Received: 4 April 2021 | Revised: 16 October 2021 | Accepted: 10 November 2022

DOI: 10.1111/1477-8947.12275

ORIGINAL ARTICLE

NRF NATURAL RESOURCES FORUM WILEY

Toward sustainable use of natural resources: Nexus between resource rents, affluence, energy intensity and carbon emissions in developing and transition economies

Chinazaekpere Nwani[1] | Festus V. Bekun[2,3] | Bright A. Gyamfi[4] | Ekpeno L. Effiong[5] | Andrew A. Alola[6,7]

[1]Department of Economics and Development Studies, Alex Ekwueme Federal University, Ndufu-Alike, Nigeria

[2]Faculty of Economics Administrative and Social sciences, Istanbul Gelisim University, Istanbul, Turkey

[3]Adnan Kassar School of Business, Department of Economics, Lebanese American University, Beirut, Lebanon

[4]School of management, Sir Padampat Singhania University, Bhatewar- Udaipur, India

[5]Department of Economics, University of Uyo, Uyo, Nigeria

[6]CREDS-Centre for Research on Digitalization and Sustainability, Inland Norway University of Applied Science, Elverum, Norway

[7]Faculty of Economics, Administrative and Social Sciences, Nisantasi University, Istanbul, Turkey

Correspondence
Chinazaekpere Nwani, Department of Economics and Development Studies, Alex Ekwueme Federal University, Ndufu-Alike, Ebonyi State, Nigeria.
Email: nwani.chinazaekpere@funai.edu.ng; nwanichinaza@gmail.com

Abstract

Sustainable use of natural resources would entail ensuring that derived economic benefits today do not undermine the welfare of generations to come. On this basis, this study examines the nexus between natural resource rents and carbon dioxide (CO_2) emissions disaggregated into production and consumption-based (i.e., trade-adjusted) CO_2 emissions for a selected panel of 45 developing and transition economies over the period 1995–2017. The empirical model also incorporates the impacts of population, affluence, and energy intensity. The results show that affluence increases production-based CO_2 emissions by 1.407%, with the EKC's predicted inverted U-shaped curve only explaining consumption-based CO_2 emissions. Economic reliance on natural resource rents and energy intensification contribute 0.022% and 0.766%, respectively, to CO_2 emissions embedded in territorial production inventories and 0.035% and 0.583%, respectively, to CO_2 emissions embedded in consumption inventories. The bootstrap non-causality test shows that historical data on each variable has significant predictive power for future CO_2 emissions from both sources. The historical information about natural resource rents has significant predictive power over the future levels of affluence and energy intensity. Clearly, the results show that the environmental impact of natural resource rents is stronger when CO_2 emissions are adjusted for trade and varies among the countries, with Bangladesh, Guinea, India, Malaysia, Mexico, Nigeria, Pakistan, Saudi Arabia, Vietnam, and Zimbabwe among the most affected countries. Overall, this study provides motivation for policies to keep the use of natural resources within sustainable limits.

KEYWORDS
affluence, carbon emissions, energy intensity, environmental sustainability, natural resource rents

1 | INTRODUCTION

Natural resources constitute a significant proportion of the wealth in many countries. The World Bank's report shows that rents from oil, natural gas, coal, minerals, and forest resources in 2018 accounted for about 2.5% of the world's GDP on average, and over 10% of GDP in at least 40 countries, mostly developing and transitioning economies (World Development Indicators [WDI], 2020). Policy discussions in recent years have been directed toward ensuring that derived economic benefits are sustainable (Adedoyin et al., 2020; Badeeb et al., 2020; Danish Baloch et al., 2019; Khan, Hou, Le, & Ali, 2021; Ulucak & Ozcan, 2020; Umar et al., 2020). Following the Brundtland Report (see WCED, 1987), sustainability would entail ensuring that derived economic benefits "meet the needs of the present without compromising the ability of future generations to meet their own needs" (Du Pisani, 2006; Robert et al., 2005). On the basis of this condition, we examine whether economic dependence on resource rents induces unsustainable consumption and production patterns and consequently contributes to the growing environmental challenges, particularly carbon dioxide (CO_2) emissions in developing and transition economies.

This study is motivated by two factors: One, the expansion of the extractive industries drives economic activity in many developing and transition economies (Reed, 2002). A number of recent studies have shown that this pathway to growth has the capacity to create environmental challenges capable of limiting the long-term economic benefits (Edwards et al., 2014; Behrens et al., 2007; Joshua & Alola, 2020; Nathaniel et al., 2020; Nathaniel et al., 2021). A good example is the gas venting and flaring from the production activities of oil and gas firms in Nigeria, Iran, and other oil-rich economies. Two, as an integral part of fiscal policy instruments in many countries, rents are managed by the government (Segal, 2012). Based on the resource curse hypothesis, the government is not efficient in resource allocation due to rent-seeking behavior among public office holders and, consequently, the obligation to align resource distribution with political interests (Graafland, 2019; Tacconi & Williams, 2020). Policy discussions and empirical evidence arguably posit that aligning the distribution of rents to political interests, as evident in fossil fuel subsidies in many developing and transition economies, encourages wasteful consumption and retards the development of clean energy sources (Hertog, 2017; Li & Sun, 2018). These factors underscore the importance of resource rents in understanding the growing environmental sustainability concerns in developing and transition economies. The Global Carbon Project (GCP) (see Friedlingstein et al., 2019) and WDI (World Bank, 2020) show that 10 developing and transition economies, including China, India, Iran, Russia, Saudi Arabia, Indonesia, Mexico, South Africa, Brazil, and Turkey are today among the top 20 contributors to global carbon emissions. This condition, if not mitigated, will significantly limit the attainment of the climate action targets of SDG 13.

The motivation for policies to keep the use of natural resources within sustainable limits in developing and transition economies raises other critical issues, in particular, the need to account for the role of affluence and intensity of energy use. Developing and transition countries follow carbon intensive pathways in their quest for "catch-up" via seeking for higher per capita income and poverty reduction, and are also more energy intensive than developed countries (Wu et al., 2018). Therefore, we include affluence and energy intensity in our empirical model to avoid omitting variable issues. The economic literature has attempted to provide some explanations for the nexus between natural resource rents, affluence, energy intensity, and CO_2 emissions. However, empirical findings are not only diverse but also largely limited to explaining emissions directly generated through the use of fossil fuels in domestic production activities (i.e., emissions calculated using production-based accounting), neglecting the growing environmental impact of trade-induced consumption in developing and transition economies. To address this issue, we use both production-based and trade-adjusted (consumption-based) carbon emissions. Consumption-based accounting calculates carbon emissions by taking into account the indirect contributions, such as carbon emissions embedded in international trade (see Davis & Caldeira, 2010; Karakaya et al., 2019; Rocco et al., 2020). As shown in Figure 1, many developing and transition economies now have more CO_2 emissions embedded in their consumption than production through trade (i.e., net importers of CO_2 emissions). Based on available data, Figure 1 shows that over 80% of countries in Africa and South America are net importers of CO_2 emissions. This condition shows the extent to which the dependence of these economies on overseas production to serve domestic demand contributes to their environmental impacts. Given these gaps in the existing literature, this study examines the nexus between natural resource rents, affluence, energy intensity, and CO_2 emissions embodied in both territorial production activities and trade-induced consumption patterns and lifestyles of developing and transition economies using a large data set of 45 countries from 1995 to 2017.

Our empirical analysis contributes to the existing literature in three key areas.

- First, to the best of our knowledge, this is one of the rare studies to investigate the effects and causal relationship between natural resource rents, population, energy intensity, and affluence on emissions (consumption-based

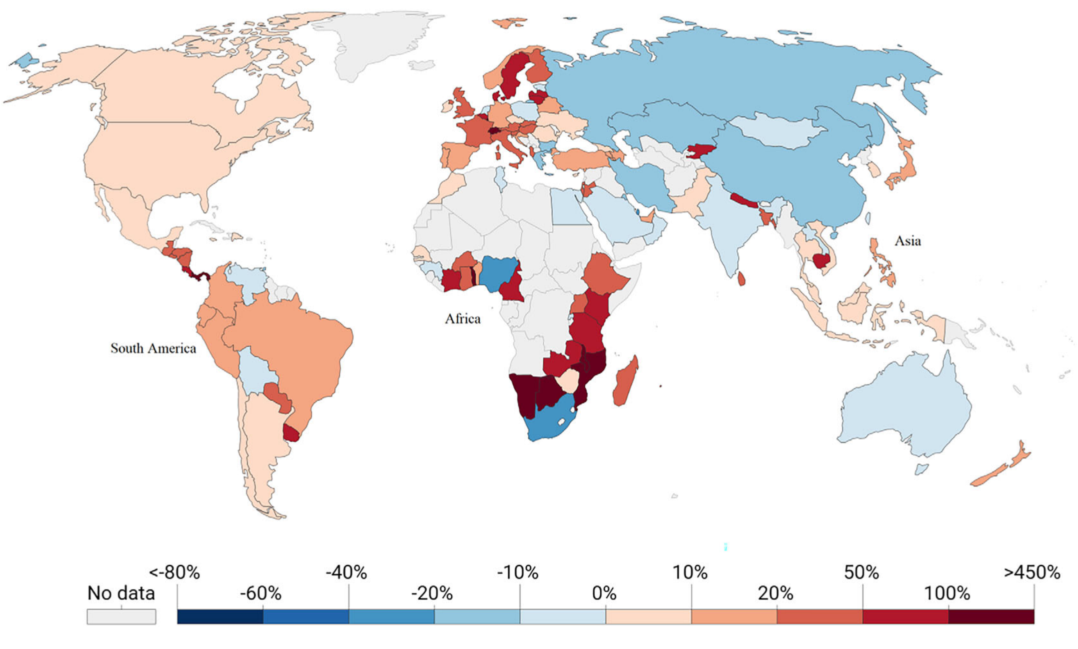

FIGURE 1 Carbon emissions embedded in trade, 2018. Share of CO_2 emissions embedded in trade measured as emissions exported or imported as the % of domestic production emissions. Positive values (in RED) represent net importers of CO_2. Negative Values (in BLUE) represent net exporters of CO_2. *Source*: Global Carbon Budget (see Friedlingstein et al., 2019). Compiled by Our World in Data: https://ourworldindata.org/grapher/share-co2-embedded-in-trade

CO_2 emissions and production-based CO_2 emissions) in developing and transition economies. Thus, taking this direction is important in two ways: (i) it will guide policymakers in the area of identifying an appropriate approach for ensuring sustainable use of resource rents; and (ii) it will help prevent aggregation bias by revealing the differential effects of resource rents based on consumption and production measures of CO_2 emissions.

- Second, we provide both panel and country specific analyses for 45 developing and transition economies, including major contributors to global carbon emissions like China, India, Iran, Russia, Saudi Arabia, Indonesia, Mexico, South Africa, Brazil and Turkey, and other economies with heavy reliance on natural resource rents. An expert review of the literature shows that many of these countries have received limited or no empirical investigation, among them, Guinea, Kazakhstan, Togo, Trinidad and Tobago, Vietnam, and Zimbabwe.
- Third, our econometric approaches distinctly account for cross-sectional dependence and slope heterogeneity issues in the nexus between natural resource rents, affluence, energy intensity, and CO_2 emissions in the case of developing and transition economies. To ensure robust and reliable empirical evidence, we use the second-generation unit root tests suggested by Pesaran (2003, 2007), the error correction panel cointegration test proposed by Westerlund (2007), the Augmented Mean Group (AMG) estimator by Eberhardt and Teal (2010), and the Granger non-causality test of Dumitrescu and Hurlin (2012). The AMG estimator, in a simulation analysis, proved highly robust, unbiased, efficient and reliable in handling CDs in panel data, with no limitations by the stationarity properties of the variables, making unit root and cointegration tests unessential steps (see Eberhardt and Bond, 2009). While the Dumitrescu and Hurlin (2012) Granger causality test in this study helps in showing the true direction of causation among the understudied variables as seen in the procedures in extant studies (Bekun et al., 2019; Khan, Ju, Latif, & Khan, 2021; Shahbaz et al., 2015).

Section 2 provides a brief review of related literature. Section 3 discusses the model and econometric methodologies. Section 4 presents and discusses the empirical results. Section 5 concludes and makes some policy remarks.

2 | REVIEW OF RELATED EXISTING LITERATURE

Some of the earlier studies that modeled CO_2 emissions accounted for the role of natural resource rents, while a number of others focused on the roles of affluence and energy intensity. This section provides a brief summary and review of these studies.

2.1 | Population, affluence, energy intensity, and carbon emissions

Most recent studies have relied on the stochastic impacts by regression on population, affluence, and technology (STIRPAT) equation by Dietz and Rosa (1994) to assess the impact of population, affluence, and energy intensity on CO_2 emissions. For a panel of 11 developing economies using data for the period 1991–2013, Ghazali and Ali (2019) showed that population, affluence and energy intensity increase CO_2 emissions. The study also identified a unidirectional causality running from affluence and energy intensity to CO_2 emissions in the selected countries. In another study, Pham et al. (2020) used data from 28 European countries for the period 1990–2014 and showed that population, affluence, and energy intensity have significant long-run degrading impacts on the environment through growth in CO_2 emissions. Similarly, the empirical results from Liddle (2015), Zhang and Zhao (2019), and Kwakwa et al. (2020) show similar findings for the Organization for Economic Co-operation and Development (OECD) countries, China and Ghana, respectively. Moreover, closer to the case of the OECD countries are the series of studies conducted for the International Energy Agency (IEA) member countries within the framework of socio-economic and environmental sustainability (Khan & Hou, 2021a; Khan & Hou, 2021b). For instance, Khan and Hou (2021a) utilized the fully modified least square (FMOLS) empirical approach for a panel of 38 IEA member countries over the 1995–2018 period and found that both energy utilization and sector-specific economic activity (such as tourism) promote economic prosperity. However, the result further revealed that energy utilization in the examined panel of 38 IEA member countries is detrimental to environmental quality.

Further empirical modeling of the impact of affluence on CO_2 emissions has focused on ascertaining the validity of the Environmental Kuznets Curve (EKC) hypothesis. The EKC equation predicts an inverted U-shaped relationship between CO_2 emissions and affluence (Grossman & Krueger, 1991). This suggests that affluence is more carbon intensive at the early stage of growth and the condition remains until a certain level of income is achieved. After this turning point, further increases in income shift the economy from carbon intensive activities to low-carbon patterns of growth (Liddle, 2013; Tenaw & Beyene, 2021). The reason, according to the findings of Grossman and Krueger (1991), is that people will become more concerned about the environmental impact of their activities as their income levels increase, boosting the development and adoption of clean and less energy-intensive technologies (Tenaw & Beyene, 2021). Empirical findings from recent studies on the validity of the EKC hypothesis have produced mixed conclusions. Some studies show an inverted U-shaped relationship between affluence and CO_2 emissions as predicted by the EKC hypothesis (Altinoz & Dogan, 2021; Badeeb et al., 2020; Tauseef Hassan et al., 2021; Zhang & Zhao, 2019), while others detect either no significant relationship, a monotonic increasing (decreasing), or a U-shaped relationship between the variables (Danish Baloch et al., 2019 for the case of India; Halliru et al., 2020; Nwani, 2021).

2.2 | Natural resource rents and carbon emissions

A number of recent empirical studies have examined the nexus between natural resource rents and CO_2 emissions, some focusing on developing and transition economies while others are focused on developed countries (Altinoz & Dogan, 2021; Badeeb et al., 2020; Bekun et al., 2019; Danish Baloch et al., 2019; Gyamfi et al., 2021; Khan, Hou, & Le, 2021; Ulucak & Ozcan, 2020; Umar et al., 2020; Zafar et al., 2021). Ulucak and Ozcan (2020) examined the environmental impact of some drivers of economic activity in the OECD countries for the period 1980–2016 and show that a significant positive relationship and unidirectional causality run from natural resource rents to CO_2 emissions in these countries. Other recent studies with similar evidence on the linkage between resource rents and CO_2 emissions include Mahmood and Furqan (2020) for the case of Gulf Cooperation Council countries, Danish Baloch et al. (2019) for the case of South Africa, Umar et al. (2020) for the case of China, Zafar et al. (2021) for the case of Asian countries, Tauseef Hassan et al. (2021) for the case of Pakistan, Kwakwa et al. (2020) for the case of Ghana, Joshua and Bekun (2020) for the case of South Africa and Nathaniel et al. (2021) that explored the case of Latin American and the Caribbean economies.

Specifically, Khan, Ju, Latif, and Khan (2021) explored the case of the top 10 manufacturing countries by using econometric approaches to illustrate whether natural resources, urbanization, and value-added by merchandise and manufacturing aspects affect environmental quality. By examining both the environmental and economic effects of urbanization, manufacturing, and merchandise value-added over the period 1970–2016, the study revealed that natural resources contribute to the environmental quality of the panel countries. However, the study revealed that the protection of natural resources hinders the economic growth of the countries. Nathaniel et al. (2020) and Balsalobre-Lorente et al. (2018) are other studies that identified a significant mitigation effect for natural resource rents for the BRICS and EU-5 countries, respectively. Altinoz and Dogan (2021) extended the empirical discussion on the topic using a quantile regression technique and data from 82 countries over the period 1990–2014. The results from the analysis showed a significant mitigation effect for natural resource rents in countries at lower quantiles of CO_2 emissions and a positive impact for countries at the middle and upper quantiles of the distribution. Meanwhile, the findings from Khan, Hou, and Le (2021) and Khan, Hou, and Le (2021) revealed the country-specific cases for environmental quality and the natural resources nexus for the United States and Pakistan, respectively. For instance, Khan, Hou, and Le (2021) investigated the case of Pakistan using data for the period 1990–2015 and revealed that natural resource rents have no significant causal impact on CO_2 emissions in Pakistan. Meanwhile, Khan, Hou, and

Le (2021) revealed that natural resources are responsible for improvements in environmental quality in the United States, especially during the investigated period (1971 to 2016). Similar findings were also documented by Danish Baloch et al. (2019) for Brazil, China, and India using data that covered the period 1990–2015. Danish Baloch et al. (2019) also show that natural resource rents have significant mitigation impacts on CO_2 emissions in Russia. In a recent related study, Badeeb et al. (2020) show how natural resource rents moderate the relationship between economic growth and CO_2 emissions in Malaysia using the EKC specification and data that cover the period 1970–2016. The results show that economic reliance on natural resource rents can affect the theoretically predicted EKC pattern. Specifically, the study provides empirical evidence to show that natural resource rents intensify the contribution of affluence to growth in CO_2 emissions at the early stage of development and weaken the environmental benefits of attaining higher levels of income.

2.3 | The lead in the current study

Based on the above documentation of the existing literature, we can identify variances between the existing literature and the current study. The conducted review above hinted at the variation from the aspect of the examined cases, period of examination, control variable(s) employed and the quantification/type of proxy adopted to represent environmental quality. For instance, most of the aforementioned studies relied on CO_2 stemming from production activities (production-based CO2 emissions) within the territory, thus lacking in empirical evidence as to whether natural resource rents contribute to the growing CO_2 emissions embedded in the trade and consumption patterns of developing and transition economies. However, the current study models CO_2 emissions based on production activities (i.e., territory-based CO_2 emissions) and consumption patterns (i.e., trade-induced CO_2 emissions). Importantly, in achieving this task, the current study further narrowed the existing gap in the literature by focusing on both panel and country specific analyses for 50 developing and transition economies (including different income-level economies). Furthermore, the current approach reconciles the aforementioned objectives by using a STIRPAT augmented EKC model that allows us to explore the common relationship between natural resource rents, population, affluence, energy intensity, and CO_2 emissions. Considering that the countries included in the panel are both major contributors to global carbon emissions (such as China, India, Iran, Russia, Saudi Arabia, Indonesia, Mexico, South Africa, Brazil, and Turkey) and economies with heavy dependence on natural resource rents (such as Guinea, Kazakhstan, Togo, Trinidad and Tobago, Vietnam, and Zimbabwe), appropriate econometric tools are employed to account for expected issues related to heterogeneity. Thus, by narrowing this gap in the literature, this study has the potential to help in designing appropriate policies for reshaping carbon mitigation challenges through cleaner and more sustainable use of natural resource wealth.

3 | METHODOLOGY

3.1 | Analytical framework and model specification

To aid the understanding of the impact of human activities on the environment, Dietz and Rosa (1994) proposed an analytical framework known as the STIRPAT (stochastic impacts by regression on population, affluence, and technology) model, based on an earlier work by Ehrlich and Holdren (1971). The basic equation of the STIRPAT model is as follows:

$$I = a_0 . P^{\alpha_1} . A^{\alpha_2} . T^{\alpha_3} . \varepsilon \tag{1}$$

In Equation (1), the driving forces for the environmental impacts are defined as a function of three variables: population size (*P*), affluence (*A*), defined as per capita gross domestic product (GDP), and technological progress (*T*). The parameters, α_0 refers to the constant term; α_1, α_2, and α_3 serve as the elastic coefficients of the influencing factors *I*, *A*, and *T*, respectively, and ε represents the error term. The STIRPAT equation allows for more driving factors to be included in the definition of environmental impacts, widening the applicability of the model in empirical studies. Following empirical specification in York et al. (2003), Yang et al. (2018), and Vélez-Henao (2020), T is defined using the intensity of energy use (EI). The extended STIRPAT equation for this present study takes the form:

$$I = a_0 . P^{\alpha_1} . A^{\alpha_2} . \mathrm{EI}^{\alpha_3} . \mathrm{NRR}^{\alpha_4} . \varepsilon \tag{2}$$

where NRR represents the impact of natural resource rents. Taking logs, the linear transformation of Equation (2) is generated to produce the following baseline regression model for explaining the environmental impact of carbon emissions:

$$\mathrm{lnCO}_{2it} = a_0 + \alpha_1 \mathrm{lnP}_{i,t} + \alpha_2 \mathrm{lnA}_{i,t} + \alpha_3 \mathrm{lnEI}_{i,t} + \alpha_4 \mathrm{lnNRR}_{i,t} + \varepsilon_{it} \tag{3}$$

where "ln" indicates logarithmic transformation of the variables. Cross-sections are represented by *i* (i.e., selected developing and transitional economies), while *t* refers to the period under study. CO_2 emissions are disaggregated into production-based (CO2Prd) and consumption-based (CO2Con). Overall, we derive the following model specifications for investigation:

$$\mathrm{lnCO2Prd}_{it} = a_0 + \alpha_1 lnP_{i,t} + \alpha_2 lnA_{i,t} + \alpha_3 \mathrm{lnEI}_{i,t} + \alpha_4 \mathrm{lnNRR}_{i,t} + \varepsilon_{it} \tag{4}$$

$$\mathrm{lnCO2Con}_{it} = a_0 + \alpha_1 lnP_{i,t} + \alpha_2 lnA_{i,t} + \alpha_3 \mathrm{lnEI}_{i,t} + \alpha_4 \mathrm{lnNRR}_{i,t} + \varepsilon_{it} \tag{5}$$

To account for the assumptions of the EKC hypothesis, Equations (3) and (4) are augmented with the square of affluence (A). The equations take the following form:

$$\mathrm{lnCO2Prd}_{it} = a_0 + \alpha_1 \mathrm{lnP}_{i,t} + \alpha_2 \mathrm{lnA}_{i,t} + \alpha_3 \, \mathrm{ln\,A^2}_{i,t} + \alpha_4 \mathrm{lnEI}_{i,t} + \alpha_5 \mathrm{lnNRR}_{i,t} + \varepsilon_{it} \tag{6}$$

$$\mathrm{lnCO2Con}_{it} = a_0 + \alpha_1 \mathrm{lnP}_{i,t} + \alpha_2 \mathrm{lnA}_{i,t} + \alpha_3 \, \mathrm{ln\,A^2}_{i,t} + \alpha_4 \mathrm{lnEI}_{i,t} + \alpha_5 \mathrm{lnNRR}_{i,t} + \varepsilon_{it} \tag{7}$$

where the square of Affluence $\left(A^2\right)$ is included in both Equation (6) and Equation (7) to form quadratic equations required for testing the EKC hypothesis. Equation (6) and Equation (7) can yield a number of functional relationships between affluence and CO_2 emissions subject to the value of α_2, the coefficient of *lnA*, and the value of α_3, the coefficient of the square (lnA^2). Among these possible functional relationships, the EKC hypothesis predicts positive α_2 and negative α_3, which would indicate an inverted U-shaped relationship between growth in affluence and CO_2 emissions (Chen & Taylor, 2020).

3.2 | Data

This analysis makes use of annual data series spanning the years 1995 to 2017. The Global Carbon Budget provides data on consumption and production-based carbon emissions (Friedlingstein et al., 2019). Production-based accounting focuses on emissions embodied in the territorial production of goods and services, regardless of whether they are consumed locally or exported. Consumption-based emissions were computed by adding emissions embodied in imports and subtracting emissions embodied in exports (i.e., territorial emissions plus net emissions from trade) (see Friedlingstein et al., 2019; Peters et al., 2011). The World Bank's WDI provide data on population, GDP per capita for affluence, and natural resource rents. The data on energy intensity comes from two sources: WDI for 1995–2015, and the United Nations' SDG Indicators Global Database for 2016 and 2017. To choose developing and transition nations, we used the United Nations' World Economic Situation and Prospects (WASP) country classifications (see United Nations, 2020) and focused on countries with no missing data for all selected variables. Table 1 provides a detailed definition of the selected variables along with their data sources, a list of the included countries in the panel, and some descriptive statistics to aid in a better understanding of the variables.

3.3 | Estimation techniques

Recent studies have used two classes of econometric techniques: first generation and second generation approaches. First generation techniques overlook the existence of cross-sectional dependence and slope heterogeneity, limiting their robustness and reliability (Pesaran, 2004). Second generation techniques overcome these issues by allowing for cross-sectional dependence and slope heterogeneity. In the panel data created for this study, we evaluated the possibilities of cross-sectional dependence and slope homogeneity. As a result, second generation econometric methods are utilized to verify that estimates for policy analysis are consistent and reliable. To complete the estimating process, the following steps are taken:

3.3.1 | Cross-sectional dependence (CSD), slope heterogeneity and panel unit root tests

Because developing and transitional economies have strong linkages among themselves, it is very likely that factors explaining changes in economic, social, political, and even environmental conditions in these countries will have CSD. Hence, we use the Pesaran (2004) test, which is resilient for both small and large cross-sectional dimensions and works well for small time dimensions, to check for CSD in the panel data. To test for slope homogeneity, we use the Pesaran and Yamagata (2008) test. Next, we check the stationary properties of the variables as part of the initial required steps by applying the cross-sectionally augmented Dickey-Fuller (CADF) and cross-sectionally augmented Im-Pesaran-Shin (CIPS) panel unit root tests proposed by Pesaran (2007).

3.3.2 | Cointegration test

To account for the possibility of CSD in the panel data used in this analysis, we use Westerlund's (2007) error-correction based cointegration test to check whether a long-run relationship exists between the variables. The equation is as follows:

$$\Delta Y_{i,t} = \mu_i' d_t + \omega_i \left(Y_{i,t-1} - \beta_i' X_{i,t-1} \right) + \sum_{j=1}^{k} \emptyset_{ij} \Delta Y_{i,t-j} + \sum_{j=1}^{k} \gamma_{ij} \Delta X_{i,t-j} + \varepsilon_{i,t} \tag{8}$$

In Equation (8), ω_i shows the speed of adjustment toward equilibrium (i.e., the error correction term coefficient), Y_{it} and X_{it} are dependent and explanatory variables, respectively. Equation (8) can be used to calculate the following country-specific and panel test statistics:

$$G_t = \frac{1}{N} \sum_{i=1}^{N} \frac{\widehat{\omega}_i}{se(\widehat{\omega}_i)} \tag{9}$$

TABLE 1 Data description and sources.

Variable	Description	Calculation	Database	Mean	Maximum	Minimum	Observations
CO2Prd	Production-based emissions CO_2 emissions	Million tonnes	Peters et al. (2012) updated data available in the Global Carbon Budget Friedlingstein et al. (2019)	315.107	9838.754	0.624	1035
CO2Con	Consumption-based (trade adjusted) CO_2 emissions	Million tonnes	Peters et al. (2012) updated data available in the Global Carbon Budget Friedlingstein et al. (2019)	282.448	8548.534	0.786	1035
P	population, Total	Millions	WDI, World Bank	98,352,913	1,390,000,000	1,254,200	1035
A	GDP per capita	Constant 2010 US$	WDI, World Bank	5640.129	64,864.720	406.277	1035
EI	Energy intensification	MJ/$2011 PPP GDP	WDI, World Bank & SDG Indicators Global Database, United Nations	6.497	26.699	1.993	1035
NRR	Total natural resources rents	% of GDP	WDI, World Bank	7.926	55.341	0.097	1035

Note: List of sampled countries: Albania, Armenia, Azerbaijan, Bangladesh, Bolivia, Botswana, Brazil, Burkina Faso, Cameroon, Chile, China, Colombia, Ecuador, El Salvador, Guinea, India, Indonesia, Iran, Jamaica, Kazakhstan, Madagascar, Malaysia, Mexico, Morocco, Namibia, Nicaragua, Nigeria, Pakistan, Panama, Paraguay, Peru, Philippines, Russia, Saudi Arabia, South Africa, Sri Lanka, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, Ukraine, United Arab Emirates, Vietnam, Zimbabwe.

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\widehat{\omega}_i}{1-\sum_{j=1}^{k}\omega_{ij}} \tag{10}$$

$$P_t = \frac{\widehat{\omega}}{se(\widehat{\omega})} \tag{11}$$

$$P_a = T\widehat{\omega} \tag{12}$$

The G_t expressed in Equation (9) and G_a in Equation (10) are statistics for testing the existence of cointegration in at least one cross-sectional group (i.e., country-specific estimates). The P_t in Equation (11) and P_a in Equation (12) are statistics for testing cointegration in the entire group (i.e., panel estimates).

3.3.3 | Parameter estimation

To ensure robustness, we estimate the parameters of the model specifications under consideration using the AMG estimator developed by Eberhardt and Teal (2010). In a simulation analysis, the AMG estimator demonstrated to be highly robust, unbiased, efficient and reliable in handling CDs in panel data, with no limitations imposed by the stationarity conditions of the variables, rendering unit root and cointegration tests unnecessary (see Eberhardt and Bond, 2009). The technique is carried out in two steps. The first step is in the form of Equation (13) below:

$$Y_{it} = \lambda_i + \alpha_i \Delta X_{it} + \tau_i \delta_t + \sum_{t-1}^{T}\phi_t D_t + \varepsilon_{it} \tag{13}$$

The second step is in the form:

$$\text{AMG} = \frac{1}{N}\sum_{i=1}^{N}\widehat{\alpha}_i \tag{14}$$

In this study, Y_{it} is defined as measures of carbon emissions (i.e., CO2Prd and CO2Con), X_{it} is defined as population size (lnP), affluence (lnA), energy intensification ($\ln EI$) and natural resource rents (lnNRR). λ_i is the intercept of the model. In the second step of the AMG estimation process, the group specific parameters are averaged across the panel, so that $\widehat{\alpha}_i$ become estimates of α_i.

3.3.4 | Causality test

We use the Dumitrescu and Hurlin (2012) test to discover dynamic links (i.e., direction of causality) among the variables in order to broaden the relevance of this study to policy formulation. To account for heterogeneity and CSD in panel data, Dumitrescu and Hurlin (2012) modified the non-causality test by Granger (1969). The test is explained by the following equation:

$$Y_{it} = \pi_i + \sum_{k=1}^{K}\psi_{ik} Y_{i,t-k} + \sum_{k=1}^{K}\eta_{ik} + \varepsilon_{it} \tag{15}$$

where, the coefficients of $Y_{i,t-k}$ and $X_{i,t-k}$ for unit $i(i=1,2,...,N)$ are given as ψ_{ik} and η_{ik}, respectively. The time dimension is indicated by $t=1,2,...,T$. The panel data is assumed to be balanced, with all units having the same lag duration, k. The null hypothesis can be expressed as:

$$H_0:\eta_{i1}=...=\eta_{ik}=0,\forall_i=1,...,N \tag{16}$$

In the alternative form, the heterogeneous non-causality hypothesis takes the form:

$$H_1:\eta_{i1}=...=\eta_{ik}=0,\forall_i=1,...,N_1 \tag{17}$$

$$\eta_{i1}\neq or...or\,\eta_{ik}\neq 0\,\forall_i=N_1+1,...,N \tag{18}$$

where N_1 is a natural number that satisfies the condition: $0\leq\frac{N_1}{N}\leq 1$. Dumitrescu and Hurlin (2012) recommend regressing Equation (15) for N individuals and implementing F test for K linear hypothesis $\varphi_{i1}=...=\varphi_{ik}=0$ and then averaging the Wald statistics (W_i) for N individuals. The Wald test statistic $(\overline{W})$ is defined as:

$$\overline{W}=\frac{1}{N}\sum_{i=1}^{N}W_i \tag{19}$$

In the above specification, W_i provides a chi-squared distribution with K degrees of freedom when $T\rightarrow\infty$. Assuming W_i are independently and identically distributed across units, the linear combination of $\overline{W}$ and K, defined as $\overline{Z}$ will follow standard normal distribution.

$$\overline{Z}=\sqrt{\frac{N}{2K}}(\overline{W}-K)\rightarrow N(0,1) \tag{20}$$

In addition, Dumitrescu and Hurlin (2012) shows that the approximated standardized statistic $\tilde{Z}$, adjusted for fixed T dimension will as well follow a standard normal distribution:

$$\tilde{Z}=\sqrt{\frac{N}{2K}\times\frac{(T-2K-5)}{T-K-3}}\times\left[\frac{T-2K-3}{T-2K-1}\overline{W}-K\right]\rightarrow N(0,1) \tag{21}$$

4 | EMPIRICAL RESULTS AND DISCUSSION

The results from Pesaran's (2004) cross-sectional dependence test are summarized in Table 2. At a significance level of 1%, the null hypothesis of no cross-sectional dependence is rejected for all variables. As a result, each variable has cross-sectional dependence, implying that shocks in one country affect the other nations in the panel. Table 3 shows the results from Pesaran and Yamagata's (2008) slope heterogeneity test. The estimates reject the null hypothesis of slope homogeneity, indicating slope heterogeneity concerns in the panel data. Table 4 summarizes the results from Pesaran's (2007) cross-sectionally augmented ADF and IPS panel unit root tests. The estimations show that all the variables are stationary only at the first difference. Because all of the variables are stationary only when initially different, we use the Westerlund (2007) cointegration test to see if there is a long-run link between them. Table 5 displays the outcomes of the test. We examine the p-values for the Pt and Pa statistics for cointegration. The *p*-value for Pt Statistics indicates that in the panel for the model specifications, the null hypothesis of no cointegration is rejected. In keeping with the study's core purpose, these findings enable us to investigate the relationship between natural resource rents, affluence, energy intensity, and CO_2 emissions. According to the *p*-values for Gt statistics,

TABLE 2 Pesaran CD-test.

Variables	CD-test	*p*-value	Average joint	Mean ρ	Mean abs(ρ)
lnCO2Prd	99.343***	.000	23.00	0.66	0.81
lnCO2Con	105.516***	.000	23.00	0.70	0.75
lnP	101.101***	.000	23.00	0.67	0.97
lnA	103.721***	.000	23.00	0.69	0.80
$\ln A^2$	103.776***	.000	23.00	0.69	0.80
lnEI	40.954***	.000	23.00	0.27	0.56
lnNRR	59.273***	.000	23.00	0.39	0.52

Note: *p*-values close to zero indicate data are correlated across panel groups.
***Respectively denote statistically significant at 1% levels.

TABLE 3 Pesaran-Yamagata slope heterogeneity test.

Model specification	Delta tilde ($\tilde{\Delta}$)	Adjusted delta tilde ($\tilde{\Delta}_{Adj}$)
lnCO2Prd, lnP, lnA, lnEI, lnNRR	21.402	24.894
	(0.000)	(0.000)
lnCO2Prd, lnP, lnA, $\ln A^2$, lnEI, lnNRR	19.187	23.004
	(0.000)	(0.000)
lnCO2Con, lnP, lnA, lnEI, lnNRR	22.775	26.491
	(0.000)	(0.000)
lnCO2Con, lnP, lnA, $\ln A^2$, lnEI, lnNRR	19.891	23.849
	(0.000)	(0.000)

cointegration exists in at least one cross-sectional unit (country). This indicates that the panel study can be expanded to account for country-specific conditions.

Results from two estimators are presented in Table 6. Estimates in the first column (1) and fourth column (4) were derived using the Mean Group (MG) estimator by Pesaran and Smith (1995) for lnCO2Prd and lnCO2Con, respectively. To accommodate the possible distorting effect of CSD and slope heterogeneity in the panel data, we rely on the estimates from the AMG estimator by Eberhardt and Teal (2010) in columns (2), (3), (5), and (6) for analysis. Estimates in Columns (2) and (5) are based on the extended STIRPAT model specification that incorporates the impact of natural resource rents. The extended STIRPAT model in columns (3) and (6) incorporates the quadratic specifications of the EKC model.

To begin with, the coefficient of lnP is positive and statistically significant at the 1% level across all lnCO2Prd and lnCO2Con specifications. The results show that increasing population size by one unit increases production-based CO_2 emissions by 1.164% to 1.334% and consumption-based CO_2 emissions by 1.005–1.064%. The estimates in columns (2) and (5) based on the extended STIRPAT model specification, show a positive and statistically significant environmental impact for affluence (lnA). In column (2), the coefficient of lnA shows that for a unit increase in affluence (economic growth), there is a corresponding increase in territorial CO_2 emissions of 1.153%, while estimates in column (5) show a corresponding increase of 1.523% in consumption-based CO_2 emissions. The estimate for the impact of lnEI is statistically significant across all the model specifications. According to the positive coefficient, a unit increase in energy intensity increases production-based CO_2 emissions by 0.742% to 0.766%, and consumption-based CO_2 emissions by 0.583% to 0.601%. These findings are in line with theoretical predictions by Dietz and Rosa (1994). Previous empirical studies, such as Ghazali and Ali (2019). Zhang and Zhao (2019) and

TABLE 4 Results of panel unit root tests.

		Level I(0)		1st difference I(1)		
	Variables	Intercept	Intercept and trend	Intercept	Intercept and trend	Decision
CIPS	lnCO2Prd	−2.332	−2.440	−4.523***	−4.564***	I(1)
	lnCO2Con	−2.207	−2.433	−4.763***	−4.847***	I(1)
	lnP	−1.833	−1.131	−2.952***	−3.207***	I(1)
	lnA	−1.338	−1.239	−3.200***	−3.620***	I(1)
	lnA^2	−1.297	−1.218	−3.148***	−3.578***	I(1)
	lnEI	−2.160	−2.300	−4.568***	−4.762***	I(1)
	lnNRR	−2.206	−2.499	−4.579***	−4.713***	I(1)
CADF	lnCO2Prd	−1.843	−1.911	−3.291***	−3.471***	I(1)
	lnCO2Con	−2.015	−2.151	−3.259***	−3.470***	I(1)
	lnP	−1.917	−2.496	−3.247***	−3.497***	I(1)
	lnA	−1.651	−1.637	−2.242***	−2.916***	I(1)
	lnA^2	−1.628	−1.634	−2.211**	−2.891***	I(1)
	lnEI	−1.681	−1.763	−3.084***	−3.383***	I(1)
	lnNRR	−1.917	−2.474	−3.295***	−3.592***	I(1)

***Respectively denote statistically significant at 1% levels.
**Respectively denote statistically significant at 5% levels.

TABLE 5 Results of panel cointegration tests (Westerlund).

Model specification	Statistic	Value	*Z*-value	Robust *p*-value
lnCO2Prd, lnP, lnA, lnEI, lnNRR	Gt	−3.288***	−5.919	.000
	Ga	−5.547	6.487	.895
	Pt	−15.201***	−0.728	.000
	Pa	−3.936	4.751	.895
lnCO2Prd, lnP, lnA, lnA^2, lnEI, lnNRR	Gt	−3.429***	−5.508	.000
	Ga	−4.107	8.845	.975
	Pt	−16.053***	−0.124	.000
	Pa	−3.437	6.343	.790
lnCO2Con, lnP, lnA, lnEI, lnNRR	Gt	−3.448***	−7.042	.000
	Ga	−5.170	6.817	.923
	Pt	−17.457****	−2.811	.000
	Pa	−4.369	4.368	.785
lnCO2Con, lnP, lnA, lnA^2, lnEI, lnNRR	Gt	−3.857***	−8.524	.000
	Ga	−4.690	8.370	.877
	Pt	−19.620***	−3.424	.000
	Pa	−4.115	5.796	.739

***Respectively denote statistically significant at 1% levels.
**Respectively denote statistically significant at 5% levels.
*Respectively denote statistically significant at 10% levels.

TABLE 6 Results MG and AMG estimators.

	Production-based CO_2 emission			Consumption-based CO_2 emissions		
	(1)	(2)	(3)	(4)	(5)	(6)
	STIRPAT Model Using MG estimator	STIRPAT Model Using AMG estimator	STIRPAT Augmented EKC Model Using AMG estimator	STIRPAT Model Using MG estimator	STIRPAT Model Using AMG estimator	STIRPAT Augmented EKC Model Using AMG estimator
lnP	1.041***	1.334***	1.164***	1.089***	1.064***	1.005***
	(0.169)	(0.172)	(0.189)	(0.270)	(0.313)	(0.276)
	[6.144]	[7.739]	[6.159]	[4.026]	[3.403]	[3.640]
lnA	1.032***	1.153***	1.407	1.241***	1.523***	13.639***
	(0.076)	(0.080)	(2.018)	(0.138)	(0.125)	(4.889)
	[13.653]	[14.337]	[0.697]	[8.999]	[12.166]	[2.790]
lnA^2			−0.005			−0.744**
			(0.120)			(0.299)
			[−0.043]			[−2.488]
lnEI	0.793***	0.742***	0.766***	0.621***	0.601***	0.583***
	(0.105)	(0.104)	(0.102)	(0.131)	(0.134)	(0.114)
	[7.548]	[7.113]	[7.532]	[4.745]	[4.472]	[5.122]
lnNRR	0.029***	0.037***	0.022**	0.031*	0.066***	0.035**
	(0.010)	(0.011)	(0.011)	(0.017)	(0.018)	(0.017)
	[2.794]	[3.369]	[1.959]	[1.786]	[3.597]	[2.094]
Constant	−21.989***	−27.887***	−31.887**	−26.631***	−26.688***	−73.094***
	(2.565)	(2.373)	(12.737)	(3.790)	(4.333)	(24.610)
	[−8.571]	[−11.751]	[−2.503]	[−7.027]	[−6.160]	[−2.970]
Observations	1035	1035	1035	1035	1035	1035
Number of ID	45	45	45	45	45	45

Note: Standard errors in (); *t*-statistics in [].
***Respectively. denote statistically significant at 1% levels.
**Respectively. denote statistically significant at 5% levels.
*Respectively. denote statistically significant at 10% levels.

TABLE 7 Country-specific AMG estimates.

Countries	Dependent variable: lnCO2Prd			Dependent variable: lnCO2Con		
	Coefficient of lnNRR	Std. err	*p*-value	Coefficient of lnNRR	Std. err	*p*-value
Albania	0.064*	0.034	.059	0.030	0.042	.476
Armenia	0.035	0.036	.329	−0.113***	0.041	.006
Azerbaijan	−0.018	0.023	.431	0.036	0.059	.537
Bangladesh	0.047***	0.018	.009	0.082**	0.038	.029
Bolivia	0.058***	0.016	.000	−0.010	0.040	.804
Botswana	0.032	0.022	.141	0.320**	0.152	.036
Brazil	−0.003	0.024	.897	−0.032	0.025	.211
Burkina Faso	0.108	0.078	.166	0.083	0.170	.624
Cameroon	0.011	0.145	.938	0.091	0.093	.330
Chile	−0.068*	0.040	.087	0.018	0.048	.711
China	0.003	0.014	.810	0.008	0.019	.667
Colombia	−0.058	0.036	.108	−0.018	0.042	.662
Ecuador	0.023	0.051	.653	0.062	0.047	.190
El Salvador	0.051	0.050	.313	0.007	0.063	.910
Guinea	0.182*	0.100	.068	0.302**	0.124	.015
India	0.042**	0.017	.014	0.084***	0.021	.000
Indonesia	0.095	0.089	.283	0.115	0.088	.190
Iran	0.068	0.042	.112	0.090*	0.052	.086
Jamaica	0.017	0.094	.859	−0.011	0.149	.942
Kazakhstan	0.002	0.046	.958	0.068	0.070	.331
Madagascar	0.134	0.131	.305	0.133	0.085	.117
Malaysia	0.236***	0.057	.000	0.208***	0.062	.001
Mexico	0.080***	0.023	.001	0.129***	0.032	.000
Morocco	0.012	0.013	.351	0.043*	0.025	.090
Namibia	0.108**	0.047	.023	−0.074	0.227	.745
Nicaragua	−0.128***	0.026	.000	−0.124***	0.040	.002
Nigeria	0.427***	0.137	.002	0.241*	0.132	.068
Pakistan	0.043***	0.016	.005	0.084***	0.024	.000
Panama	0.035	0.069	.612	0.681	0.445	.126
Paraguay	0.152	0.103	.142	−0.052	0.089	.563
Peru	0.059	0.058	.310	0.044	0.047	.339
Philippines	−0.055**	0.028	.048	−0.006	0.026	.828
Russia	−0.032**	0.014	.020	−0.007	0.029	.806
Saudi Arabia	0.155***	0.048	.001	0.240**	0.107	.024
South Africa	−0.018	0.044	.679	−0.047	0.059	.429
Sri Lanka	−0.069	0.069	.317	−0.046	0.073	.531
Thailand	0.014	0.016	.368	0.098***	0.029	.001
Togo	0.029	0.100	.771	0.329***	0.088	.000
Trinidad and Tobago	0.045	0.038	.242	−0.356**	0.146	.014

(Continues)

TABLE 7 (Continued)

Countries	Dependent variable: lnCO2Prd Coefficient of lnNRR	Std. err	*p*-value	Dependent variable: lnCO2Con Coefficient of lnNRR	Std. err	*p*-value
Tunisia	0.012	0.016	.440	0.052	0.052	.320
Turkey	0.030	0.023	.181	0.089**	0.040	.026
Ukraine	0.021	0.047	.653	0.129	0.083	.122
United Arab Emirates	0.076	0.083	.361	0.281***	0.061	.000
Vietnam	0.163***	0.041	.000	0.211***	0.047	.000
Zimbabwe	0.237**	0.106	.025	0.674***	0.129	.000

***Respectively, denote statistically significant at 1% levels.
**Respectively, denote statistically significant at 5% levels.
*Respectively, denote statistically significant at 10% levels.

Kwakwa et al. (2020) have already indicated that population size, affluence, and energy intensity increase CO_2 emissions in developing countries. Looking at the respective elasticities of lnA and lnEI, it is clear that affluence has a stronger degrading impact on the environment through the consumption activities and lifestyles of these developing and transition economies. Energy intensity, on the other hand, exerts a stronger impact on the environment through territorial production activities.

Further evidence on the environmental impact of affluence is modeled by augmenting the STIRPAT model with the quadratic specification of the EKC hypothesis. The estimates in column (3) show statistically insignificant coefficients for both lnA and the quadratic term (lnA^2), indicating that the EKC hypothesis does not validly explain the path to mitigating production-based CO_2 emissions for this panel of developing and transition economies. For consumption-based CO_2 emissions, the estimates in column (6) show that lnA has a positive and statistically significant coefficient, while the quadratic term (lnA^2) has a negative coefficient that is statistically significant. Thus, an inverted U-shaped relationship in line with the EKC hypothesis exists between affluence and consumption-based CO_2 emissions for the panel. Comparatively, previous empirical findings regarding the validity of the EKC hypothesis in developing and transition economies show mixed conclusions. Nwani (2021) shows no validity for Venezuela, Badeeb et al. (2020) and Tauseef Hassan et al. (2021) document an inverted U-shaped relationship for Malaysia and Pakistan, respectively, while Halliru et al. (2020) show a U-shaped relationship for West African countries. Based on a sample of 45 developing and transition economies, this study shows in Table 6 that the inverted U-shaped relationship between affluence and consumption-based CO2 emissions is only valid in terms of consumption activities. This suggests that economic agents (i.e., households, firms, and institutional bodies) will become more concerned about the environmental impact of their consumption patterns and lifestyles as their income levels increase, leading to the adoption of cleaner and less energy-intensive technologies.

Next, we consider the environmental impact of natural resource rents. For lnCO2Prd, the estimates in columns (2) and (3) of Table 6 show a degrading environmental impact for lnNRR and indicate that a unit increase in economic dependence on natural resource rents contributes to production-based CO_2 emissions by 0.022% to 0.037% in the selected developing and transition economies. The coefficient of lnNRR in the lnCO2Con specification in columns (5) and (6) is also positive and statistically significant. For a unit increase in economic dependence on natural resource rents, the coefficient suggests a corresponding increase of 0.035% to 0.06% in consumption-based CO_2 emissions. These estimates support the findings documented by a number of previous empirical studies for developing and transition economies, including the findings of Mahmood and Furqan (2020), Danish Baloch et al. (2019), Umar et al. (2020), Zafar et al. (2021), Tauseef Hassan et al. (2021), Kwakwa et al. (2020), Joshua and Bekun (2020), and Nathaniel et al. (2021). Taking a comparative look at the estimates reveals that economic dependence on natural

TABLE 8 Dumitrescu-Hurlin Granger non-causality test.

Null hypothesis	*Z*-bar. Stat.	*p*-value	90% critical value
Production-based carbon emissions			
lnP ≠ lnCO2Prd	36.9039*	.0923	34.8536
lnCO2Prd ≠ lnP	43.1005***	.0100	23.6020
lnA does ≠ lnCO2Prd	17.9025***	.0104	13.5062
lnCO2Prd ≠ lnA	9.7914	.2154	11.6867
$\ln A^2$ ≠ lnCO2Prd	17.3033**	.0154	14.5714
lnCO2Prd ≠ $\ln A^2$	9.4870	.3231	11.9671
lnEI ≠ lnCO2Prd	16.7617***	.0000	12.4571
lnCO2Prd ≠ lnEI	8.1769	.1692	9.5632
lnNRR ≠ lnCO2Prd	6.0315***	.0000	2.4378
lnCO2Prd ≠ lnNRR	17.0011**	.0400	12.4486
Consumption-based carbon emissions			
lnP ≠ lnCO2Con	44.0917**	.0308	35.5942
lnCO2Con ≠ lnP	27.5468***	.0000	18.6547
lnA ≠ lnCO2Con	19.7159***	.0000	14.5760
lnCO2Con ≠ lnA	9.6141*	.0615	6.9797
$\ln A^2$ ≠ lnCO2Con	19.4175***	.0000	14.7931
lnCO2Con ≠ $\ln A^2$	9.4433**	.0308	7.6700
lnEI ≠ lnCO2Con	23.3342***	.0000	10.7180
lnCO2Con ≠ lnEI	6.5296	.1846	7.6256
lnNRR ≠ lnCO2Con	11.7258***	.0000	6.9245
lnCO2Con ≠ lnNRR	4.0123	.4462	14.8624
Natural resource rents and affluence			
lnA ≠ lnNRR	9.2419**	.0462	5.9528
lnNRR ≠ lnA	4.3383	.5692	13.3847
Natural resource rents and energy intensity			
lnEI ≠ lnNRR	9.8495***	.0000	5.1801
lnNRR ≠ lnEI	6.7493	.8000	11.7089

Note: ≠ indicates the null hypothesis that X does not cause Y; Rejection of the null hypothesis indicates that X does Granger-cause Y for at least one country; *p*-values computed using bootstrap replications of critical values (CV). Lags tested: 1 to 5 with optimal selection based on Alkaike information criterion (AIC).
***Respectively denote statistically significant at 1% levels.
**Respectively denote statistically significant at 5% levels.
*Respectively denote statistically significant at 10% levels.

resource rents has a stronger environmental impact through the consumption patterns and lifestyles of the selected developing and transition economies.

To provide additional evidence, we examine country-specific estimates. Table 7 shows that natural resource rents contribute significantly to growth in territorial production-induced CO_2 emissions in 13 of the countries (Albania, Bangladesh, Bolivia, Guinea, India, Malaysia, Mexico, Namibia, Nigeria, Pakistan, Saudi Arabia, Vietnam, and Zimbabwe). From the estimates, only four (4) countries in the panel (Chile, Nicaragua, Philippines, and Russia) have significantly different results. For consumption-based CO_2 emissions, lnNRR has a positive and statistically significant coefficient for 18 countries (Bangladesh, Botswana, Guinea, India, Iran, Malaysia, Mexico, Morocco, Nigeria, Pakistan, Saudi Arabia, Thailand, Togo, Turkey, Ukraine, United Arab Emirates, Vietnam, and Zimbabwe). Apart from Armenia, Nicaragua, and Trinidad and Tobago, the coefficient is statistically insignificant for other countries in the lnCO2Con model. In line with the panel estimates in Table 6, the results in Table 7 show that natural resource rents intensify environmental impacts in developing and transition economies more through their consumption patterns and lifestyles. In the third group, we have countries like Bangladesh, Guinea, India, Malaysia, Mexico, Nigeria, Pakistan, Saudi Arabia, Vietnam, and Zimbabwe, where natural resource rents intensify environmental impacts from both production and consumption activities.

In Table 8, the null hypothesis (H_0) that lnA does not Granger-cause lnCO2Prd is rejected at the 1% significance level, but the H_0 that lnCO2Prd does not Granger-cause lnA is not rejected. This suggests a one-way causality running from affluence to production-based CO_2 emissions. For consumption-based CO_2 emissions, the H_0 that lnA does not Granger-cause lnCO2Con is rejected at the 1% significance level, and there is also statistical evidence that the H_0 that lnCO2Con does not Granger-cause lnA should as well be rejected but at the 10% level. This implies that there are countries where lnCO2Con has a causal impact on lnA. As a result, affluence and consumption-based CO_2 emissions are linked in a two-way causal chain. The findings also point to a one-way causal relationship between energy intensity and both production- and consumption-based CO_2 emissions. For causal linkages with natural resource rents, the H_0 that lnNRR does not Granger-cause lnCO2Prd and lnCO2Con are both rejected at 1% significance level. While the H_0 that lnCO2Prd does not Granger-cause lnNRR is rejected at the 5% level, the corresponding test for consumption-based CO_2 emissions (i.e., lnCO2Con does not Granger-cause lnNRR) is not rejected. These results imply a bidirectional causality between natural resource rents and production-based CO_2 emissions and a unidirectional causality that runs from natural resource rents to consumption-based CO_2 emissions. Extending the investigation, we discovered a number of other causal connections. One is the unidirectional causal relationship between natural resource rents and affluence, which runs from natural resource rents to affluence. Another example is a one-way causal link that runs from natural resource rents to energy intensity.

Overall, the results in Tables 6–8 highlight the depth of sustainability challenges in developing and transition economies. The focal point is economic dependence on natural resources. Not surprisingly, a unidirectional causal impact runs from natural resource rents to affluence. With economic dependence on natural resources also comes a lack of institutional and technological capacity to promote efficiency in energy use (Jimenez & Mercado, 2014). Together, these conditions question the sustainability of natural resource utilization in many developing and transition economies. Our findings therefore provide a new perspective on the course of natural resources in developing and transition economies through environmental sustainability challenges, in particular, CO_2 emissions. Taking a comparative look at the Resource Curse Vulnerability Index (RCVI) recently constructed by Biresselioglu et al. (2019) reveals that 10 of the countries with high RCVI (Bangladesh, Bolivia, India, Iran, Mexico, Nigeria, Pakistan, Saudi Arabia, Thailand, and Vietnam) are among those where natural resource rents contribute significantly to CO_2 emissions.

5 | CONCLUSION, POLICY AND STUDY PROSPECTS

Increasing collaboration between the United Nations Development Programme and stakeholders across the world has continued to urge a global drive toward attaining sustainable resource consumption and production, one of the United Nations Sustainable Development Goals (SDG 12). Thus, the direction of this study provides more insights for governments, intergovernmental agencies, business sectors, and other private actors on the pathway to shifting society's way of life away from unsustainable consumption and production of goods and services. In achieving this objective, the current study further uncovers the drivers of production- and consumption-based carbon emissions vis-à-vis consumption- and production-based environmental sustainability, especially for a selected panel of developing and transition economies covering the period 1995–2017. Specifically, the study implemented a series of econometric techniques (these include panel and country-specific cointegration such as second-generation unit root tests suggested by Pesaran (2003, 2007), the error-correction panel cointegration test proposed by Westerlund (2007), the AMG estimator by Eberhardt and Teal (2010), and Granger causality approaches) and presented that population size, affluence (income per person), energy intensity, and natural resource rents significantly contribute to production- and consumption-based carbon emissions, thus hampering environmental sustainability.

- Considering the degree of elasticities, natural resource rents have a stronger environmental degrading impact through consumption-based activities, while the impact of energy intensity is stronger through production-based activities. Further evidence on the environmental impact of affluence shows that the inverted U-shaped curve of the EKC hypothesis is only supported for consumption-based carbon emissions.
- Moreover, there are country-specific inferences, especially from the perspective of natural resources. In a significant proportion, natural resource rents positively impact carbon emissions (environmental degradation) from territorial production activities in some countries (Albania, Bangladesh, Bolivia, Guinea, India, Malaysia, Mexico, Namibia, Nigeria, Pakistan, Saudi Arabia, Vietnam, and Zimbabwe) and negatively in others (Chile, Nicaragua, Philippines, and Russia). Natural resource rents have a positive impact on carbon emissions from consumption activities in some countries (Bangladesh, Botswana, Guinea, India, Iran, Malaysia, Mexico, Morocco, Nigeria, Pakistan, Saudi Arabia, Thailand, Togo, Turkey, Ukraine, United Arab Emirates, Vietnam, and Zimbabwe), but have a negative impact in Armenia, Nicaragua, and Trinidad and Tobago.
- Finally, using Granger causality inferences, historical data on population size, affluence, and energy intensity can predict the future emission of carbon dioxide from both territorial production activities and trade-induced consumption activities with some accuracy. In addition, significant evidence of bidirectional causality exists between resource rents and production-based CO_2 emissions, and a unidirectional Granger causality that runs from natural resource rents to consumption-based carbon emissions, affluence, and energy intensity.

Several policy implications can be drawn from the above results for resource-based developing and transition economies. First, high natural resource dependence means less economic diversification and over-reliance on an energy-intensive production structure, which in turn generates environmental degradation through the scale effect arguments of the EKC hypothesis. For resource-based economies, promoting economic diversification from resource-intensive production structures to information-based industrial and service activities remains pivotal in the march toward achieving a sustainable path for growth and development. Therefore, the adoption of clean and renewable technology-based production techniques that harness composition and technique effects on the environment would be paramount in curtailing further environmental damage. This would also be essential in minimizing unwanted production waste through carbon emissions and resource spillage as a result of over-dependence on fossil-fuel energy consumption in natural resource extraction activities. Second, the efficiency and sustainability of the utilization of natural resources demand the design of an effective framework for natural resource management with transparent institutions and governance mechanisms in the extraction and use of natural resources. International agencies will have to look toward supporting policies that will promote and strengthen a good governance culture and responsible institutions that will incorporate environmental performance into national policies and demonstrate a strong will to implement environmental regulations and standards. Third, the evidence that natural resource rents induce consumption-based CO_2 emissions and have a causal impact on energy intensity implies that the energy mix needs to be skewed in favor of clean alternatives by prioritizing the use of renewable energy and technologies that are energy-saving and efficient across all consumption activities. In particular, our findings suggest the need for energy efficiency policies, technologies, and a diversified energy mix. These measures can be complemented by fiscal and market-based instruments, such as taxes on energy-intensive activities.

Concerning future studies, the country-specific aspects of other determinants of consumption- and production-based carbon emissions can be examined. In addition, this dimension can be explored in the future, especially from the perspective of production- and consumption-based carbon emissions across major sectors of the economy (such as tourism, agriculture, transportation, industrial, etc.).

ORCID

Chinazaekpere Nwani https://orcid.org/0000-0003-4451-1833
Festus V. Bekun https://orcid.org/0000-0003-4948-6905
Ekpeno L. Effiong https://orcid.org/0000-0002-4185-9140
Andrew A. Alola https://orcid.org/0000-0001-5355-3707

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How to cite this article: Nwani, C., Bekun, F. V., Gyamfi, B. A., Effiong, E. L., & Alola, A. A. (2023). Toward sustainable use of natural resources: Nexus between resource rents, affluence, energy intensity and carbon emissions in developing and transition economies. *Natural Resources Forum*, 1–22. https://doi.org/10.1111/1477-8947.12275