Environ Monit Assess (2023) 195:1071
https://doi.org/10.1007/s10661-023-11617-8

RESEARCH

# The role forest resources, energy efficiency, and renewable energy in promoting environmental quality

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Received: 8 June 2023 / Accepted: 19 July 2023 / Published online: 24 August 2023


**Abstract** At a time when environmental concerns are rising in the world, natural resources, such as trees and other green plants, remain the most crucial factors responsible for reducing environmental degradation. Green plants inhale carbon dioxide and prevent the soil from wash and wear, hence their significant role in enhancing environmental quality. Therefore, it is essential to come up with state-of-the-art researches on the role of green plants to the environment. The present research is aimed at adding to the growing body of literature by investigating the effect of forest resources, together with renewable energy and energy efficiency in enhancing environmental quality. In this research, we use the data of the seven emerging countries, seven developed nations and 15 developing west African nations, from 1990 to 2019. The current research adds to the growing body of literature in that it presents a comparative analysis of the three important economic blocks, as well as employing three major methodologies of data analysis, the CS-ARDL, AMG, and CCEMG techniques, which are strong over cross-sectional dependence, heterogeneity, and dynamics. Major research outcomes show that renewable energy and energy efficiency negatively affects carbon emissions, while gross domestic product positively affects carbon emissions in all three regions. Population size and forest resources reduces carbon emissions in the emerging countries and seven developed countries, respectively. Non-renewable energy promotes carbon emissions in the seven developed countries, while in the emerging countries it reduces emissions. This research recommends the efficient utilization of energy, use of renewable energy, and forest preservation to promote carbon neutrality goal.

**Keywords** Ecological footprint · Carbon emissions · Renewable energy · Non-renewable energy

## Introduction

Natural resources are essential in promoting environmental quality; yet, there still remains a dearth in the literature on this topic. Thus, more research on this subject is imminent, for the purpose of devising policy recommendations meant to advance and preserve natural resources around the world. Among the few studies available on the link between natural resources and the environment, Abid et al. (2022); Amer et al. (2022); Ali et al. (2022), it is observed that natural resources

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play a vital role in reducing ecological footprint (EFP). The aforementioned studies also concur with the overwhelming evidence provided in recent researches (Akadiri & Adebayo, 2022; Bakhsh et al., 2022; Banga et al., 2022; Boukhelkhal, 2021; Deka et al., 2022), which shows the importance of renewable energy (RE) in reducing EFP, hence enhancing environmental quality. Therefore, natural resources are vital, just like RE, in ensuring the attainment of a clean environment around the globe. While there exist many types of natural resources around the world, trees are by far the most significant in ensuring a clean and safe environment. Scientifically, trees and all green plants are known for inhaling carbon dioxide ($CO_2$) and exhaling oxygen ($O_2$) during photosynthesis, a process by which plants make their food in the presents of light, water, and $CO_2$. Thus, the presence of a large and vast area of forest resources is paramount in reducing carbon content in the air. The unnecessary cutting down of trees greatly harms the environment. Past researches have concentrated more on looking at the measures required to stop carbon emissions (CE), which is exacerbated by the use of non-renewable energy (NRE) (Akadiri & Adebayo, 2022; Bakhsh et al., 2022; Banga et al., 2022; Boukhelkhal, 2021; Deka et al., 2022), and the transition to the use of RE which is carbon free has been encouraged. However, the atmosphere has already accumulated more carbon due to past harmful human activities. What can be done to trap the carbon content existing in the atmosphere? Transitioning to the use of RE can only stop further emission, without doing anything to remove the already accumulated carbon content. Therefore, it is essential to come up with various innovative technologies, if the carbon content present in the air is to be trapped, and natural resources advancement, such as planting of more green plants remains one of the best ways.

The emerging economies have largely contributed to CE, hence environmental degradation, in their transition from developing countries to emerging nations. Among the emerging economies, China is regarded as the largest emitter, while India is considered as the third largest emitter (Qin et al., 2021). The reason behind the vast emissions of carbon is the use of NRE to achieve high growth of the economy. The European Union (EU) countries too, are considered as the leading CE region (Balsalobre-Lorente & Leitão, 2020; Deka et al., 2022). However, some African countries are less polluting, with some even consuming 0% fossil fuels, as per the data provided by the World Bank. Nations of the globe have to this date decided to work towards achieving carbon neutrality. For example, the Paris Climate Accord seeks to decrease global warming to 2°C or less. On the other hand, individual countries and/or regions have set goals to reduce CE: China seeks to achieve carbon neutrality by 2060, while the UK also seeks to achieve net-zero CE by 2050. Due to various commitments made by different world countries and regions, the European Green Deal estimated a 55% decrease in CE by 2050, while the United Nations (UN) estimates a 7.6% CE reductions per annum during the period 2020–2030.

This research is employed to further the growing body of literature on the role of forest resources, RE, and energy efficiency (EE) in reducing the carbon content. The present research is based on the strong scientific grounds, which shows that green plants take in $CO_2$ and gives out $O_2$ during the process called photosynthesis. Furthermore, other researches done in the past, Abid et al. (2022); Amer et al. (2022); Ali et al. (2022), show the importance of natural resources in enhancing the quality of the environment, even though a dearth still remains in the field. The current research adds to the growing body of literature in that it presents a comparative analysis of the three important economic blocks, the emerging seven countries (the E7 nations, that is, Russia, Turkey, Mexico, Indonesia, India, Brazil, and China); the seven developed nations of the world (G7 countries, that is, Japan, Canada, the UK, Germany, Australia, the USA, and France); and the developing west African nations (ECOWAS countries, that is, Togo, Sierra Leone, Senegal, Niger, Nigeria, Mali, Liberia, Ghana, Gambia, Cote d'ivorie, Burkina Faso, Benin, Guinea, Guinea Bissau, and Cabo Verde), as well as employing three major methodologies of data analysis, the common correlated effects mean group (CCEMG), augmented mean group (AMG), and cross-sectionally augmented autoregressive distributive lag (CS-ARDL) techniques, which are strong over cross-sectional dependence, heterogeneity, and dynamics. The dataset employed, for these three economic blocks, ranges from 1990 to 2019. The data of the three economic blocks is separately analyzed and the findings are compared and contrasted. The present research endeavors in answering the following questions: what is the role of forest resources in reducing carbon content in the air? What is the effect of EE and RE on CE? Is there any asymmetry on the impact of forest resources, RE and EE among the three economic blocks of the world, that is, the E7, G7, and ECOWAS nations?

## Literature review

A wide range of researches have been done to examine the major factors which exacerbate environmental degradation and/or reduce environmental degradation. On the relationship between EFP and energy use, various studies have ascertained the positive link between the two indicators (Abbas et al., 2021; Ali, Rehman, et al., 2022; Amer et al., 2022). According to Abbas et al. (2021) in a study of Pakistan, EFP has been observed to be positively impacted by energy use. The findings of Abbas et al. (2021) are supported by the postulations of Amer et al. (2022), in a study of the Gulf Cooperation council, which gives the existence of a strong positive effect of energy consumption on EFP. Ali et al. (2022) also support the significant positive impact of energy use on EFP. The positive impact of energy use on EFP is because of the inclusion of NRE in the energy use factor (Banga et al., 2022; Deka et al., 2022). This is backed by studies that give a strong positive effect of NRE on EFP and a negative effect of RE on EFP. NRE positively affects EFP (Ansari, 2022), whereas RE and natural resources are observed to decrease EFP (Abid et al., 2022; Ali et al., 2022; Amer et al., 2022). As a result, NRE use must be shunned by countries due to its harmful effects to the environment, while RE which has little or no harm to the environment should be adopted to attain carbon neutrality goal, together with high economic growth. These sources of energy are promoted through financial development and foreign direct investment (Akpanke et al., 2023; Banerjee, 2022; Batool et al., 2022); hence, the importance of the government to channel these resources toward raising RE which is safe.

On the relationship between RE and the emissions of $CO_2$, past studies allude that RE posits a strong effect on CE which is negative (Abbas et al., 2021; Ajide & Mesagan, 2022; Akadiri & Adebayo, 2022; Akram et al., 2022; Balsalobre-Lorente & Leitão, 2020; Bhat, 2018; Mathiesen et al., 2011). These findings depict that RE is paramount in lowering carbon footprint, hence promoting the environmental improvement in the world. Deka et al. (2022) and Banga et al. (2022) actually depict that promoting RE lowers the emission of $CO_2$ by a greater margin. Therefore, using RE in promoting economic growth is vital, since this source of energy significantly enhances the quality of the surroundings through lowering CE. Thus, there is ample evidence pointing to the fact that environmental degradation is exacerbated by NRE use, while RE use help improve environmental quality. Therefore, it is crucial that nations shift from NRE to the use of RE sources that encourages environmental quality and at the same time promoting economic growth. If world economies take the broad step towards shunning NRE, this will help mitigate environmental degradation and the carbon neutrality goal is attained. However, few other researchers depict that RE positively influences CE, see Anser et al. (2021). This is also supported in the outcomes provided by Adedoyin et al. (2020), which show that the generation of RE causes an increase in CE. On the other hand, Menyah and Wolde-Rufael (2010) allude that RE and CE are not significantly associated. A no association and positive association between CE and RE can be attributed to the high prices of RE compared to NRE (Becker & Fischer, 2013). In as much as, the cost of RE is high in relation to that of NRE, it must be noted that the long-run cost, including the cost to the environment is high (Becker & Fischer, 2013), hence using RE which has relatively lower long-term costs is ideal.

In addition to the importance of RE in reducing environmental degradation, natural resources are essential too. The researches of Abid et al. (2022), Amer et al. (2022), and Ali et al. (2022) postulate the importance of natural resources in advancing the best quality of the environment. Abid et al. (2022), Amer et al. (2022), and Ali et al. (2022) show that natural resources in conjunction with RE are vital for achieving clean and safe environment. Mesagan and Vo (2023) depict the presents of a significant feedback between pollution and natural resources. Raihan and Tuspekova (2022) specifically show that increasing forest area lowers CE. The claims of the aforementioned researches are robust considering the role of green plants in reducing carbon content in the air. Green plants are scientifically known for using $CO_2$ and water in the presents of light to make their food, in a process called photosynthesis. Thus, green plants are vital in reducing carbon content that is trapped in the atmosphere. However, despite the importance of green plants in reducing carbon content in the air, there remains a dearth in the literature on the studies that ascertain this association. Therefore, it is vital for more researches to be done on this subject, and the present research is an attempt to cover this gap by adding to the existing growing body of literature.

Of paramount importance, EE is in protecting the environment from degrading. The study of Akram et al. (2022) and Deka et al. (2022) gives a strong effect of EE on environmental degradation. Therefore, the aforementioned research depicts that environmental quality is achieved through the wise utilization of energy resources, avoiding wastage, and producing the highest output level per each unit of energy (Deka et al., 2022). Other researchers, Razzaq et al. (2021), Ponce and Khan (2021), Zakari et al. (2022), give that the level of CE is significantly reduced by EE. EE, on the other hand, is observed to increase economic growth (Kadir et al., 2023; Razzaq et al., 2021). Sohag et al. (2021) also observed increases in economic growth due to substantially increase EE. Li and Colombier (2009) are of the view that promoting EE reduces energy consumption, hence reduces CE and promotes environmental quality. However, the research of Mahapatra and Irfan (2021) argues that the impact of EE on CE is not consistent. Therefore, while many research findings concurs on the importance of EE in promoting best quality of the environment, there still exist other studies which provides contradicting findings, hence the importance of further analyzing the effects of EE on the environment among various world regions. Thus, the present research seeks to further the discussion on the importance of EE in fostering the attainment of the high-quality environment in the World.

Gross domestic product (GDP) according to Abid et al. (2022) significantly impacts EFP. In fact, Ali et al. (2022) allude that economic growth increases ecological pressure. Just as energy use and NRE, posits for a significant positive effect on EFP, GDP also positively affects CE (Ansari, 2022; Asif et al., 2021; Boukhelkhal, 2021). The proxy of environmental degradation, CE, is also observed to be significantly impacted by economic growth (Abbas et al., 2021; Akadiri & Adebayo, 2022; Balsalobre-Lorente & Leitão, 2020; Ben Mbarek et al., 2018; Bouyghrissi et al., 2021). GDP growth's positive effect on CE results from NRE use in attaining high economic growth, by nations. Thus, under such circumstances, rising economic growth is linked with rising use of NRE which in turn exacerbates CE. Boukhelkhal (2021) is of the view that CE and economic growth exhibit for a two-way causal link, such that economic growth impacts CE, which in turn impacts economic growth, too. The harmful effect of economic growth on the environment is best explained by the high usage of energy resources that are harmful to the surroundings in order to attain high GDP levels. This is true in the case of China, according to the postulations of Qin et al. (2021), which shows that it has developed to an emerging economy from being a developed nation through using more NRE resources, hence the reason of it being identified as the greatest world emitter.

The evidence presented above depicts that a wide range of research has been done in ascertaining the factors influencing environmental degradation. On the findings presented above, mixed outcomes are observed on how RE impacts environmental degradation, which shows that more work is required to ascertain this link, using dataset from various world regions and employing robust methods of data analysis. The present research adds to the growing body of literature on this topic by employing the CS-ARDL, AMG, and CCEMG techniques that overcomes cross-sectional dependence, which usually exists in panel datasets. Unlike other past researches which have failed to cater for the presence of cross-sectional dependence, the current study gives more robust outcomes in that respect. While there exists vast evidence on the importance of RE in promoting the quality of the surroundings, other outcomes presented in other studies depict that RE has the effect of degrading the surroundings. Therefore, it is necessary to come up with more studies in various world regions and employ contemporary data analysis methods to ensure that proper policies are formulated. We also observe that while many research outcomes depict that EE and forest resources are vital in ensuring the surroundings are protected and preserved, there is still a dearth in the literature. There is still need to come up with the state-of-the-art research, which uses contemporary methods of data analysis on this topic for the purpose of furthering the growing literature body. The present research compares and contrasts the findings from the three methods of data analysis employed, as well as comparing the findings presented from the three economic blocks; hence, these findings are crucial in formulating policies meant to improve the quality of the environment in these regions.

### Theories of environmental degradation

The first and most popular theory of environmental degradation is the "*Environmental Kuznets Curve (EKC)*" theory, which depicts for an inverted *U*-shaped link between economic growth and environmental degradation (Arouri et al., 2012; Grossman & Krueger, 1995; Ma et al., 2021; Selden & Song, 1994; Shafik, 1994; Stern et al., 1996). This inverted *U*-shaped link as indicated in the EKC theory, implies the initial rise of environmental degradation due to a rise in economic growth, with a turning point being reached once a peak is arrived at (Majeed & Luni, 2019), after which a further rise in economic growth is associated with a decline in environmental degradation. The first part of the EKC is usually connected with the period in which the economy is promoted by factors that impact on the environment. The turning point is arrived at once nations realize the negative effects of NRE and shifts to the use of RE that is clean and safe. Thus, the last part of the EKC shows rising economic growth associated with declining impact on the environment. The EKC theory is however credited to the work of Kuznets (1955), who provides for an inverted *U*-shaped link between income and income inequality. EKC theory derives its basis from the notion that low level economic growth societies are income oriented, thus the first goal is to achieve high GDP, whereas high-level economic growth societies are motivated by lances and checks, hence the desire to balance the environmental quality. This is true considering Abraham Maslow's hierarchy of needs, where people first seek those needs at the bottom part of the pyramid (basic needs, such as food and shelter), once these lower level needs are satisfied they cease to motivate workers, hence high level needs become paramount motivators. In the same lines, when poor societies improve their level of economic growth, GDP growth ceases to be a target goal, hence other goals such as improving environmental quality come in play.

Empirical studies have supported the EKC proposition. The research by Khan et al. (2019) in Pakistan ascertains that economic growth and the degradation of the environment are strongly correlated, while Chang (2010) in China, observed a unidirectional causal association between economic growth and CE. Moreover, environmental degradation and economic growth are found to exhibit for a one-way causal association (Hussain et al., 2012; Rahman & Mamun, 2016; Safi et al., 2021; Wahab et al., 2020). On the other hand, the study of Jardon et al. (2017) observed a negative association between the two indicators. Rahman and Mamun (2016) postulate that environmental degradation and economic growth are not significantly linked. Frankly speaking, while the EKC proposition might seem questionable considering the mixed findings by various past researches, it is essential in showing that economic growth is the main factor behind environmental degradation.

The other crucial theory of environmental degradation is the *environmental transition theory (ETT)*, which provides that numerous environment-based challenges are faced, as economies grow, due to the demand of energy. The ETT proposition gives for the existence of dynamic links between the quality of the environment and economic development. The ETT alludes that, firstly, development in the economy is associated with environmental challenges that are associated with the brown agenda, comprising of sewage, water supply, and sanitation issues. The second phase is when economic growth starts rising, causing cities to face the gray agenda, that is, environmental challenges associated with industrial- and auto-related pollution, while post-industrial societies face environmental challenges associated with the green agenda, that is, associated with non-point source pollution, rise in urban waste, depletion of ozone layer, and greenhouse gas (GHG) emissions. In the study of Majeed and Luni (2019) is of the postulations that shifting from one concern of the environment to the other correlates to shifting from local to global level. The aforementioned theories of environmental degradation are essential in providing a theoretical background on the factors affecting environmental degradation and are essential in formulating the model specification of the current research.

## Methodology and data

### Research model

The current research model derives its theoretical basis from the environmental Kuznets curve, and the environmental transition theory, which provides economic growth and energy use as the main factors responsible for environmental degradation. Thus, the factors economic growth and energy use are modeled explain CE, the major proxy of environmental degradation, in the present research. Both types of energy (RE and NRE) are included to investigate their effect on CE, following the model specification of past researches, such as Apeaning (2021), Amirnejad et al. (2021), and Akram et al. (2022). Population growth has also been provided as a major driver of CE in the various nations of the world Apeaning (2021), hence is considered as one of the explanatory variables in the present research. Furthermore, we include energy EE in the present model, following the postulations of Adedoyin et al. (2020), Akadiri and Adebayo (2022), and Akram et al. (2022). In addition to that, due to the postulations of Abid et al. (2022), Amer et al. (2022), and Ali et al. (2022) who shows the importance of natural resources on the quality of the environment, also considering the scientific evidence which shows that green plants capture $CO_2$ from the air during photosynthesis, we use forest resources in the model of the present study. This is essential in addressing the role of forest resources in reducing the content of carbon in the air, hence adding to the growing literature body. The current research, therefore, follows the models of past studies by expressing CE as a function of the consumption of NRE and RE, population size, EE, and forest resources. Therefore, the specified research model is illustrated in Equation 1 as follows:

$$\mathbf{CE} = \mathbf{f}\,(\mathbf{GDP}, \mathbf{FR}, \mathbf{REC}, \mathbf{NREC}, \mathbf{GDP/EU}, \mathbf{POP}) \tag{1}$$

where CE stands for emissions of $CO_2$ into the atmosphere, GDP is short for gross domestic product, FR is the forest resources, REC is the intake of renewable energy, NREC is the intake of non-renewable power, EU is the energy use, while POP is the size of the population. It also follows that GDP/EU represents the EE indicator, according to Deka et al. (2022) and Kadir et al. (2023). Consequently, the statistical study model is illustrated in the Equation 2.

$$\begin{aligned}\mathbf{CE}_t = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1 \mathbf{lnFR}_t + \boldsymbol{\beta}_2 \mathbf{REC}_t + \boldsymbol{\beta}_3 \mathbf{NREC}_t \\ + \boldsymbol{\beta}_4 \mathbf{lnEE}_t + \boldsymbol{\beta}_5 \mathbf{lnPOP}_t + \boldsymbol{\beta}_6 \mathbf{lnGDP}_t + \mathbf{et}\end{aligned} \tag{2}$$

In the Equation 2, **EE** is energy efficiency, **ln** represents the log value of a variable, $\boldsymbol{\beta}_0$ is the constant value of the model, while $\boldsymbol{\beta}_1$ too $\boldsymbol{\beta}_6$ are the coefficient values of the independent variables, and **et** is the white noise error term.

## Data

The data employed is panel data of the three economic blocks of the world, that is, the E7, G7, and ECOWAS countries, for the time frame which ranges from 1990 through to 2019. The data of all the variables for all the regions considered is obtained from World Bank, data.worldbank.org, except for forest resources of the E7 nations which is obtained from data.oecd.org. GDP is the total market value of goods and services that are produced in an economy in a specific given time period (Mankiw, 2010). The GDP value used in this research is measured as a total value per year in US dollars. Population size shows the total number of people residing in a country, according to the World Bank. RE is the energy resources that are safe to the surroundings, which can be used over and over again (Banga et al., 2022; Deka & Dube, 2021). RE in this case is expressed as a percentage of the total value of energy use, according to the World Bank. NREC are the sources of energy that diminishes with use and pollutes the surroundings (Deka et al., 2022). EE refers to the amount of output produced from each unit of energy and is obtained by dividing GDP with total energy use (see for instance, Deka et al., 2022; Kadir et al., 2023). Forest resources is the is the intensity of forest resources use for timber, including the number of trees that have died or fell during the specified period of time, data.oecd.org. It is also the size of land that is under forest resources, data.worldbank.org. Table 1 gives a brief summary of all the variables employed, while Table 2 gives a descriptive statistics summary, that is, the mean, standard deviation and maximum of each and every variable used.

## Method

The methodology of this research, starts by running the preliminary testing of cross-sectional dependence (CD), unit root test, slope heterogeneity test, and cointegration test, to identify the best model to employ for data analysis. For the purposes of CD test, the second-generation (SG) test in STATA software is

**Table 1** Variables' summary (source: authors' own estimations and presentation)

| Series name | Abbreviation | Nature | Measurement | Source |
|---|---|---|---|---|
| Gross domestic product | GDP | Independent variable | Current value of GDP in US$ | World Bank |
| Population size | POP | Independent variable | Total number | World Bank |
| Forest resources | FR | Independent variable | Intensity of use ratio/% of land | OECD/World Bank |
| Renewable energy use | RE | Independent variable | % of total final energy consumption | World Bank |
| Energy efficiency | EE | Independent variable | GDP per energy | World Bank |
| Carbon emissions | CE | Dependent variable | Metric tons per capita of $CO_2$ emissions | World Bank |
| Non-renewable energy | NRE | Independent variable | % of total energy | World Bank |

employed, to test the existence of CD in each panel variable employed. If variables exhibit the presence of CD, then unit root test techniques and models that overcome CD can be used. To investigate the integration order of the indicators, the SG techniques, Levin-Lin-Chu, Fisher-type, and Im-Pesaran-Shin, which overcomes CD problems are used. Checking the order of integration is essential in identifying the most appropriate method to use in analyzing the data. Other methods have pre-requisite that all series must be stationary, to ensure that the occurrence of spurious regressions is prevented. Other methods, such as the ARDL techniques accepts series that are either integrated of zero order, one or a mixture, Pesaran et al. (1997, 1999, 2001), while cointegration regression tools require all indicators to be integrated of order one (Engle & Granger, 1987; Granger, 1986). The third preliminary test employed is to check cointegration by using the Kao, Westerlund, and Pedroni tools. According to Granger (1986), variables that are cointegrated exhibit a strong association in the long run. Therefore, the findings of cointegration tests, in this research, help in understanding if the indicators are cointegrated, and hence select the most appropriate method. This research employs the slope heterogeneity test technique to examine the presence of slope heterogeneity in the specified model.

Due to the existence of mixed order of integration in the variables selected, in the present research model, the ARDL tool which works with indicators whose integration orders are either one or zero, or both is used. The ARDL tool is vital because it ascertains both the short-run estimates and long-run estimates. The

**Table 2** Results of descriptive statistics (source: authors' own estimations and presentation)

| | CE | EE | FR | GDP | NREC | POP | REC |
|---|---|---|---|---|---|---|---|
| E7 nations | | | | | | | |
| *Mean* | 3.788 | 710,000,000 | 2,488,061 | 1,390,000,000,000 | 63.932 | 450,000,000 | 25.811 |
| *Maximum* | 14.631 | 4710,000,000 | 8,153,116 | 14,300,000,000,000 | 93.396 | 1410,000,000 | 58.653 |
| *Std. Dev.* | 3.343 | 862,000,000 | 2,750,506 | 2250,000,000,000 | 30.555 | 491,000,000 | 17.934 |
| *Observations* | 210 | 210 | 210 | 210 | 210 | 210 | 210 |
| G7 nations | | | | | | | |
| *Mean* | 10.269 | 655000000 | 34.807 | 3920000000000 | 68.764 | 102,000,000 | 8.791 |
| *Maximum* | 20.472 | 2680000000 | 68.494 | 21400000000000 | 94.633 | 328,000,000 | 22.769 |
| *Std. Dev.* | 4.805 | 554000000 | 15.738 | 4170000000000 | 29.349 | 83,000,000 | 6.655 |
| *Observations* | 210 | 210 | 210 | 210 | 210 | 210 | 210 |
| ECOWAS nations | | | | | | | |
| *Mean* | 0.282 | 28,800,000 | 32.569 | 22,000,000,000 | 10.032 | 17,900,000 | 68.515 |
| *Maximum* | 1.143 | 716,000,000 | 88.509 | 547,000,000,000 | 55.165 | 201,000,000 | 94.989 |
| *Std. Dev.* | 0.227 | 77,000,000 | 22.069 | 70,900,000,000 | 15.551 | 34,600,000 | 24.272 |
| *Observations* | 450 | 450 | 450 | 450 | 450 | 450 | 450 |

statistical representation of the ARDL tool used in the present research is given in the Equation 3.

$$\begin{aligned} CE_t = \beta_0 &+ \sum_{i=1}^{p} \beta_{1i} \Delta CE_{t-i} + \sum_{i=1}^{q} \beta_{2i} \Delta \ln FR_{t-i} + \sum_{i=1}^{q} \beta_{3i} \Delta REC_{t-i} \\ &+ \sum_{i=1}^{q} \beta_{4i} \Delta NREC_{t-i} + \sum_{i=1}^{q} \beta_{5i} \Delta \ln EE_{t-i} + \sum_{i=1}^{q} \beta_{6i} \Delta \ln POP_{t-i} \\ &+ \sum_{i=1}^{q} \beta_{7i} \Delta \ln GDP_{t-i} + \beta_{8i} CE_{t-1} + \beta_{9i} \ln FR_{t-1} + \beta_{10i} REC_{t-1} \\ &+ \beta_{11i} NREC_{t-1} + \beta_{12i} \ln EE_{t-1} + \beta_{13i} \ln POP_{t-1} + \beta_{14i} \ln GDP_{t-1} \\ &+ \beta_{15i} ECT_{t-1} + et \end{aligned} \tag{3}$$

In Equation 3, $\Delta$ represents the difference operator in the model's short-run estimates of the series; $\beta_0$ is the constant in the ARDL technique; $\beta_1$ through to $\beta_7$ are the ARDL short-run estimation coefficients; $\beta_8$ through to $\beta_{14}$ are the long-run estimation coefficients; $\beta_{15}$ is the error correction term (ECT)'s coefficient; et is the white error noise which caters for the omitted indicators.

In this research, we also test for slope heterogeneity, which is also essential in identifying the most suitable method of data analysis. Therefore, because of the presence of slope heterogeneity and CD, panel ARDL cannot be used since it does not overcome these issues, rather the CS-ARDL method is used. The CS-ARDL model is attributed to the work of Chudik and Pesaran (2015) and is a modification of the traditional ARDL model, which is structured to overcome CD, dynamics, and heterogeneity problems. It is observed that many panel datasets exhibit for cross-sectional dependence and a model that corrects this problem, such as the CS-ARDL technique is required. The CS-ARDL method overcomes, heterogeneity, dynamics, and CD problems. To ensure that the findings presented by the CS-ARDL are robust, we employ the AMG method of Eberhardt and Bond (2009), Eberhardt and Teal (2010), and the CCEMG method of Pesaran (2006). The AMG and CCEMG methods overcome heterogeneity, dynamics, and CD problems. They give reliable outcomes regardless of CD, dynamics, and heterogeneity issues. The findings of all three methods are compared and contrasted. The residual diagnostic tests of CD are also run to ensure that these methods have successfully overcome CD problems.

## Results

The preliminary test outcomes of Pesaran (2015)'s CD test is crucial to understand the presence of CD in a panel data. Panel data that exhibit for CD requires the SG methods of unit root test. However, if no CD exists in the panel data, then first-generation (FG) methods of unit root can be used. Table 3 gives the outcomes of CD test, based on Pesaran (2015). The outcomes of the CD test in Table 3 illustrates that all the indicators CE, NRE, RE, population size, forest resources, EE, and GDP have CD problems; therefore, SG unit root test methods that overcome SG should be employed, for all indicators in all three regions.

Due to the presence of CD in the panel dataset employed, in this research, the SG methods of unit root test of Levin-Lin-Chu, Fisher-type, and Im-Pesaran-Shin are employed. Table 4 gives the findings of the

**Table 3** Pesaran (2015) CD test (source: authors' own estimations and presentation)

| *Variables* | Economic regions | | | | | |
|---|---|---|---|---|---|---|
| | E7 | | G7 | | ECOWAS | |
| | *CD test* | *p-value* | *CD test* | *p-value* | *CD test* | *p-value* |
| *CE* | 18.54 *** | 0.000 | 22.48*** | 0.000 | 35.63*** | 0.000 |
| *NREC* | 22.24 *** | 0.000 | 24.83*** | 0.000 | - | - |
| *REC* | 20.75 *** | 0.000 | 18.85*** | 0.000 | 41.52*** | 0.000 |
| *lnPOP* | 11.83 *** | 0.000 | 17.71*** | 0.000 | 55.71*** | 0.000 |
| *lnFR* | −3.72 *** | 0.000 | 8.36*** | 0.000 | - | - |
| *lnEE* | 23.53 *** | 0.000 | 25.09*** | 0.000 | 26.63*** | 0.000 |
| *lnGDP* | 22.86 *** | 0.000 | 21.10*** | 0.000 | 51.00*** | 0.000 |

* stands for 10% significant; ** stands for 5% significant; *** stands for 1% significant

Levin-Lin-Chu, Fisher-type, and Im-Pesaran-Shin test of unit root. The unit root test results of Levin-Lin-Chu, in Table 4, concur with the outcomes of Im-Pesaran-Shin unit root test, by showing that CE, NRE, RE, log of EE, and log of GDP, the E7 nations, are non-stationary in their level form. These variables are observed to be stationary at first-difference. Moreover, it is also observed that the log of population size and the log of forest resources are stationary at level, see the findings of Im-Pesaran-Shin and Levin-Lin-Chu tests in Table 4. In the case of the G7 and ECOWAS nations, the findings of the Im-Pesaran-Shin and Fisher-type tests depict that CE, NRE, RE, EE, and the log of GDP are not stationary in the level form, but stationary in the first-difference form. Furthermore, we observe that forest resources and log of population size, of the G7 and ECOWAS, are stationary in the level form as per the outcomes of the Fisher-type test, while the Im-Pesaran-Shin test shows that these indicators are not stationary in the level form. The log of population as per the Im-Pesaran-Shin tool, for both the G7 and ECOWAS, however is stationary in the first-difference form. The unit root test of this research shows that some variables are stationary at level, while others are stationary at first-difference. Therefore, this research employs a model that works with indicators that are integrated of both order zero and one, such as the ARDL model.

The test of cointegration of Kao, Westerlund, and Pedroni are employed to determine the existence of a long-run association among the indicators specified in the model, for all the three regions. The outcomes provided in the Table 5 show the existence of a significant long-run association among the indicators. The results show that the series employed in the present research model are cointegrated. Therefore, since there is a significant cointegration relationship in a model, we employ the CS-ARDL model that provides both short-run and long-run coefficients of the model.

Moreover, this research checks the slope heterogeneity of the model to determine if the model has significant heterogeneity problems. The findings of the slope heterogeneity test, for the model in the three regions, are given in Table 6. The outcomes given in Table 6 provide the presence of heterogeneity in the models. Therefore, a research method of analyzing data that is strong over heterogeneity problems needs to be used. This research employs the CS-ARDL technique, because it is strong over heterogeneity, CD, and dynamics. In addition to employing the CS-ARDL tool, the AMG and CCEMG techniques, which provide significant outcomes in the presence of CD are employed to check the robustness of the findings given by the CS-ARDL tool. The CS-ARDL model is a modification of the traditional ARDL technique of Pesaran et al. (1997, 1999, 2001); hence, it works with indicators which are integrated of different orders.

**Table 4** Results of unit root (source: authors' own estimations and presentation)

| Variables | Economic regions | | | | | |
|---|---|---|---|---|---|---|
| | E7 | | G7 | | ECOWAS | |
| | *Levin-Lin-Chu z-statistic* | *Im-Pesaran-Shin z-statistic* | *Im-Pesaran-Shin z-statistic* | *Fisher-type t-statistic* | *Im-Pesaran-Shin z-statistic* | *Fisher-type t-statistic* |
| *CE* | 0.8210 | 2.6031 | 2.8570 | 2.4994 | 3.0553 | 2.6825 |
| *NREC* | 4.4322 | 3.2184 | 4.3181 | 4.1971 | - | 1.7031 |
| *REC* | 0.5116 | 1.7835 | 7.6326 | 4.4447 | 2.0643 | 2.2267 |
| *lnPOP* | −1.7880** | −7.7874*** | 0.9436 | 3.5960*** | 7.5824 | −6.9806*** |
| *lnFR* | −0.01*** | −4.0746*** | −1.3185* | −2.6510*** | - | 12.3259*** |
| *lnEE* | 4.6985 | 3.3456 | 3.6720 | 3.6120 | 2.7235 | 2.3601 |
| *lnGDP* | -0.9541 | 2.4969 | 0.2301 | 0.2969 | 5.6115 | 5.2445 |
| *ΔCE* | −3.5802*** | −6.0462*** | −7.7775*** | -12.4402*** | −10.9844*** | −17.0515*** |
| *ΔNRE* | −5.7665*** | −7.5296*** | 7.5569*** | 11.3741*** | | 11.1137*** |
| *ΔREC* | −4.2683*** | −6.9160*** | −6.4227*** | 9.5972*** | −10.9326*** | −16.8631*** |
| *ΔlnEE* | −5.7524*** | −7.5001*** | −7.4992*** | −16.8900*** | −8.3885*** | 13.0006*** |
| *ΔlnGDP* | −5.0020*** | −6.3528*** | 5.6584*** | −7.5312*** | −10.6378*** | −16.0303*** |
| | | | 5.9675*** | | 2.1503** | |

Δ stands for first-difference operator; * stands for 10% significant; ** stands for 5% significant; *** stands for 1% significant

**Table 5** Results of cointegration test (source: authors' own estimations and presentation)

| | Economic regions | | | | | |
|---|---|---|---|---|---|---|
| | E7 | | G7 | | ECOWAS | |
| | *t-Statistic* | *p-value* | *t-Statistic* | *p-value* | *t-Statistic* | *p-value* |
| Kao test | | | | | | |
| *Modified DF* | −8.6014 *** | 0.0000 | −7.2942*** | 0.0000 | −2.0210** | 0.0216 |
| *DF* | −1.3417* | 0.0898 | −2.3351*** | 0.0098 | −1.5533* | 0.0602 |
| *ADF* | −1.4557* | 0.0727 | −2.4215*** | 0.0077 | −1.6959** | 0.0450 |
| *Unadjusted modified DF* | −8.6014*** | 0.0000 | −7.2942*** | 0.0000 | −2.3253** | 0.0100 |
| *Unadjusted DF* | −1.3417* | 0.0898 | −2.3351*** | 0.0098 | −1.6889** | 0.0456 |
| Pedroni test | | | | | | |
| *Modified PP* | 1.7512** | 0.0400 | 2.1385** | 0.0162 | 1.9110** | 0.0280 |
| *PP* | −4.5181*** | 0.0000 | −0.8629 | 0.1941 | −1.6431* | 0.0502 |
| *ADF* | −2.3254*** | 0.0100 | −1.0338 | 0.1506 | −2.2725** | 0.0115 |
| Westerlund test | | | | | | |
| *Variance ratio* | −1.3789* | 0.0840 | 0.1280 | 0.4491 | −1.9086** | 0.0282 |

DF stands for Dickey-Fuller; ADF stands for augmented Dickey-Fuller; PP stands for Phillips Perron; * stands for 10% significant; ** stands for 5% significant; *** stands for 1% significant

At this juncture, we present the findings of the CS-ARDL, AMG, and the CCEMG techniques. We begin by presenting the outcomes observed from the G7 countries, followed by the outcomes of the west African countries, and lastly the outcomes of the E7 countries. Table 7 gives the outcomes of the CS-ARDL, AMG, and the CCEMG techniques for the G7 countries. The findings of the short-term estimations provided in Table 7 depict that RE gives a significant negative effect on CE in the G7 countries. The CS-ARDL technique and the CCEMG tool concurs that RE, in the short run and among the G7 countries, is essential in reducing CE. The findings depict that a rise in RE among the G7 countries has the impact of reducing CE by 0.099 and 0.119 units, according to the findings of the CS-ARDL and the CCEMG techniques respectively. The findings of the AMG technique show that RE is not significant in reducing or affecting CE among the G7 countries. In addition to that, we observe that forest resources, according to the findings of the CS-ARDL and the AMG technique, do not provide any significant impact on CE among the G7 countries in the short run. However, the CCEMG tool show that forest resources significantly reduce CE in the short run in the G7 countries. The findings of the CCEMG tool in Table 7 depict that increasing RE by a single unit has the impact of reducing CE by 2.05 units in the short run. We also observe, according to the findings of the CS-ARDL, AMG, and the CCEMG techniques, that EE provides a significant impact on CE among the G7 countries. The findings of the three methods depict that EE significantly reduces CE in the G7 countries, such that when EE is promoted by a single percent it will have the impact of reducing CE by 4.98%, 0.297%, and 5.78%, according to the findings of the CS-ARDL, AMG, and the CCEMG techniques respectively. Therefore, it is crystal clear, according to the findings provided by the three methods in Table 7,

**Table 6** Slope heterogeneity test results (source: authors' own estimations and presentation)

| | Economic regions | | | | | |
|---|---|---|---|---|---|---|
| | E7 | | G7 | | ECOWAS | |
| | *Delta* | *p-value* | *Delta* | *p-value* | *Delta* | *p-value* |
| | 11.604*** | 0.000 | 15.576*** | 0.000 | 11.647*** | 0.000 |
| *adj.* | 13.551*** | 0.000 | 17.789*** | 0.000 | 13.951*** | 0.000 |

* stands for 10% significant; ** stands for 5% significant; *** stands for 1% significant

**Table 7** G7 results (source: authors' own estimations and presentation)

| | CS-ARDL | | AMG | | CCEMG | |
|---|---|---|---|---|---|---|
| | *Coefficient* | *z-statistic* | *Coefficient* | *z-statistic* | *Coefficient* | *z-statistic* |
| *Short-run estimations* | | | | | | |
| *L.CE* | 0.0059 | 0.13 | | | | |
| *REC* | −0.0987 | 2.83*** | 0.0943 | 1.62 | −0.1192 | −2.19** |
| *FR* | −19.5295 | −0.99 | −1.3732 | −1.07 | −2.0522 | −2.01** |
| *lnPOP* | 0.8008 | 0.08 | −6.2684 | −0.59 | 8.2831 | 0.83 |
| *lnEE* | −4.9805 | −4.75*** | −0.2969 | −15.06*** | −5.7820 | −6.97*** |
| *lnGDP* | 5.6636 | 5.90*** | 0.3336 | 0.79 | 5.9138 | 9.42*** |
| *NREC* | 0.1149 | 2.28** | 0.1120 | 5.00*** | 0.0636 | 2.25** |
| *Long-run estimations* | | | | | | |
| *REC* | −0.1053 | −2.86*** | | | 0.0899 | 2.60*** |
| *FR* | −15.9569 | −0.98 | | | 0.3016 | 0.14 |
| *lnPOP* | 2.2224 | 0.21 | | | 16.7886 | 0.46 |
| *lnEE* | −5.18102 | −4.29*** | | | 5.7361 | 16.47*** |
| *lnGDP* | 5.9187 | 5.04*** | | | −5.1547 | -4.30*** |
| *NREC* | 0.1143 | 2.25** | | | 0.0453 | 0.60 |
| *CD statistic* | | −1.84* | | −1.316 | | 2.006** |

* stands for 10% significant; ** stands for 5% significant; *** stands for 1% significant

that RE, forest resources, and EE are essential in reducing CE among the G7 countries in the short run. Therefore, policies towards improving the use of RE, improving forest resources, as well as enhancing EE should be adopted.

The short-run estimation outcomes presented in Table 7 also show that GDP and NRE are the main factors that are responsible for promoting CE among the G7 countries. According to the findings presented by the CS-ARDL and the CCEMG techniques, increasing GDP by a single percent in the short run has the effect of raising CE by 5.66% and 5.91% respectively. While the findings provided by the CS-ARDL and the CCEMG tools show that GDP significantly affects CE in the short run, the AMG outcomes show that this relationship is not strong. However, it is crystal clear from the findings provided by the CS-ARDL and the CCEMG techniques that GDP strongly promotes CE in the short run, among the G7 countries. In addition to that, it is observed according to the short-run estimation outcomes in Table 7 that raising NRE by a single percent in the short run has the effect of raising CE by 0.115%, 0.112%, and 0.064%, according to the findings of the CS-ARDL, AMG, and the CCEMG techniques respectively. This shows that the three methods presented in this research concur on the fact that using NRE promotes CE among the G7 countries. Population size, according to the short-term estimations of all the three methods in Table 7, has no significant effect on CE. Therefore, policies that are meant towards reducing the use of energy sources that are harmful to the environment should be adopted for the purpose of reducing CE.

The long-run outcomes of the CS-ARDL and the CCEMG techniques, presented in Table 7 of the G7 countries, are not in agreement. The findings of the CS-ARDL tool show that RE and EE are significant in reducing CE among the G7 countries in the long run, while GDP and NRE have the effect of raising CE in this region, in the long run. According to the CS-ARDL tool, raising RE by a single unit in the long run has the effect of reducing CE by 0.105 units in the long run, and raising EE by a single percent has the effect of reducing CE by 5.18% in the long run. The CS-ARDL findings also show that increasing GDP by a single percent in the long run, among the G7 countries has the effect of promoting CE by 5.92%, while increasing the use of NRE by a single unit tends to raise CE by 0.114 units. These findings show that RE and EE are essential in promoting a clean environment through lowering the levels of CE among the G7 countries, while the use of NRE and those activities meant to increase economic growth, but are harmful to the environment should be shunned. However, the findings presented by the CCEMG technique show that RE and EE positively impact CE among the G7 countries in the long run, while GDP has the effect of reducing CE in this region, and NRE do not provide any significant effect. The long-run estimation outcomes of the CCEMG in Table 7 show that raising RE by a single unit has the effect of raising CE by 0.089 units, while raising EE by a single percent has the effect of raising CE by 5.736%. The CCEMG long-run estimations also depict that raising GDP by a single percent has the effect of reducing CE by 5.15%. The difference is observed among the outcomes of the CS-ARDL and the CCEMG technique, because the CCEMG technique has failed to overcome the effects of CD; hence, biased results may be presented. Therefore, the present research upholds the outcomes presented by the CS-ARADL technique which has managed to overcome the issues of CD.

Table 8 presents the outcomes of the west African countries, for the three methodologies of data analysis, that is, the CS-ARDL, AMG, and the CCEMG techniques, employed. The findings of these three methodologies of data analysis are compared and contrasted in order to formulate proper policies to reduce CE in this region. The short-run estimation outcomes of the CS-ARDL, AMG, and the CCEMG techniques EE are essential in reducing CE among the west African countries, while GDP is responsible for exacerbating the CE in this region. The findings show that raising RE by a single unit in the short run has the effect of reducing CE among the west African countries by 0.0079, 0.0084, and 0.0089 units respectively, according to the findings of the CS-ARDL, AMG, and the CCEMG techniques. We also observe according to the findings of the short-run estimates given in Table 8 that raising EE by a single percent has the effect of reducing CE in the west African countries by 0.33%, 0.29%, and 0.285%, according to the findings of the CS-ARDL, AMG, and the CCEMG techniques respectively. Furthermore, the short-run estimate outcomes presented in Table 8 also show that raising GDP by a single percent has the effect of promoting CE by 0.37%, 0.3%, and 0.34%, according to the findings of the CS-ARDL, AMG, and the CCEMG techniques respectively. The other series, forest resources, population size, and NRE do not significantly impact CE among the west African countries in the short run.

In addition to that, the long-run estimation outcomes presented in Table 8 of the CS-ARDL and

**Table 8** ECOWAS results (source: authors' own estimations and presentation)

| | CS-ARDL | | AMG | | CCEMG | |
|---|---|---|---|---|---|---|
| | *Coefficient* | *z-statistic* | *Coefficient* | *z-statistic* | *Coefficient* | *z-statistic* |
| *Short-run estimates* | | | | | | |
| *L.CE* | −1.0238 | −18.83*** | | | | |
| *REC* | −0.0079 | −4.18*** | −0.0084 | 6.13*** | −0.0089 | −3.71*** |
| *FR* | −0.1658 | −0.80 | 0.0050 | 0.56 | −0.0240 | −1.47 |
| *lnPOP* | −2.8024 | −1.06 | 0.5183 | 1.22 | −1.3344 | −0.73 |
| *lnEE* | −0.3322 | −4.14*** | −0.2948 | −3.93*** | −0.2851 | −2.34** |
| *lnGDP* | 0.3729 | 4.02*** | 0.3036 | 3.95*** | 0.3425 | 2.70*** |
| *NREC* | 0.0007 | 0.46 | 0.00003 | 0.07 | −0.00001 | −0.02 |
| *Long-run estimates* | | | | | | |
| *REC* | −0.0039 | −4.18*** | | | 0.0058 | 2.24** |
| *FR* | −0.0713 | −0.78 | | | −0.0309 | −0.98 |
| *lnPOP* | −1.2477 | −1.07 | | | 0.2713 | 0.73 |
| *lnEE* | −0.1613 | −4.44*** | | | 0.0966 | 1.04 |
| *lnGDP* | 0.1805 | 4.30*** | | | −0.1647 | −1.59 |
| *NREC* | 0.0004 | 0.55 | | | 0.0001 | 1.53 |
| *CD* | | −1.91* | | −2.344** | | −2.136** |

* stands for 10% significant; ** stands for 5% significant; *** stands for 1% significant

the CCEMG techniques provide different findings. The long-run estimation findings of the CS-ARDL technique depict that RE and EE are the main factors that are responsible for reducing CE among the west African countries in the long run, while GDP tends to promote CE in this region. The long-run findings of the CS-ARDL tool depict that raising RE by a single unit, in the long run, has the effect of reducing CE by 0.0039 units, while raising EE by a single percent significantly reduces the CE by 0.16%. The long-run findings of the CS-ARDL technique also depict that raising GDP by a single percent will significantly increase CE by 0.18%. The long-run estimation outcomes of the CS-ARDL tool also depict that forest resources and population size do not significantly impact CE in the west African region. However, the findings of the CCEMG technique show that RE improvement has the effect of promoting CE among the west African countries in the long run, while the other factors do not significantly impact CE. The differences observed on the long-run estimation outcomes of the CS-ARDL and the CCEMG techniques is due to the fact that the CCEMG technique has failed to overcome the problem of CD, as indicated by the CD statistic which is significant at 5%. Therefore, the findings of the CS-ARDL technique are upheld in the present research.

Table 9 presents the outcomes of the CS-ARDL and the CCEMG techniques for the E7 countries. The AMG has been dropped in analyzing the dataset of the E7 countries because it has produced insignificant results, hence no reason to include it. The short-run estimation outcomes presented in Table 9 of the E7 countries show that RE and population size are vital in reducing CE in this region, while GDP is the main factor that is responsible for promoting emissions among the E7 countries. The short-run estimation outcomes depict that raising RE by a single unit in the short run has the impact of reducing CE by 0.039 and 0.042 units, according to the CS-ARDL and the CCEMG techniques respectively. Moreover, reducing the size of the population by a single percent in the short run has the effect of reducing CE by 19.29% and 9.67%, according to the findings of the CS-ARDL and the CCEMG techniques respectively. While the CS-ARDL tool show that EE might have the impact of reducing CE among the E7 countries, it is not statistically significant at the level of 5%, but significant at 10%. These findings show that improving RE use, enhancing EE and reducing the size of the population, among the E7 countries, in the short run, will significantly reduce CE in this region. The findings of the short-run estimations in Table 9 also depict that, at the level of 10%, GDP positively impact CE

**Table 9** Results from E7 (source: authors' own estimations and presentation)

| | CS-ARDL | | CCEMG | |
|---|---|---|---|---|
| | *Coefficient* | *z-statistic* | *Coefficient* | *z-statistic* |
| *Short-run estimations* | | | | |
| *L.CE* | −0.8367 | −6.77*** | | |
| *REC* | −0.0390 | −2.53** | −0.0415 | −2.52** |
| *lnFR* | −35.6679 | −1.52 | 6.9627 | 1.01 |
| *lnPOP* | −19.2981 | −1.84* | −9.6738 | −2.05** |
| *lnEE* | −0.6369 | −1.71* | −0.0661 | −1.58 |
| *lnGDP* | 0.7406 | 1.89* | 0.2264 | 1.65* |
| *NREC* | −0.0532 | −1.76* | −0.0009 | −0.03 |
| *Long-run estimations* | | | | |
| *REC* | −0.0205 | −2.27** | 0.13423 | 3.15*** |
| *lnFR* | −18.4521 | −1.55 | −0.0202 | −1.12 |
| *lnPOP* | −9.5649 | −1.98** | 29.5846 | 1.05 |
| *lnEE* | −0.3676 | −1.77* | −.1009 | −0.42 |
| *lnGDP* | 0.4376 | 1.98** | 0.4869 | 2.06** |
| *NREC* | −0.0308 | −1.82* | 0.0479 | 0.66 |
| *CD Statistic* | | 0.31 | | 1.13 |

* stands for 10% significant; ** stands for 5% significant; *** stands for 1% significant

among the E7 countries, such that raising GDP by a single percent in the short run raises CE among the E7 countries by 0.74% and 0.226%, according to the CS-ARDL and the CCEMG outcomes. While the effect of GDP is not strong, according to the short-run findings of the E7 countries, its positive coefficient and statistical significance at 10% show that engaging in economic activities that are meant to promote economic growth, but harm the environment should be shunned among the E7 countries. NRE has negative coefficients as per the short-run estimations of both methodologies employed, but this is not statistically significant; hence, it does not significantly impact CE in the short run among the E7 countries.

The long-run estimation outcomes presented in Table 9 of the CS-ARDL technique depicts that RE, population size, and EE are the main factors that are responsible for reducing CE among the E7 countries, while GDP significantly promotes CE in this region. The long-run estimation outcomes of the CS-ARDL tool depicts that raising RE by a single unit significantly reduces CE by 0.02 units in the long run, while raising population size and EE by a single percent reduces CE by 9.56% and 0.37% respectively. The CS-ARDL's long-run estimation outcomes for EE is not significant at 5%, but significant a 10% showing that there is no strong association with CE. However, EE remains one of the most important factors in reducing CE. Moreover, the long-run estimations outcomes of the CS-ARDL show that raising GDP by a single percent has the effect of raising CE by 0.44%. Forest resources and NRE are observed to have a negative coefficient, according to the findings of the CS-ARDL technique, but these findings are not statistically significant depicting that their association with CE in the E7 region is not statistically strong. The positive effect of GDP on CE is also supported by the findings of the CCEMG technique which shows that raising GDP by a single percent has the effect of raising CE among the E7 countries by 0.49%. However, the CEMG long-run estimations show that RE positively affects CE in the E7 countries, which is in contrary to the postulations of the CS-ARDL technique. Both the CS-ARDL technique and the CCEMG technique outcomes show that CD problems have been successfully overcome, hence robust results are presented. However, in the presence of different outcomes presented by these two methods, we uphold the findings presented by the CS-ARDL technique which has been consistent in giving robust outcomes in the findings presented in the preceding regions, see Table 7 and Table 8.

## Discussion

The findings of the current research are of paramount importance to environmentalists, engineers, economists, and governments at large, in ascertaining the proper policy actions to implement and achieve carbon neutrality goal in the G7, E7, and west African nations. The present findings are also crucial in answering the research questions outlined in the introduction section. Firstly, it is essential to ascertain the importance of the three methods of data analysis, the CS-ARDL, AMG, and CCEMG techniques, in the present research. These methods of data analysis are preferred under circumstances, such as the ones presented in the present research, where significant heterogeneity and CD problems are present because they overcome these issues, hence presenting robust outcomes. In the results of the G7 countries, the findings presented by the CS-ARDL and AMG tools are upheld, since these two methods successfully overcome CD problems. The CCEMG technique failed to overcome CD problem, hence its findings cannot be relied on. In the findings of the west African countries, the findings of the CS-ARDL technique are upheld, since it has successfully overcome CD problem, while the AMG and CCEMG failed to overcome CD problem, hence may present biased outcomes. Moreover, in the findings of the E7 countries, both CS-ARDL and CCEMG techniques successfully overcome CD problems; hence, its findings are robust. However, in the event of different outcomes presented by the two models, we rely on the findings of the CS-ARDL technique which has been consistent in providing robust outcomes in the dataset of the other regions. Secondly, the present outcomes are essential because they compare the factors that affect environmental degradation in the three crucial world economic regions, the G7, E7, and west African countries. This is essential in comparing on whether RE, EE, NRE, forest land, population size, and GDP impacts CE in the same or different manner across all the three regions.

The findings show that in all the three regions, CE is reduced through the use of RE and EE, depicting the importance of RE and EE in promoting the quality of the environment across all regions. The study findings support the findings of past researchers on the significant negative effect of RE on CE (Abbas et al., 2021; Ajide & Mesagan, 2022; Akadiri & Adebayo, 2022; Akram et al., 2022; Balsalobre-Lorente & Leitão, 2020; Banga et al., 2022; Bhat, 2018; Deka et al., 2022; Mathiesen et al., 2011). We also provide in the present research that there are no asymmetries on the effect of RE among the three regions. RE has been long pointed as an appropriate source of energy which improves environmental quality. However, RE has been observed as more exorbitant in comparison with NRE, hence making it difficult for poor-financial resource nations to consume it; however the long-term cost of RE is relatively low compared to the cost of NRE, plus its health and environmental costs (Becker & Fischer, 2013). Therefore, it is recommended to utilize RE sources, which is safe to the environment and has relatively lower long-term costs compared to NRE. However, the findings of this study differ from few other studies which give for the existence of a positive effect of RE use on CE (Anser et al., 2021). The outcomes of Adedoyin et al. (2020) show that the generation of RE causes an increase in CE. On the other hand, Menyah and Wolde-Rufael (2010) allude that RE and CE are not significantly associated. These differences on the empirical results can be directed to differences in the economic conditions of different societies, as well as the differences in the methods employed. Some methods do not give robust results; hence, a more robust methodology needs to be employed when carrying out research. The other major factor that reduces CE in the E7, G7, and ECOWAS is EE. These outcomes are in support of Akram et al. (2022); Deka et al. (2022); Razzaq et al. (2021); Zakari et al. (2022); Ponce and Khan (2021) who provides for a significant negative effect of EE on environmental degradation. Thus, energy should be efficiently utilized without wasting it.

Forest resources are observed to negatively affect CE in the G7 countries, according to the findings presented by the CCEMG technique, though this technique has failed to overcome CD problems, hence the possibility of presenting biased outcomes. This shows that forest resources are vital in reducing the CE in the G7 countries, hence reducing the degradation of the environment. The findings of the CS-ARDL technique of the G7 countries which successfully overcome CD problem shows that the coefficient of forest resources is negative but insignificant. Moreover, findings from other regions, the E7 and west African countries give a negative coefficient of forest resources with insignificant $z$-statistics. Therefore, while forest resources may have a tendency of lowering CE, its influence is statistically insignificant, and hence cannot be relied on for making policies. The negative coefficients of forest resources in the G7 and west African regions as shown by the CS-ARDL tool show that forest resources are essential in reducing CE. This implies that when more trees are used as timber, this will further degrade the environment. These findings concur with the postulations of past researches which observe natural resources to significantly decrease EF (Ali et al., 2022; Amer et al., 2022). This implies that natural resources are crucial in enhancing environmental quality. In essence, Raihan and Tuspekova (2022) show that if forest area is increased CE will decrease, because trees inhale $CO_2$ and exhales oxygen; hence, the intensive use of forest resources should promote environmental degradation.

In addition to that, NRE positively influence CE in the G7 countries, do not significantly influence CE in the west African nations and negatively influence CE in the E7 countries. This shows that NRE has different effects on CE across the three different regions. NRE is generally known for exacerbating environmental degradation, and a negative or insignificant effect observed in the E7 and west African countries can be best explained by the policies adopted by these countries to shift to clean energy sources. The positive effect of NRE on CE in the G7 countries is supported by past studies (Ajide & Mesagan, 2022; Akadiri & Adebayo, 2022; Bakhsh et al., 2022; Banga et al., 2022; Boukhelkhal, 2021; Deka et al., 2022). Therefore, NRE must be shunned, countries should shift to the consumption of RE sources. This research also observes in its findings that, GDP positively impacts CE. This shows that economic growth is directly related with environmental degradation in these regions, hence the importance of ensuring the use of energy sources which promote growth, but do not harm the environment. These findings concur with the postulations of Ali et al. (2022) that economic growth increases ecological pressure. Just as energy use and NRE posits for a significant positive effect on EF, economic growth also positively affects CE (Ansari, 2022; Asif et al., 2021; Boukhelkhal, 2021). Moreover, past studies give that CE is significantly impacted by economic growth

(Abbas et al., 2021; Akadiri & Adebayo, 2022; Balsalobre-Lorente & Leitão, 2020; Ben Mbarek et al., 2018; Bouyghrissi et al., 2021), hence supporting the results of the current research. Lastly, population size is only observed to reduce CE in the E7 countries, while in the other regions, it does not have any significant effect. The west African nations gives a negative coefficient of population size which might imply that population size reduces CE, but it is insignificant, while the G7 gives a positive coefficient of population which is insignificant too.

## Conclusion

The current research compares and contrasts the findings of the three major economic blocks, that is, E7, G7, and west African nations from 1990 to 2019, and employs the CS-ARDL, AMG, and CCEMG techniques which gives robust results in the presence of dynamics, CD, and heterogeneity. We show that CS-ARDL tool is a powerful tool in overcoming CD problems; hence, research that uses data which has CD problems must rely on the CS-ARDL tool. We also show that RE and EE are the main factors which reduces the emission of carbon across all three regions. GDP exacerbates CE in all the three regions. NRE increases CE, while forest resources reduce CE in the G7 nations. The current study gives crucial theoretical and practical implications. Firstly, it shows that EE is crucial in reducing environmental degradation. An increase in energy efficiency is associated with a decrease in the emissions of carbon content in the atmosphere. These study results show how crucial it is to manage the use of energy in the production of goods and services, ensuring that each unit of energy is channeled in such a way that it produces maximum output. Therefore, wastage of energy is one factor that enhances environmental degradation. Secondly, the findings of this research concur with the theoretical implications of past studies which gives RE as a driver of environmental quality. RE is one of the major factors that can significantly promote carbon neutrality goal. Thirdly, this study results highlight the importance of forest resources in achieving environmental quality. Trees and forests need to be preserved by putting laws that restrict unnecessary cutting down of trees and/or license timber companies by giving them quotas on the number of trees to be cut each year.

### Policy recommendations

- The use of RE must be promoted. Nations should encourage the shift from using NRE to the use of RE sources, since RE sources reduces emissions of carbon and NRE sources promotes emissions of carbon.
- Planting of more trees and preservation of forests should be promoted to deter environmental degradation in the world.
- Energy efficiency improvements are necessary to ensure that each unit of energy is channeled towards that production of the highest possible level of output, avoiding wastage of energy in order to achieve carbon neutrality goal.

### Future study direction

Future studies need to provide a detailed examination on the relationship between forest resources and CE, in other world regions, since the present research is only limited to the G7, E7, and west African regions. The current study gives an important insight on this important association; however, more work is needed to be done.

**Acknowledgements** The authors would like to acknowledge the authors of past papers as cited and referenced in this paper. Their contribution to the growing body of literature has made this paper a success

**Author contribution** Thomas Abuobeleye Akpanke Wrote main manuscript text, Abraham Deka analyzed the data and provided results, Mehdi Seraj structured the method and research model, and Huseyin Ozdeser supervised the work. All authors reviewed the manuscript.

**Data availability** The data used in this paper is secondary data and was retrieved from the World Bank, https://data.worldbank.org/ and https://data.oecd.org.

## Declarations

**Ethics approval** All authors have read, understood, and have complied as applicable with the statement on “Ethical responsibilities of Authors” as found in the instructions for authors.

**Consent to participate** Not applicable.

**Consent to publish** The authors guarantee that this manuscript has not been previously published in other journals and is not under consideration by other journals. The authors also guarantee that this manuscript is original and is their own work.

**Competing interests** The authors declare no competing interests.

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