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RESEARCH ARTICLE

Does agricultural development induce environmental pollution in E7? A myth or reality

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Abstract
Environmental degradation caused by various human activities has been a subject of attention over the globe. There is a concern on how to maintain a clean environment and at the same time achieve optimum production of food and non-food products amidst global energy demand. To this end, this study examines the impact of agricultural development, energy use, and economic growth on CO_2 emissions in the emerging seven countries that comprises China, India, Brazil, Mexico, Russia, Indonesia, and Turkey for the annual time frequency from 1990 to 2016. The study uses a battery of econometrics techniques for soundness of analysis the consist of pooled mean group autoregressive distributed lag methodology, dynamic ordinary least squares, and fully modified ordinary least squares as estimation techniques alongside Dumitrescu and Hurlin causality test for the direction of causality analysis. Empirical results revealed that value-added agriculture and economic growth are drivers of CO_2 emission in the E7 countries, and the rise in renewable energy causes a reduction in CO_2 emissions, while in the short run, economic growth has a positive impact on emissions in the focus countries. Causality analysis shows that there is a feedback causality between economic growth and emissions, between value-added agriculture and energy usage, between emission and value-added agriculture, and between economic growth and agricultural development. Furthermore, energy use does not cause emissions directly; it causes economic growth and value-added agriculture which causes emissions. This position aligns with the advocacy of the United Nations Sustainable Development Goal (UN-SDG) Targets 7 and 13 of clean energy access and mitigation of climate changes issues.

Keywords Agricultural development · Energy consumption · Economic growth · CO_2 emissions · E7 countries

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Introduction

The Food and Agricultural Organization (2017) report states that for many developing, transition, and emerging economies, the key characteristics of global population growth, declining fertility rates, increasing standard of living, and protracted aging levels demonstrate that a substantial rise for inhabitants is expected to occur in anticipation of around the end of the 21st century. Over one-third of the world, inhabitants are subsistence focused on agriculture, and most are in Asia[1]. Consequently, the agriculture field remains dominant in all territories and plays a significant function throughout the sectors for development, notably in underdeveloped countries. Nonetheless, some areas, such as soil pollution, habitat destruction, resource scarcity, and habitat destruction, hold out as environmental and economic challenges and appeal for

[1] Food and Agriculture Organization of the United Nations (FAO) 2017

further infrastructure in agriculture sustainability (Balsalobre-Lorente et al. 2019).

The pioneering study of Kraft and Kraft (1978) outlined the pivotal role of energy to drive the gross national product of the USA. This assertion has been reinforced in the energy literature (Reynolds and Wenzlau 2012; Sinha and Sengupta 2019). In particular, the agriculture industry utilizes non-renewable power bases, such as fossil fuels, coal, fume and oil, and coke, for the operation of industrial machinery, for heating or cooling structures, and for providing lighting systems on the farm, and unintentionally for fertilizers, equipment, and pesticides manufactured out of the farm. As a result of its heavy use of fossil fuels, the ratio of the agriculture sector to global pollutant (GHG) production is roughly 14–30% (Balsalobre-Lorente et al. 2019).

Given the environmental implications and increasing questions about the ability of the agriculture sector to decrease GHG pollution, the usage of clean energy power has appeared as an essential aspect of global energy use. According to FAO (2016), 20% of GHG contributions from anaerobic decomposition in livestock, rice development in submerged areas through the use of NPK fertilizers in addition to waste are produced by cultivation, forestry in addition to the cultivation of land reform, contributing to anthropogenic greenhouse reform and greenhouse gases.

Best (1998) declared that attention in the development of agriculture ought to be driven by homegrown cultural, ecological, and communal requirements. Carbon strategy production will blend regional energy production strategies with geographically considered preferences. Focus ought to be put on non-fossil petroleum replacements for providing energy infrastructure in cultivation in emerging nations. Renewable energy techniques should be implemented in countless places around the realm for numerous farming implementations to mitigate greenhouse gas (CO_2) consumption from fossil fuels, minimize energy market uncertainty impact on the environment, and thereby improve economic development (Tiwari 2011; Shafiei and Salim 2014; Shahbaz et al. 2020).

Through the use of clean sources of energy, advancement in addition to enhancement of productivity potential in farming is of vital significance intended for sustainability development in emerging countries. The PWC study (2017) estimated that the global economy continues to expand at an estimated annual premier league experience of about 2.5% annually within 2016 and 2050. The trend, combining with a rise in energy consumption, will be fueled primarily by emerging nations such as the Emerging 7 nations commonly known as the E7 nations which are made up of Brazil, China, India, Indonesia, Mexico, Turkey, and Russia—rising next to an estimated yearly pace of about percentage of 3.5 during the subsequent 34 years, opposed to just approximately 1.6% for developed G-7 nations. Bloomberg's novel Power Finance Account (2016) also reported that emerging markets were for the first opportunities ahead of advanced nations within 2015 in expressions of actual fresh investments in clean power sources.

Capital expenditure in clean energy in Brazil, India, and China, which are the biggest 3 nation within the E7, rose by 16% of $120.2 billion in 2015, while other developed nations experienced a 30% boost in the direction of $36.1 billion (Aydoğan and Vardar 2020). The presence of an actual powerful clean power resource is identified as the core problem of economic development in farming as well as the extension of manufacturing of farm inputs for E7 states. Argument by Kaygusuz et al. (2007), Kaygusuz et al. (2007), Zafar et al. (2019), and Sinha et al. (2017) was based on the decision to encourage sustainable energy sources which will not only contribute to ever more restructuring of the power market, nonetheless but also help the fiscal performance in addition to corporate social responsibility goals of the various countries. Given the advent of renewable sources of energy in a potential discussion on clean energy in emerging countries, it is important to keep in mind the interactions regarding per capita CO_2 pollution and growth of the economy, value-added agriculture, and clean energy utilize across E7 countries over the timeframe 1990–2016 is the main motivation for this study

There have been good documented theoretical studies that investigate the relationship between environment, income, energy, and economic growth literature for several regions and countries. However, there has been no consensus on the empirical outcomes given the diverse econometrics modeling techniques, sample procedure, and much. There been vast theoretical studies such as (Soytas and Sari 2009; Bekun et al. 2019a, 2019b). The intuition of the carbon-income function is premised on the environmental Kuznets Curve phenomenon that expresses the relationship between environmental degradation and income level. Our study advances the arguments by augmenting the conventional liner carbon-income model with agriculture as a key determinant of GHGs for the case of E7. To this end, based on the literature trajectory the current study complements the extant literature by exploring the carbon-environment and economic growth nexus by augmenting the carbon-income function with the addition of energy consumption and agriculture as an additional determinant for pollutant emission for the case of E7 countries which has received less attention on the literature. This study employs robust and econometric analysis consistent with literature such as Pool mean group autoregressive distributed lag (PMG-ARDL), dynamic ordinal least square (DOLS), and full modified ordinary least square (FMOLS) for long-run regression among the outlined study variables while for detection of causality direction, Dumitrescu and Hurlin causality test is employed. Our study relies on a first-generation panel analysis on the premise of the Pesaran (2007) cross-sectional dependency (CD) test that is a common shock effect among the blocs investigated for robustness purposes as well as to avoid spurious analysis. The CD test result fails to support second-generation modeling; as such, we proceed with the first-generation panel estimator hereafter. The blocs investigated also share a common economic structure and characteristics, which makes valid the assumption of homogeneity in the panel investigated. As outlined by the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment report for conventional energy consumption, economic expansion is a key driver of anthropogenic pollutant emissions (Etokakpan et al. 2020; Blanco et al. 2014). Thus, our study is motivated by the United Nations (UN) Sustainable Development Goals (SDGs) and its influence that by 2030, pertinent issues that concern humans and its activities are addressed. To this end, our study variables are informed by the above-stated SDGs namely clean energy consumption (renewable energy consumption) (SDG-7), economic growth (SDG-8), responsible consumption (SDG-12), and climate change mitigation issues (SDG-13). These variables combinations align with existing literature and it is time to re-visit the theme for the case of E7 in an era of global energy awareness, energy security, and a clean environment. This study seeks to further add to the existing literature ample policy guide and a prescription for the rest of other developing economies by serving as a benchmark

The rest of this paper is structured as follows: the "Literature review" section provides a review of related literature. The "Data and methods" section focuses on the data and methodological procedure employed. While the "Results and discussions" section concentrates on the interpretation of empirical findings. Finally, the "Conclusion and policy implications" section concludes the study with policy prescriptions accordingly.

Literature review

During the last two decades, large literature reviews have rigorously studied many of the variables that connect consumption of energy with growth as well as emissions of CO_2 (Agboola and Bekun 2019; Bekun et al. 2019a, b; Adedoyin et al. 2020a, b; Kirikkaleli et al. 2020; Udi et al. 2020: Gyamfi et al. 2020a, b, c). These characteristics involve economic activity, energy efficiency, clean power and non-renewable power intake, import and export, travel, urbanization, fiscal advancement, FDI, and tourism. Concerning the various geographical regions and states as well as the diverse period ranges and the diverse methodological methods, the association regarding CO_2 concentrations and the factors identified proposed a variety of suggestions and regulatory consequences for the survey states (inter alia Chebbi 2010; Chebbi et al. 2011; Iwata et al. 2011; Saboori et al. 2012; Farhani and Shahbaz 2014; Shahbaz et al. 2014; Apergis and Ozturk 2015; Ben Jebli and Ben Youssef 2015a, b; Ben Jebli et al. 2015; Baek 2015; Bölük and Mert 2015; Ahmad et al. 2016; Bouznit and Pablo-Romero 2016; Lin et al. 2016; Saboori et al. 2016; Youssef et al. 2016; Danish Zhang et al. 2017; Qureshi et al. 2017; Zhang et al. 2017)

Foer a vogueish comparison towards the influence of all the considerations listed on CO_2 emission, research on the effect of agricultural practices gained relatively minimal publication consideration from scholars, economic experts, and authorities. Utilizing one-state (Karkacier et al. 2006; Mushtaq et al. 2007; Turkekul and Unakitan 2011) in addition to/otherwise boundary-nation documents established (Rafiq et al. 2016) popular modern research, in presence are research on the partnership involving power use besides agriculture. Research by Karkacier et al. (2006) explores how the effect of power usage scheduled the production of Turkish agriculture across the span of 1971 through to 2003. Quantitative findings confirm the presence of a close association regarding energy usage versus agricultural efficiency, which suggests that agricultural growth decreases with an improvement in energy intake. Using a co-integration and error correction template, Mushtaq et al. (2007) have identified a uni-directional cause and effect connection between agricultural GDP and oil consumption as well as power intake, and agricultural GDP for Pakistan across the period of 1972–2005. The findings have some strategy ramifications for policymakers and authorities in terms of upgrading facilities and subsidizing remote and industrial energy to increase agricultural production.

Turkekul and Unakitan (2011) measure the immediate and longstanding connection regarding power use and agricultural GDP in addition to oil values in Turkey throughout 1970 and 2008. Depending on the findings of the Granger causality study, oil costs have a major effect on electricity usage. Therefore, the presence of uni-directional connection since fuel plus electrical utilization to agricultural development implies the value of the power reliant on budget, which implies that any improvement in agricultural development would require a long-term improvement in fuel and electrical utilization. Energy usage in agriculture would also be promoted to increase the productivity of the international community. Sebri and Abid (2012) are researching the cause and effect connection involving energy use (petroleum and electric power) and value-added agriculture, regulating the opening up of trade in Tunisia within the span of 1980 to 2007. The findings of the connection analyses confirm the presence of a one-way causality starting efficiency power use and lubricant use to agricultural assessment supplementary in the temporary. The longstanding causal connection has identified a uni-directional cause and effect relationship between accessibility to trade and power use and value-added agriculture. Additionally, the findings confirm clear cause and effect since agricultural assessment supplementary to petroleum resource use in Tunisia.

Furthermore, Rafiq et al. (2016) examine the effect of agriculture as well as trading transparency on CO_2 consumption in a group of 53 large, low-to-medium-earning states over the century, leveraging the generalized stochastic regression effect, contamination, affluence and innovation (STIRPAT) and EKC theory. Analytical findings show that the retail segment and value-added agriculture have a major function to play in lowering emissions in large-income economies, while industrialization raises contamination rates. Both the capital investment in utilities and agriculture contribute to reducing pollution. The results set out the political ramifications of the integration of industrialization initiatives and green regulations to minimize CO_2 pollution from trade liberalization around the globe, regardless of the country's earnings rates.

In addition to exploring the EKC theory, our research reflects on the interaction involving clean power utilization, fiscal development, farming, and pollutants. As stated before, while experiments are investigating the connection regarding farming and overall energy utilization in the documentation, the various examinations exploring the connection regarding renewable energy use, economic development, agriculture, and CO_2 are very low. One small group of experiments is Ben Jebli and Ben Youssef (2017a) exploring the relation regarding CO_2 discharges; healthy, unclean power use; GDP; value-added agriculture; and import and export transparency in Tunisia. Considering the vector error correction model (VECM) in addition to causal research, the methodological results confirm the presence of short as well as bi-effects on farming assessment supplementary in addition to CO_2 as well as on value-added agriculture and trade. While the definition of the EKC is not recognized in Tunisia during the 1980 to 2011 era, there is a lengthy-term bi-directional cause and effect over all of the variables described. In contrast, there is indeed a considerable improvement in the influence of non-renewable power, exports, and value-added agriculture on pollutants, while the influence of clean energy on CO_2 output is rising.

In the framework of a community of northern Africa states, Ben Jebli and Ben Youssef (2017b) investigate the energetic causal relationship regarding value-added agriculture, CO_2 emission, green power usage, and real GDP over the 1980 to 2011 span. Researchers contemplate the inclusion of a bi-directional causal association involving agriculture as well as CO_2 pollution both in the short and long terms. Findings from long-term parameter projections that an intensification in the use of clean power or GDP outcomes in an upsurge in CO_2 discharges, although an improvement in farming assessment supplementary has a declining effect on CO_2 greenhouse gases. According to earlier research, Liu et al. (2017) explored the influence of clean power usage and value-added agriculture on CO_2 reductions in 4 designated ASEAN nations. They explore the occurrence of the EKC phenomena from 1970 to 2013 council of these nations. The findings never confirm the EKC theory. We also discover that renewable energies and agriculture have a major and detrimental effect on CO_2 production, while non-renewable generation does so favorably. This study varies from those of Ben Jebli and Ben Youssef (2017b) and Liu et al. (2017), primarily because we use a separate data collection, which included a comprehensive data point of E7 nations across the 1990–2018 span. Relative to their territorial circumstances and many agricultural commodities provided along with their economic progress and extensive use of clean energy and energy utilization, the study of the position of agricultural additional value, real GDP, clean energy intake on CO_2 pollution, and the development of the EKC phenomenon fills this void and adds to the analytical research.

The trajectory of the highlighted literature survey shows a vacuum in the extant literature for the need to explore the connection between value-added agriculture and CO_2 in a comprehensive manner. There have been vast theoretical studies such as Soytas and Sari (2009) and Bekun et al. (2019a, b). The intuition of the carbon-income function is premised on the environmental Kuznets curve phenomenon that expresses the relationship between environmental degradation and income level. Our study advances the arguments by augmenting the conventional liner carbon-income model with agriculture as a key determinant of GHGs for the case of E7. This study employs robust and econometric analysis consistent with literature such as pool mean group autoregressive distributed lag (PMG-ARDL), dynamic ordinal least square (DOLS), and full modified ordinary least square (FMOLS) for long-run regression among the outlined study variables while for detection of causality direction, Dumitrescu and

Table 1 Description of variables

Name of indicator	Abbreviation	Proxy/scale of measurement	Source
Carbon dioxide emissions per capita	CO_2	Measured in metric tons	WDI
Gross domestic product	GDP	Constant of 2010 US$	WDI
Value-added agriculture	AVA	Constant 2010 US$	WDI
Renewable energy consumption	EC	% of total final energy consumption	WDI

Note: WDI represents the World Bank Development indicator of the World Bank database sourced from https://data.worldbank.org/

Hurlin causality test is employed. Our study relies on first-generation panel analysis on the premise of the Pesaran (2007) cross-sectional dependency (CD) test that is a common shock effect among the blocs investigated for robustness purposes as well as to avoid spurious analysis. In particular, this study varies from those of Ben Jebli and Ben Youssef (2017b) and Liu et al. (2017), primarily because we use a separate data collection, which included comprehensive data of E7 nations across the span 1990–2016.

Data and methods

Data and variables

Annual frequency data was obtained from the World Bank Development Indicators database (WDI) is employed to investigate the relationship between our study outlined variables from 1990 to 2016. To this end, four-time series variables for E7 were employed to analyze the effect of value-added agriculture, energy usage, and economic growth on environmental degradation (CO_2 emissions). These variables include value-added agriculture (constant 2010 US$) which was denoted as AVA, second, GDP per capita (constant 2010 US$) which was symbolized as GDP, third, CO_2 pollutant (metric tons per capita) which was denoted as CO_2, and fourth, renewable energy consumption (% of total final energy consumption) which was denoted as EC. The definition of these variables, their value, symbol, and sources are shown in Table 1. The overview of E7 nations discussed in this study comprises China, India, Brazil, Mexico, Russia, Indonesia, and Turkey.

Table 2 Summary statistics

	$LNCO_2$	LNAVA	LNGDP	LNEC
Mean	1.083766	25.25140	8.415671	2.994691
Median	1.013691	24.99841	8.882699	3.199113
Maximum	2.637626	27.29698	9.551284	4.071636
Minimum	−0.343899	23.94471	6.355242	1.171799
Std. Dev.	0.777889	0.881508	0.915770	0.907475
Skewness	0.304724	0.661540	−0.763776	−0.695471
Kurtosis	2.273311	2.361353	2.208560	2.272043
Jarque-Bera	7.083594	16.99747	23.30835	19.40905
Probability	0.028961	0.000204	0.000009	0.000061
Sum	204.8318	4772.515	1590.562	565.9967
Sum Sq. Dev.	113.7608	146.0866	157.6634	154.8200
Observations	189	189	189	189

Source: Authors computation with data from WDI

Table 3 Correlation matrix analysis

Variables	$LNCO_2$	LNAVA	LNGDP	LNEC
$LNCO_2$	1.0000			
p-value	-			
LNAVA	−0.242858***	1.0000		
p-value	0.0008	--		
LNGDP	0.633316***	−0.635632***	1.0000	
p-value	0.0000	0.0000	-	
LNEC	−0.953087***	0.362113***	−0.560876***	1.0000
p-value	0.0000	0.0000	0.0000	---

Note: ***, **, and * are 1%, 5%, and 10% significant level respectively

Model and methods

This study sets to investigate the contribution of agricultural value addition, GDP, and energy consumption to emissions in the E7 countries. As shown in the literature review, several studies have been carried out in this area; we attempt to investigate the nexus between our study variables for E7 countries for some distinct reasons.

First, E7 countries are responsible for the second-highest contribution by economic integration globally being outperformed by the G7 alone[2]. Hence, understanding the relationship between large-scale economic activities and emissions will help in no small way in pursuing a global reduction in CO_2 emissions and the UN-SDGs globally. Second, on the other hand, the E7 countries are responsible for a huge share of global CO_2 emissions; thus, it is necessary to understand the contributing factors to such high emissions to enable a reduction in global emissions leading to an improvement in the natural environment and a healthier living environment.

In particular, this study varies from those of Ben Jebli and Ben Youssef (2017b) and Liu et al. (2017), primarily because we use a separate data collection, which included comprehensive data of E7 nations across the span 1990–2016[2]. The extensive period covered in the study gives room for sufficient observations to draw policy inferential conclusions. Also, several environmentally relevant policy meetings such as the first Copenhagen climate summit 2009 and its succeeding conferences and global climate meetings such as the Kyoto protocol and other significant meetings have been held within the study period. This then enables the study to measure the implementation of resolutions from this meeting in mitigating global warming by way of reducing emissions. This study considering the position of agricultural additional value, real GDP, clean energy intake on CO_2 pollution, and the development of the EKC proposes the following model equations:

[2] Emerging Economies Will Hold Increasing Amounts of Global Economic Power by 2050. https://globalsecurityreview.com/will-global-economic-order-2050-look-like/

Table 4 Cross-sectional dependency test

Dependent/models	Pesaran (2007) CD
$LNCO_2$=*f*(LNAVA,LNGDP, LNEC)	1.529 (0.126)

Note: ***, **, and * are 1%, 5%, and 10% significant level respectively

$$LNCO_2 = f(LNAVA, LNEC, LNGDP) \quad (1)$$

$$LNCO_{2it} = \alpha_0 + \beta_1 LNAVA_{it} + \beta_2 LNEC_{it} + \beta_3 LNGDP_{it} + \varepsilon_{it} \quad (2)$$

The logarithmic transformation has been performed to enable the variables in the current studies to maintain constant variance across all the series highlighted in our study, where $LNCO_2$, LNAVA, LNEC, and LNGDP are logarithmic transformations of all variables and ε_{it}, α, and βs represent the stochastic, intercept, and partial slope coefficients respectively.

To ascertain whether to apply the first-generation or the second-generation panel data econometric technique, the cross-sectional dependency (CD) test was carried out. The estimators are incomplete, contradictory, and useless if the CD is not considered (Dong et al. 2018; Nathaniel et al. 2020). The study used the Pesaran (2007) CD test for robustness purposes. The CD test takes a null hypothesis of no cross-sectional dependence and the equation is specified as:

$$CD_p = \left(\frac{1}{N(N-1)}\right)^{\frac{1}{2}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T_{ij} \widehat{\gamma}_{ij} \rightarrow N(0.1) \quad (3)$$

Consequently, three estimation techniques are utilized in this study, FMOLS, DOLS, and the pooled mean group-ARDL by Pedroni (2004, 2001) and Kao and Chiang (2000), and Pesaran et al. (1999) respectively. Interestingly, the DOLS can correct for correlation between the dependent variable and the stochastic term it also adds lags of the independent variables. Before the estimation of relationship estimation, we conducted the unit root test of the outlined variables to ascertain the stationarity properties of the variables and avoid the pitfall of spurious regression. This study relies on first-generation panel unit root as supported by the CD test (Nathaniel et al. 2020).

The DOLS is estimated using Eq. 2 which is given as:

$$\begin{aligned} LnCO_{2it} = & \mu_i + x_{i,t} \Psi_{i,t} + \sum_{j=-p}^{p} \beta_j LNC02_{i.t-j} \\ & + \sum_{j=-q0}^{q0} p_{1.j} LNAVAGDP_{i.t-j} \\ & + p_{2.j} \sum_{j=-q1}^{q1} LNEC_{i.t-j} \\ & + p_{3.j} \sum_{j=-q2}^{q2} LNGDP_{i.t-j} + \varepsilon_{it} \end{aligned} \quad (4)$$

p and q are the numbers of leads/lags. The long-run relationship is estimated from the FMOLS equation given as:

$$LnCO2_{i,t} = \mu_{i,t} + x_{i.t}\psi + v_{it} \quad (5)$$

$$x_{i.t} = x_{i.t} + \mathfrak{C}_{i.t}$$

where x 5*1 is the vector of explanatory variables and μ_i is the intercept while $\mathfrak{C}_{i.t}$ and v_{it} are the error terms. However, the estimation of ψ is expressed as:

$$\widehat{\psi}_{FMOLS} = \left(\sum_{i=1}^{N}\sum_{t=1}^{T}\left(x_{i.t}-\overline{x}_{i.t}\right)*\left(x_{i.t}-\overline{x}_{i.t}\right)'\right)^{-1}*\left(\sum_{i=1}^{N}\left(\sum_{t=1}^{T}\left(x_{i.t}-\overline{x}_{i.t}\right)*\widehat{LNC02}_{it}-T\widehat{\Delta}_{v\mathfrak{C}}\right)\right) \quad (6)$$

Table 5 Unit root test

	ADF				PP			
	At level		At 1st level		At level		At 1st level	
Variables	$\pi\tau$	$\pi\vartheta$	$\pi\tau$	$\pi\vartheta$	$\pi\tau$	$\pi\vartheta$	$\pi\tau$	$\pi\vartheta$
$LNCO_2$	0.8710	0.0241**	0.1316***	0.2529***	0.8734	0.6565*	0.0002***	0.0014***
LNAVA	0.8983	0.0085	0.0000***	0.0000	0.9734	0.0073	0.0000***	0.0000***
LNGDP	1.0000	0.3170	0.0010**	0.0016**	1.0000	0.3113	0.0008**	0.0000**
LNEC	0.9664	0.6397	0.0489***	0.1470***	0.9881	0.8112	0.0521***	0.1497***

Note: ***, **, and * are 1%, 5%, and 10% significant level respectively Note: ***, **, and * are 1%, 5%, and 10% significant level respectively; thus, $\pi\tau$ is with constant, $\pi\vartheta$ is with constant and trend

Table 6 Pedroni co-integration test

	Weighted stat	*p*-value		Statistic	*p*-value
Deterministic intercept and trend					
Panel *v*-stat	−0.553170	0.7099	Group rho-stat	0.338732	0.6326
Panel rho-stat	−0.265955	0.3951	Group PP-stat	−2.604123***	0.0046
Panel PP-stat	−2.929334***	0.0017	Group ADF-stat	−1.183671	0.1183
Panel ADF-stat	−2.311594**	0.0104			
No deterministic trend					
Panel *v*-stat	0.680441	0.2481	Group rho-stat	0.136768	0.5544
Panel rho-stat	−0.981008	0.1633	Group PP-stat	−1.197786	0.1155
Panel PP-stat	−2.094124**	0.0181	Group ADF-stat	−0.338211	0.3676
Panel ADF-stat	−1.484271*	0.0689			
No deterministic intercept or trend					
Panel *v*-stat	1.128436	0.1296	Group rho-stat	0.340570	0.6333
Panel rho-stat	−0.922422	0.1782	Group PP-stat	−0.734678	0.2313
Panel PP-stat	−1.564818*	0.0588	Group ADF-stat	−1.142523	0.1266
Panel ADF-stat	−1.873939**	0.0305			

Note: ***, **, and * are 1%, 5%, and 10% significant level respectively

The researchers also examined both short- and long-term forecasts utilizing the Pesaran et al. (1999) method. The study proceeded with the evaluation of value-added agriculture, GDP, and energy emissions nexus identified in Eq. (1) in the autoregressive distributed lag (ARDL: *p*, *q*) system that integrates all pollution lags including regressors, provided that:

$$\text{LnC02}_{it} = \beta_i + \sum_{j=0}^{p} \delta_{ij} \text{LNCO2 } Z_{it-j} + \sum_{j=1}^{q} \varphi \delta_{i,j} Z_{it-j} + \varepsilon_{it} \tag{7}$$

where Z_{it} = (LnAVA_{it}, LnEC_{it}, LnGDP_{it}) is a function for the explanatory variables used in this analysis. β_i indicates the country-level fixed results, δ_{ij} indicates the slope of the lagged pollution vector, and $\varphi_{i,j}$ indicates the slope of the lagged explanatory variables.

The PMG-ARDL co-integration methodology has important econometric strengths relative to conventional panel data models. It could fix endogeneity problems in econometric models and at the same time handle either short- or long-term parameters. The ARDL co-integration method is also capable of taking into account variables in a combined integration order, such as *I*(0) or/and *I*(1) but not *I*(2). Pesaran et al. (1999) also reported that the pool mean group (PMG) estimator is accurate, resilient, and high to lag orders and outliers.

Results and discussions

Pre-estimation diagnostics

This section reports the discussion of the study regression and stylized implications accordingly. The section setoff with basic summary statistics of the outlined variables is reported in Table 2 that comprises measure of central tendencies and dispersion like average, median, mean deviation, standard deviation range, and mode and subsequently correlation Pearson correlation analysis on the pairwise relationship between variables. As earlier mentioned in the introduction section, variables were informed by the UN-SDGs vision 2030. The econometrics modeling is further informed by economic intuition and empirical backing of modeling general-to-specific modeling test. Additionally, to avoid multicollinearity, the Pearson correlation analysis serves as a guide. The present study correlation analysis is satisfactory as no extreme

Table 7 Johansen-Fisher panel co-integration test

Hypothesis no. of CE(s)	Fisher stat (from trace)	*p*-value	Fisher stat (from max-eight)	*p*-value
$r \leq 0$	66.69***	0.0000	45.92***	0.0000
$r \leq 1$	32.81***	0.0031	25.02**	0.0344
$r \leq 2$	17.04	0.2539	13.26	0.5060
$r \leq 3$	24.28**	0.0424	24.28**	0.0424

Note: ***, **, and * are 1%, 5%, and 10% significant level respectively correlation is seen to pose a threat to econometrics analysis. The variance inflation factor (VIF) or tolerance factor, which is the inverse of VIF, resonates the position of Pearson correlation analysis (see Appendix Table 12 for VIF/I/VIF results). From Table 2, the summary statistics of the E7 states reveal that agriculture value addition has the highest mean of 25.25%, a median of 25%, and a maximum of 27.3% value. The result shows that CO_2 produce 1.08 metric tons of emissions as a mean, a median of 1.01 metric tons, and a maximum of 2.63 metric tons of pollutant per year. Moreover, the mean growth per year was 8.4%, a median of 8.9%, and a maximum of 9.6%. Renewable energy consumption has a mean of 3.0 metric tons of emission produce per year, a median of 3.2 metric tons, and a maximum of 4.1 metric tons per year. Nevertheless, Table 3 which shows how correlated the variables are proves that there is a negative correlation regarding CO_2, value-added agriculture, and energy consumption but a positive correction regarding value-added agriculture and real GDP. Value-added agriculture has a negative correction with real GDP but positive correction with energy consumption. Real GDP on the other hand has a negative correction with energy consumption.

Subsequently, after accessing the correlation among the variables, it was important to prove the evidence of CD in the constructs as presented in Table 4. With the outcome, the analysis cannot proceed with analytical techniques that are robust with CD test but techniques that are robust with a first-generation test because both of the CD techniques used were not significant.

It was therefore important to run the first-generation unit root to access stationary among the variables. Following the outcome of the unit root test—the ADF and Philips Perron unit root tests in Table 5—it is revealed that all variables are stable at first difference while only real GDP is stationary at level. On the other hand, the Pedroni, Johansen-Fisher, and Kao residual and ADF co-integration tests as reported in Tables 6, 7, and 8 all respectively affirm equilibrium relationship between the outlined variables, and we see that there exists a long-run relationship among the variables at various levels of significance.

Empirical results discussion

In Table 9 below, we report long-run estimates of the pooled mean group autoregressive distributed lag (PMG-ARDL), dynamic ordinal least square (DOLS), and fully modified ordinal least square (FMOLS) estimates. As expected, the coefficient for value-added agriculture is positive and significant at 1% which means that value-added agriculture is a driver of CO_2 emissions in the long run. Specifically, a 1% rise in agricultural value addition will increase emissions between the ranges of 0.31 to 0.80%. This is because the more agricultural production is, the more demand there is for the use of combustible energy resources which leads to the release of emissions into the environment. This finding is similar to that of Ben Jebli and Ben Youssef (2017a) for Tunisia and Liu et al. (2017) for 4 ASEAN countries.

On the other hand, energy use in the form of renewable energy utilization has a negative and significant coefficient at varying levels of significance. Specifically, a 1% rise in energy use will lead to a reduction in CO_2 emissions by 0.32 to 0.66% in the E7 countries. This outcome is not as expected as high-energy consumption is often associated with high emissions. However, the negative relationship between energy use and emissions points to the sustained consumption of a significant amount of renewable energy in the E7 countries which further points to the commitment of the E7 countries to attain a cleaner environment. Similar findings have been documented by Ben Jebli and Ben Youssef (2015a) for

Table 8 Kao's (1999) residual co-integration test results

	t-statistic	*p*-value
ADF	−2.812093***	0.0025
Residual variance	0.002875	
HAC variance	0.003233	

Note: ***, **, and * are 1%, 5%, and 10% significant level respectively

Table 9 Long-run results PMG-ARDL, DOLS, and FMOLS

Variables	ARDL (2, 1, 1, 1)	DOLS	FMOLS
LNAVA	0.800113***	0.305835***	0.395461***
p-value	0.0000	0.0018	0.0000
LNGDP	0.068672	0.303739***	0.255714***
p-value	0.4962	0.0004	(0.0006)
LNEC	−0.660065***	−0.318041***	−0.337560***
p-value	0.0000	0.0008	0.0001
R-square		0.995407	0.989451
ADJ *R*-square		0.991927	0.988899

Note: ***, **, and * are 1%, 5%, and 10% significant level respectively

Table 10 Results of Short-run ARDL (2, 1, 1, 1)

Short-run equation			
Variables	Coefficient	Std. error	*t*-statistic
COINTEQ01	−0.327525**	0.149874	−2.185336
D(LNCO_2(−1))	0.140419	0.110559	1.270089
D(LNAVA)	−0.107415	0.089569	−1.199236
D(LNGDP)	0.516560***	0.196576	2.627785
D(LNEC)	−0.299346	0.315816	−0.947852
Constant	−5.658413**	2.584261	−2.189567

Note: ***, **, and * are 1%, 5%, and 10% significant level respectively

Table 11 Dumitrescu and Hurlin causality test

Null hypothesis:	*Z*-bar stat	*p*-value	Causality remark
LNAVA ≠ $LNCO_2$	3.58601***	0.0003	Bi-directional causality
$LNCO_2$ ≠ LNAVA	5.27304***	1.E−07	
LNEC ≠ $LNCO_2$	1.50659	0.1319	No causality
$LNCO_2$ ≠ LNEC	0.63750	0.5238	
LNGDP ≠ $LNCO_2$	3.67205***	0.0002	Uni-directional causality
$LNCO_2$ ≠ LNGDP	1.62267	0.1047	
LNEC ≠ LNAVA	3.96118***	7.E−05	Bi-directional causality
LNAVA ≠ LNEC	3.56245***	0.0004	
LNGDP ≠ LNAVA	4.77383***	2.E−06	Bi-directional causality
LNAVA ≠ LNGDP	2.31318**	0.0207	
LNGDP ≠ LNEC	1.37200	0.1701	No causality
LNEC ≠ LNGDP	1.20824	0.2270	

Note: ***, **, and * are 1%, 5%, and 10% significant level respectively while ≠ represents no "Granger cause"

Tunisia and Bölük and Mert (2015) for Turkey and Gyamfi et al. (2021b) for the same E7 economics.

As expected, the coefficients for economic growth are positive and significant at a 1% level of significance. Specifically, a 1% increase in economic growth will lead to an increase in emissions by 0.267% to 0.307% in the focus countries. Given the high volume of economic activities in the E7 countries, high emissions are emanating from the processing and manufacturing industries in the bloc, which leads to the depletion of environmental quality. This finding is similar to Bouznit and Pablo-Romero (2016) for Algeria and Ahmad et al. 2016 for Croatia and Gyamfi et al. (2020d, e).

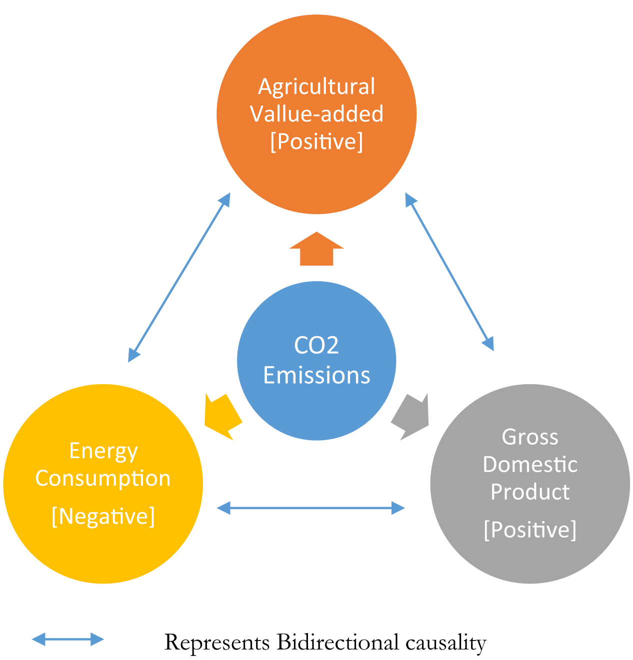

Fig. 1 Arrows (↔) represent bi-directional causality

Table 10 shows the short-run relationship between the dependent variables CO_2 emissions using the PMG-ARDL estimator. The gross domestic product still has a positive and significant coefficient which implies a positive and significant relationship between economic and emissions. Specifically, a 1% increase in economic growth will cause a rise in emissions by 0.52% in the short run in the E7 countries. Consequently, agricultural value addition and Energy use do not have a significant impact on emissions in the short run implying that it takes a longer period before agriculture value addition and energy use causes a significant impact on emissions in the E7 countries.

Heterogeneous causality test

The Dumitrescu and Hurlin Causality tests for the variables in the study are reported in Table 11. Results reveal that there is no causality between $LNC0_2$ and LNAVA and LNEC, while there is Bi-directional causality from LNAVA to $LNCO_2$. This bi-directional causality shows that while higher levels of emissions will require more focus on the agricultural sector, there is a potential rise in emissions due to higher levels of emission-generating machinery been used in the E7 countries. This also confirms the findings of Jebli and Ben Youssef's (2017a, b) examination in Tunisia from 1980 to 2011. Again, there is a bi-directional relationship between LNAVA to LNEC which fail to confirm the finding of Sebri and Abid (2012) proving a uni-directional causality regarding value-added agriculture and energy utilization. Moreover, LNAVA to LNGDP also proves a bi-directional causality by confirming the analysis of Jebli and Ben Youssef (2017b). Lastly, there is bi-directional causality between $LNCO_2$ to LNGDP which again affirms the finding of Gyamfi et al. (2020a) (Fig. 1). Moreover, there is a uni-directional causal relation between real GDP and pollutant emissions. This implies that while economic growth causes emissions, emissions can also predict economic growth. Moreover, value-added agriculture also causes emissions. However, energy use does not cause emissions directly but it causes economic growth which causes emissions.

Conclusion and policy implications

Several studies have been carried out on the nexus between agriculture value addition, energy use, economic growth, and emissions. However, this study differs by complementing the extant literature in considering the role of clean energy in a carbon-income function for the case of E7 countries, namely China, India, Brazil, Mexico, Russia, Indonesia, and Turkey, for the period 1990 to 2016. The study utilized the PMG-ARDL, DOLS, and FMOLS estimators and Dumitrescu and Hurlin causality test. According to the findings, long-run regression estimates revealed that value-added agriculture and economic growth are drivers of CO_2 emissions in the E7 countries while the rise in energy causes a reduction in CO_2 emissions. While, in the short run, economic growth has a positive impact on emissions in E7 countries, value-added agriculture and energy use have no impact on emissions in the short run. Causality tests showed that there is a feedback effect between economic growth and emissions, between energy usage and value-added agriculture, between emissions and value-added agriculture, and between value-added agriculture and economic growth. A one-way direction of causality also exists between economic growth and pollutant emissions. Also, energy consumption does not cause emissions directly; it causes economic growth and value-added agriculture which causes emissions.

As per policy recommendations, an increase in agricultural production is desirable, but the use of renewable energy in agricultural production is necessary to attain optimum agricultural products without damaging the quality of the environment. To further achieve fewer emissions, the increased use of renewable energy is encouraged in the E7 countries especially for economic activities given that the bloc is a huge economic and industrial hub. Additionally, this study demonstrates that value-added agriculture leads to a large number of pollutions in countries such as China, Indonesia, India, Brazil, Mexico, Russia, and Turkey (E7). Therefore, a policy that targets the reduction of farm activities that form part of emissions, such as bush burning, is necessary. Bush fire should be deterred; alternatively, better agricultural methods that involve less land utilization such as greenhouse agriculture should be introduced. Also, brush and weed decomposition must be embraced, which can serve as fertilizers. Nevertheless, the desire for E7 authorities to reinforce ecological agreements and laws in their institutions is also necessary to prevent environmental degradation and reduce emissions of GHGs. This will go a long way to achieve high economic growth and at the same time high-quality environment which resonates with the United Nations Sustainable Development Goal (UN-SDG) Targets 7, 12, and 13 of clean energy access and mitigation of climate changes issues.

Appendix

Table 12 VIF estimations

Variables	VIF	1/VIF
LnGDP	2.13	0.470101
LnAVA	1.68	0.595926
LnREC	1.46	0.685366
Mean VIF	1.75	

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Availability of data and materials The data for this present study are sourced from the World Development Indicators (https://data.worldbank.org/). The current specific data can be made available upon request but all available and downloadable at the earlier mentioned database and weblink.

Author contribution The first author (Dr. Festus Fatai ADEDOYIN) was responsible for the conceptual construction of the study's idea. The second author (Prof. Dr. Murad A. Bein) handled the literature section while the third author (Asst. Prof. Dr. Festus Victor Bekun) managed the data gathering and preliminary analysis. Dr. Bright Akwasi Gyamfi was responsible for proofreading and manuscript editing. The authors have read and approved the manuscript.

Declarations

Consent to participate Not applicable.

Consent to publish Applicable.

Competing interests The authors declare no competing interests.

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