics	Value	p-value
$G\tau$	-2.120a	(0.001)
$G\alpha$	-1.651a	(0.000)
$P\tau$	-4.172b	(0.015)
$P\alpha$	-2.443b	(0.026)

Note a=0.01, b=0.05 and c=0.01

The Westerlund (2007) cointegration test outputs in Table 6 provides 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.

3.3 Panel Estimations

Following the circumstances surrounding the results in section 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 Eq. 7 and Eq. 8, respectively:

$$\Delta Y_{it} = \alpha_i + \beta_i \Delta X_{it} + \sum_{t=1}^T \pi_t D_t + \varphi_i UCF_t + \mu_{it} \quad (7)$$

$$Y_{it} = \alpha_i + \beta_i X_{it} + \gamma_i Y^*_{it} + \delta_i X^*_{it} + \theta_i UCF_t + \mu_{it} \quad (8)$$

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 the 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.

$$AMG = \frac{1}{N} \sum_{i=1}^N \varphi_i \quad (9)$$

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 the 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.

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	-7.750 ^c	0.030 ^c	0.043 ^b	-0.064 ^a	-0.001 ^c	1.392 ^b		19.58 ^a	7	154
P-value	(0.045)	(0.062)	(0.091)	(0.020)	(0.006)	(0.088)	(0.012)		(0.006)		
CCEMG	0.690b	-1.270 ^c	0.003 ^c	0.054 ^c	-0.039 ^b	-0.082 ^b	2.179 ^a		45.43 ^a	7	154
P-value	(0.011)	(0.074)	(0.052)	(0.076)	(0.033)	(0.038)	(0.000)		(0.000)		
Driscoll-Kraay	1.040a	-7.510 ^b	0.245 ^a	0.468 ^b	-0.688 ^a	-0.970 ^a	0.787 ^c	0.675	304.43 ^a	7	154
P-value	(0.000)	(0.047)	(0.000)	(0.027)	(0.000)	(0.000)	(0.065)		(0.000)		

Note: a=0.01, b=0.05 and c=0.01

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 2021; 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 CO₂ 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.

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, Gyamfi et al 2021c, Bekun et al 2021b and Bekun et al 2021c.

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 CO₂ pollution 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, Alam and Salahuddin (2015) for Australia, Sarpong et al (2020) for Southern Africa region and Gyamfi et al (2021d) for E7 countries.

3.4 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.

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

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 Figure 1 in the Appendix.

Table 8. Dumitrescu and Hurlin Causality Analysis

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

Note $\alpha=0.01$, $\beta=0.05$ and $\gamma=0.01$

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.

4.1 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 intuition 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.

4.2 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*.

4.3 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 CO₂ 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-Sahara Africa, *inter alia*, using disaggregated data.

References

- Abid M (2017). Does economic, financial and institutional developments matter for environmental quality? A comparative analysis of EU and MEA countries. *J Environ Manag* 188:183–194. <https://doi.org/10.1016/j.jenvman.2016.12.007>.
- Adedoyin, F. F., Bein, M. A., Gyamfi, B. A., & Bekun, F. V. (2021). Does agricultural development induce environmental pollution in E7? A myth or reality. *Environmental Science and Pollution Research*, 28(31), 41869-41880.
- Adebayo, T. S., Agyekum, E. B., Altuntaş, M., Khudoyqulov, S., Zawbaa, H. M., & Kamel, S. (2022). Does information and communication technology impede environmental degradation? fresh insights from non-parametric approaches. *Heliyon*, 8(3), e09108.
- Adebayo, T. S., & Kirikkaleli, D. (2021). Impact of renewable energy consumption, globalization, and technological innovation on environmental degradation in Japan: application of wavelet tools. *Environment, Development and Sustainability*, 23(11), 16057-16082.
- Agboola, P. O., Hossain, M., Gyamfi, B. A., & Bekun, F. V. (2022). Environmental consequences of foreign direct investment influx and conventional energy consumption: evidence from dynamic ARDL simulation for Turkey. *Environmental Science and Pollution Research*, 1-14.
- Alola, A. A., & Kirikkaleli, D. (2019). The nexus of environmental quality with renewable consumption, immigration, and healthcare in the US: wavelet and gradual-shift causality approaches. *Environmental Science and Pollution Research*, 26(34), 35208-35217.
- Alola, A. A., Eluwole, K. K., Alola, U. V., Lasisi, T. T., & Avci, T. (2019). Environmental quality and energy import dynamics. *Management of Environmental Quality: An International Journal*.
- Amri et al., (2019). ICT, total factor productivity, and carbon dioxide emissions in Tunisia. *Technological forecast and social change*. 146, 212-217.
- Amri, F. (2018). Carbon dioxide emissions, total factor productivity, ICT, trade, financial development, and energy consumption: testing environmental Kuznets curve hypothesis for Tunisia. *Environmental Science and Pollution Research*, 25(33), 33691-33701.
- Appiah, M., Gyamfi, B. A., Adebayo, T. S., & Bekun, F. V. (2022). Do financial development, foreign direct investment, and economic growth enhance industrial development? Fresh evidence from Sub-Sahara African countries. *Portuguese Economic Journal*, 1-25.
- Arshad, Z., M. Robaina, and A. Botelho. 2020. The role of ICT in energy consumption and environment: An empirical investigation of Asian economies with cluster analysis. *Environmental Science and Pollution Research* 27 (1):1–20.
- Asongu SA (2018) ICT, openness and CO2 emissions in Africa. *Environ SciPollutRes* 25(10):9351–9359.

- Asongu, S. A., Le Roux, S., & Biekpe, N. (2017). Environmental degradation, ICT and inclusive development in Sub-Saharan Africa. *Energy Policy*, 111, 353-361.
- Asongu, S. A., Le Roux, S., & Biekpe, N. (2018). Enhancing ICT for environmental sustainability in sub-Saharan Africa. *Technological Forecasting and Social Change*, 127, 209-216.
- Asongu, S., El Montasser, G., & Toumi, H. (2016). Testing the relationships between energy consumption, CO₂ emissions, and economic growth in 24 African countries: a panel ARDL approach. *Environmental Science and Pollution Research*, 23(7), 6563-6573.
- Bakhsh, K., Rose, S., Ali, M. F., Ahmad, N., & Shahbaz, M. (2017). Economic growth, CO₂ emissions, renewable waste and FDI relation in Pakistan: New evidences from 3SLS. *Journal of environmental management*, 196, 627-632.
- Bamidele, R., Ozturk, I., Gyamfi, B. A., & Bekun, F. V. (2022). Tourism-induced pollution emission amidst energy mix: evidence from Nigeria. *Environmental Science and Pollution Research*, 29(13), 19752-19761.
- Bekun, F. V., Alola, A. A., Gyamfi, B. A., & Ampomah, A. B. (2021a). The environmental aspects of conventional and clean energy policy in sub-Saharan Africa: is N-shaped hypothesis valid?. *Environmental Science and Pollution Research*, 28(47), 66695-66708.
- Bekun, F. V., Alola, A. A., Gyamfi, B. A., & Yaw, S. S. (2021b). The relevance of EKC hypothesis in energy intensity real-output trade-off for sustainable environment in EU-27. *Environmental Science and Pollution Research*, 28(37), 51137-51148.
- Bekun, F. V., Gyamfi, B. A., Onifade, S. T., & Agboola, M. O. (2021c). Beyond the environmental Kuznets Curve in E7 economies: accounting for the combined impacts of institutional quality and renewables. *Journal of Cleaner Production*, 314, 127924.
- Bekun, F. V. (2022). Mitigating emissions in India: accounting for the role of real income, renewable energy consumption and investment in energy. 12(1), pp. 188-192
- Benzie, M., & Persson, Å. (2019). Governing borderless climate risks: moving beyond the territorial framing of adaptation. *International Environmental Agreements: Politics, Law and Economics*, 19(4), 369-393.
- Bilgili, F., Koçak, E., Bulut, Ü., & Kuloğlu, A. (2017). The impact of urbanization on energy intensity: Panel data evidence considering cross-sectional dependence and heterogeneity. *Energy*, 133, 242-256.
- Breusch, T., and A. Pagan. (1980). "The LM Test and Its Application to Model Specification in Econometrics." *Review of Economic Studies* 47: 239-254.
- Chien, F., Anwar, A., Hsu, C. C., Sharif, A., Razzaq, A., & Sinha, A. (2021). The role of information and communication technology in encountering environmental degradation: proposing an SDG framework for the BRICS countries. *Technology in Society*, 65, 101587.

- Cho, Y., J. Lee, and T. Y. Kim. (2007). The impact of ICT investment and energy price on industrial electricity demand: Dynamic growth model approach. *Energy Policy* 35 (9):4730–38. doi:10.1016/j.enpol.2007.03.030
- Çoban, O., Onifade, S.T., &Yussif, A. B. (2020). Reconsidering trade and investment-led growth hypothesis: new evidence from Nigerian economy. *Journal of International Studies*, 13(3), 98-110. doi:10.14254/2071-8330.2020/13-3/7
- Cortés, E. A., and J.-L. Navarro. (2011). Do ICT influence economic growth and human development in European Union countries? *International Advances in Economic Research* 17 (1):28–44. doi:10.1007/s11294-010-9289-5.
- De Hoyos, R. E., &Sarafidis, V. (2006). Testing for cross-sectional dependence in panel-data models. *The stata journal*, 6(4), 482-496
- Dogan, E., & Aslan, A. (2017). Exploring the relationship among CO2 emissions, real GDP, energy consumption and tourism in the EU and candidate countries: Evidence from panel models robust to heterogeneity and cross-sectional dependence. *Renewable and Sustainable Energy Reviews*, 77, 239-245.
- Dumitrescu EI, Hurlin C (2012) Testing for Granger non-causality in heterogeneous panels. *Econ Model* 29:1450–1460
- Eberhardt M, Bond S (2009) Cross-section dependence in nonstationary panel models: a novel estimator. Munich Personal RePEc Archive. <http://mpra.ub.uni-muenchen.de/17692/>
- Eberhardt M, Teal F (2010) Productivity analysis in global manufacturing production. Discussion Paper 515, Department of Economics, University of Oxford. <http://www.economics.ox.ac.uk/research/WP/pdf/paper515.pdf>
- Engelbrecht, H. J., &Xayavong, V. (2007). The elusive contribution of ICT to productivity growth in New Zealand: evidence from an extended industry-level growth accounting model. *Economics of Innovation and New Technology*, 16(4), 255-275.
- Erumban AA, Das DK (2016) Information and communication technology and economic growth in India. *Telecommun Policy* 40(5):412– 431
- Godil et al. (2020). The dynamic nonlinear influence of ICT, financial development, and institutional quality on CO2 emission in Pakistan: new insights from QARDL approach. *Environmental Science and Pollution Research* (2020) 27:24190–24200.
- Grossman, G. M., & Krueger, A. B. (1991). *Environmental impacts of a North American free trade agreement* (No. w3914). National Bureau of economic research.
- Gyamfi, B. A., Adebayo, T. S., Bekun, F. V., Agyekum, E. B., Kumar, N. M., Alhelou, H. H., & Al-Hinai, A. (2021a). Beyond environmental Kuznets curve and policy implications to promote sustainable development in Mediterranean. *Energy Reports*, 7, 6119-6129.
- Gyamfi, B. A., Adedoyin, F. F., Bein, M. A., & Bekun, F. V. (2021b). Environmental implications of N-shaped environmental Kuznets curve for E7 countries. *Environmental Science and Pollution Research*, 28(25), 33072-33082.

- Gyamfi, B. A., Adedoyin, F. F., Bein, M. A., Bekun, F. V., & Agozie, D. Q. (2021c). The anthropogenic consequences of energy consumption in E7 economies: juxtaposing roles of renewable, coal, nuclear, oil and gas energy: evidence from panel quantile method. *Journal of Cleaner Production*, 295, 126373.
- Gyamfi, B. A., Ozturk, I., Bein, M. A., & Bekun, F. V. (2021d). An investigation into the anthropogenic effect of biomass energy utilization and economic sustainability on environmental degradation in E7 economies. *Biofuels, Bioproducts and Biorefining*, 15(3), 840-851.
- Gygli, S., F. Hälg, N. Potrafke, and J.-E. Sturm (2019). The KOF Globalisation Index – revisited. *Review of International Organizations* 14 (3), 543–574.
- Hoechle, D. (2007). Robust standard errors for panel regressions with cross-sectional dependence. *The stata journal*, 7(3), 281-312.
- Kapetanios G, Pesaran MH, Yamagata T (2011) Panels with nonstationary multifactor error structures. *J Econ* 160:326–348
- Kasman, A., & Duman, Y. S. (2015). CO2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: a panel data analysis. *Economic modelling*, 44, 97-103.
- Khan, D., N. Khan, M. A. Baloch, S. Saud, and T. Fatima. (2018). The effect of ICT on CO2 emissions in emerging economies: Does the level of income matters? *Environmental Science and Pollution Research* 25 (23):22850–60. doi:10.1007/s11356-018-2379-2.
- Kretschmer, T. (2012). Information and communication technologies and productivity growth: a survey of the literature.
- Lau LS, Choong CK, Eng YK (2014) Carbon dioxide emission, institutional quality, and economic growth: empirical evidence in Malaysia. *Renew Energy* 68:276–281.
- Le H.P. and Ozturk I. (2020) “The impacts of globalization, financial development, government expenditures, and institutional quality on CO2 emissions in the presence of environmental Kuznets curve” *Environmental Science and Pollution Research* 27:22680-22697 <https://doi.org/10.1007/s11356-020-08812-2>.
- Lu, W. C. (2018). The impacts of information and communication technology, energy consumption, financial development, and economic growth on carbon dioxide emissions in 12 Asian countries. *Mitigation and Adaptation Strategies for Global Change*, 23(8), 1351-1365.
- Lv Z, Xu T (2018) Is economic globalization good or bad for the environmental quality? New evidence from dynamic heterogeneous panel models. *Technol Forecast Soc Chang* 137:340– 343
- Magazzino, C., Porrini, D., Fusco, G. and Schneider, N. (2021). Investigation the link between ict, electricity consumption air pollution, economic growth in Eu countries. *Energy Sources, Part B: Economics, Planning, And Policy* <https://doi.org/10.1080/15567249.2020.1868622>.

- Majeed MT (2018) Information and communication technology (ICT) and environmental sustainability: a comparative empirical analysis, *Pakistan Journal of Commerce and Social Sciences (PJCSS)*, ISSN 2309-8619, Johar Education Society, Pakistan (JESPK). Lahore 12(3):758–783.
- Nathaniel, S. P., Nwulu, N., & Bekun, F. (2020). Natural resource, globalization, urbanization, human capital, and environmental degradation in Latin American and Caribbean countries. *Environmental Science and Pollution Research*, 1-15.
- Nguyen, T. T., Pham, T. A. T., & Tram, H. T. X. (2020). Role of information and communication technologies and innovation in driving carbon emissions and economic growth in selected G-20 countries. *Journal of environmental management*, 261, 110162.
- Ohajionu, U. C., Gyamfi, B. A., Haseki, M. I., & Bekun, F. V. (2022). Assessing the linkage between energy consumption, financial development, tourism and environment: evidence from method of moments quantile regression. *Environmental Science and Pollution Research*, 29(20), 30004-30018.
- Onifade, S. T., Alola, A. A., Erdoğan, S., & Acet, H. (2021b). Environmental aspect of energy transition and urbanization in the OPEC member states. *Environmental Science and Pollution Research*, <https://doi.org/10.1007/s11356-020-12181-1>
- Onifade, S. T., Çevik, S., Erdoğan, S., Asongu, S., & Bekun, F. V. (2020). An empirical retrospect of the impacts of government expenditures on economic growth: new evidence from the Nigerian economy. *Journal of Economic Structures*, 9(1), 6.
- Onifade, S. T., Gyamfi, B. A., Haouas, I., & Bekun, F. V. (2021). Re-examining the roles of economic globalization and natural resources consequences on environmental degradation in E7 economies: are human capital and urbanization essential components?. *Resources Policy*, 74, 102435.
- Ozcan, B., & Ozturk, I. (2019). Renewable energy consumption-economic growth nexus in emerging countries: A bootstrap panel causality test. *Renewable and Sustainable Energy Reviews*, 104, 30-37.
- Özokcu, S., & Özdemir, Ö. (2017). Economic growth, energy, and environmental Kuznets curve. *Renewable and Sustainable Energy Reviews*, 72, 639-647.
- Park. Y., Baloch, M. and Baloch (2018). The effect on ICT, financial development, growth and trade openness on co2 emissions; an empirical study. *Environmental Science and Pollution Research* 25:30708–30719. <https://doi.org/10.1007/s11356-018-3108-6>.
- Pesaran MH (2006) Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica* 74:967–1012
- Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross section dependence. *Journal of Applied Econometrics*, 22(2), 265–312.
- Pesaran, M.H., (2015). Testing weak cross-sectional dependence in large panels. *Econom. Rev.* 34 (6–10), 1089–1117

- Raheem, I.D., Tiwari, A.K. and Balsalobre-Lorente, D. (2020). The role of ICT and financial development in CO2 and economic growth. *Environmental Science and Pollution Research* (2020) 27:1912–1922 <https://doi.org/10.1007/s11356-019-06590-0>
- Raworth, K. (2017). *Doughnut economics: seven ways to think like a 21st-century economist*. Chelsea Green Publishing.
- Rogelj, J., & Schleussner, C. F. (2019). Unintentional unfairness when applying new greenhouse gas emissions metrics at country level. *Environmental Research Letters*, 14(11), 114039.
- Sadorsky, P. (2012). Information communication technology and electricity consumption in emerging economies. *Energy Policy* 48:130–36. doi:10.1016/j.enpol.2012.04.064.
- Saint Akadiri, S., Bekun, F. V., & Sarkodie, S. A. (2019). Contemporaneous interaction between energy consumption, economic growth and environmental sustainability in South Africa: what drives what?. *Science of the total environment*, 686, 468-475.
- Salahuddin, M., and K. Alam. (2015). Internet usage, electricity consumption and economic growth in Australia: A time series evidence. *Telematics and Informatics* 32 (4):862–78. doi:10.1016/j.tele.2015.04.011.
- Salahuddin, M., and K. Alam. (2016). Information and Communication Technology, electricity consumption and economic growth in OECD countries: A panel data analysis. *International Journal of Electrical Power & Energy Systems* 76:185–93. doi:10.1016/j.ijepes.2015.11.005.
- Sarpong, S. Y., Bein, M. A., Gyamfi, B. A., & Sarkodie, S. A. (2020). The impact of tourism arrivals, tourism receipts and renewable energy consumption on quality of life: A panel study of Southern African region. *Heliyon*, 6(11), e05351.
- Saud, S., Chen, S., & Haseeb, A. (2020). The role of financial development and globalization in the environment: Accounting ecological footprint indicators for selected one-belt-one-road initiative countries. *Journal of Cleaner Production*, 250, 119518.
- Shabani, Z. D., and R. Shahnazi. (2019). Energy consumption, carbon dioxide emissions, information and communications technology, and gross domestic product in Iranian economic sectors: A panel causality analysis. *Energy* 169:1064–78. doi:10.1016/j.energy.2018.11.062
- Shafik, N. (1994). Economic development and environmental quality: an econometric analysis. *Oxford economic papers*, 757-773.
- Shahbaz, M., Nasir, M. A., & Roubaud, D. (2018). Environmental degradation in France: the effects of FDI, financial development, and energy innovations. *Energy Economics*, 74, 843-857.
- Shahbaz, M., Shahzad, S. J. H., Mahalik, M. K., & Hammoudeh, S. (2018b). Does globalisation worsen environmental quality in developed economies? *Environmental Modeling & Assessment*, 23(2), 141-156.
- Shahbaz, M., Shahzad, S. J. H., Mahalik, M. K., & Sadorsky, P. (2018a). How strong is the causal relationship between globalization and energy consumption in developed

- economies? A country-specific time-series and panel analysis. *Applied Economics*, 50(13), 1479-1494.
- Sinha, A. (2018). Impact of ICT exports and internet usage on carbon emissions: a case of OECD countries 228-257.
- Sinha, A., Sengupta, T., & Alvarado, R. (2020). Interplay between technological innovation and environmental quality: formulating the SDG policies for next 11 economies. *Journal of Cleaner Production*, 242, 118549.
- Steve, Y. S., Murad, A. B., Gyamfi, B. A., Bekun, F. V., & Uzuner, G. (2022). Renewable energy consumption a panacea for sustainable economic growth: panel causality analysis for African blocs. *International Journal of Green Energy*, 19(8), 847-856.
- Wang, N., Zhu, H., Guo, Y., & Peng, C. (2018). The heterogeneous effect of democracy, political globalization, and urbanization on PM2. 5 concentrations in G20 countries: Evidence from panel quantile regression. *Journal of cleaner production*, 194, 54-68.
- Westerlund, J. (2007). "Testing for Error Correction in Panel Data." *Oxford Bulletin of Economics and Statistics* 69: 709–748.
- World Development Indicators, WDI (2020). <https://data.worldbank.org/> Accessed Jan 2021
- Zafar, M. W., Zaidi, S. A. H., Mansoor, S., Sinha, A., & Qin, Q. (2022). ICT and education as determinants of environmental quality: The role of financial development in selected Asian countries. *Technological Forecasting and Social Change*, 177, 121547.
- Zaidi, S. A. H., Zafar, M. W., Shahbaz, M., & Hou, F. (2019). Dynamic linkages between globalization, financial development and carbon emissions: Evidence from Asia Pacific Economic Cooperation countries. *Journal of Cleaner Production*, 228, 533-543.
- Zhang, C., & Lin, Y. (2012). Panel estimation for urbanization, energy consumption and CO2 emissions: A regional analysis in China. *Energy policy*, 49, 488-498.
- Zhang, C., & Liu, C. (2015). The impact of ICT industry on CO2 emissions: a regional analysis in China. *Renewable and Sustainable Energy Reviews*, 44, 12-19.

Declarations

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

Competing interests

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

Funding

We hereby declare that there is no form of funding received for this study.

Authors' contributions

The first authors Dr. Bright A. Gyamfi was responsible for the conceptual construction of the study's idea. Second author Prof. Dr. Simplice A. Asongu handled the literature section while third authors Dr. Festus Victor Bekun managed the data gathering. Also, Asiedu B. Ampomah managed analysis and was responsible for proofreading and manuscript editing.

Acknowledgements

Author gratitude is extended to the prospective editor(s) and reviewers that will/have spared time to guide toward a successful publication.

The Author of this article also assures that they follow the Springer publishing procedures and agree to publish it as any form of access article confirming to subscribe access standards and licensing.

Many thanks in advance look forward to your favourable response

Yours truly,

Authors

Authors' information (optional)

Nil

Appendix

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	

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