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# Assessing the Effects of Natural Resource Extraction on Carbon Emissions and Energy Consumption in Sub-Saharan Africa: A STIRPAT Model Approach

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**Abstract:** This study examines the impact of natural resource extraction, population, affluence, and trade openness on carbon dioxide ($CO_2$) emissions and energy consumption in 17 sub-Saharan African (SSA) countries from 1971 to 2019, using the stochastic impacts on population, affluence, and technology (STIRPAT) model. The Westerlund and Kao cointegration tests were employed to determine long-run relationships among the variables. Pooled mean group autoregressive distributed lag (PMG-ARDL), panel fully modified ordinary least squares (FMOLS), and dimension group-mean panel dynamic ordinary least squares (DOLS) techniques were used to assess long-run multipliers. The findings of the study reveal that natural resource extraction, population, and income have a significant positive impact on energy consumption and $CO_2$ emissions over an extended period in SSA countries. Findings suggest that an increase of 1% in income (affluence), natural resource extraction, and population, in the long run, will result in a rise of carbon emissions by 0.06% to 0.90% and an increase of 0.05% to 0.36% in energy consumption in the sampled SSA countries. Conversely, trade openness demonstrates a negative effect on energy consumption and $CO_2$ emissions. This finding suggests that an increment of trade openness by 1% will lead to a reduction of 0.10% to 0.27% in the emission of carbon and a decrease of 0.05% to 0.09% in energy consumption over a long period. The study recommends that policymakers enforce stringent ecofriendly regulations, promote the adoption of green technologies and energy-saving sources, and reduce tariffs on ecofriendly commodities to enhance sustainable development in the region.

**Keywords:** carbon dioxide emissions; energy consumption; natural resource extraction; panel cointegration; STIRPAT model; sub-Saharan Africa

**JEL Classification:** Q32; O43; Q54; Q56

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## 1. Introduction

Global warming has emerged as one of the most critical contemporary challenges in recent decades, attracting worldwide attention due to its detrimental impact on humanity. As pointed out by [1], greenhouse gases (GHG), primarily $CO_2$, have a significant role to play in aggravating global warming. According to [2–4], the consequences of global warming vary across regions globally and are numerous, leading to adverse effects on the health of the population and the environment. Ref. [5] highlights that GHGs, especially $CO_2$, have a higher contribution to climate change and global warming, emphasizing the need for immediate action to reduce $CO_2$ emissions to avert future risks to national security and economic growth. Developed economies worldwide regard reducing carbon dioxide emissions, which typically account for around 81% of anthropogenic greenhouse gas, as a top priority [5]. World Development Indicators [6] report that the $CO_2$ emissions worldwide have steadily increased in recent years, with figures jumping from 3,112,685.279 metric tons per capita in 1960 to 4,555,224,176 metric tons per capita in 2016.

To tackle the challenge of global warming, world leaders have committed to ensuring mitigate the emission of carbon so that this will assist in keeping the rise in the world temperature below 2 °C [7]. Researchers, ecologists, and policymakers have been working simultaneously to analyze the likely predictors of carbon emission for a long time. Since a change in climate or global warming is a universal phenomenon that entails an encompassing approach on everyone's part to mitigate the emission of carbon, research has been conducted for undeveloped countries [8,9], developing countries [10–13], advanced countries [14–16], countries emitting low $CO_2$ [17], and countries emitting high $CO_2$ [18]. Several factors, including economic growth, trade, population, and energy consumption, have been demonstrated in these studies to play significant roles in determining $CO_2$ emission levels for countries. While extensive research has been conducted to analyze the drivers of $CO_2$ emissions in the context of finding solutions to environmental challenges, less attention has been given to understanding the implications of natural resource extraction on pollutants emission. Moreover, extracting natural resources contributes to environmental degradation through indiscriminate disposal of waste chemicals into the atmosphere, land, and water, as well as heightened energy consumption required for extraction processes.

The World Bank guidelines emphasize the importance of integrating sustainability into development planning, which encompasses environmental, social, and economic dimensions. They provide a framework for assessing the sustainability of projects, policies, and programs, considering their short- and long-term impacts (see, e.g., [19–23]). Building on the World Bank framework [24], in his groundbreaking work, introduces the concept of the triple bottom line, proposing that businesses should consider environmental, economic, and social sustainability factors in their practices. This concept has since shaped sustainability discussions and led to the development of several indicators. Ref. [25] explored diverse dimensions of environmental, economic, and social indicators and provided an overview of various sustainability indicators, explained their significance, and presented a comprehensive framework for their implementation and integration with existing systems. Ref. [26] discusses the concept of sustainable development and presents a set of sustainability indicators. These indicators encompass environmental, economic, and social dimensions and can be used to measure the performance of different sectors and organizations. Ref. [27] offer a critical review of sustainability indicators, including their development methodologies, addressing limitations and challenges associated with the practical application of these indicators, and providing directions for future research. Ref. [28], focusing on sustainable supply chain management, discusses the integration of economic, environmental, and social dimensions into decision-making processes. The authors present a review of relevant literature and propose a set of sustainability indicators that can be implemented across supply chains. In summary, the literature on environmental, economic, and social sustainability factors and indicators highlights their importance in the context of sustainable development. Various frameworks and methodologies are proposed in the reviewed articles, offering significant insights into the practical implementation and assessment of sustainable practices. The integration of these dimensions is essential to achieving long-term success and addressing global challenges.

Concerning empirical studies on energy consumption that utilized the STIRPAT model, ref. [15] found that energy intensity improves the environment. Ref. [29], for instance, discovered that energy intensity, GDP index, urbanization, and population positively affect the energy consumption of commercial buildings in China. Ref. [30] examined the factors that drive energy consumption in China using the STIRPAT model. Ref. [31] investigated the energy consumption of hotels using the STIRPAT model. Ref. [32] discovered that trade openness, capital stock, affluence, and urbanization have a substantial impact on energy consumption using the STIRPAT model. Similarly, ref. [33], employing the STIRPAT model, found that for Pakistan, transportation, technology, and income enhance energy consumption. Ref. [34] discovered that income, industrial share, and population positively affect energy consumption, whereas a nonlinear association between education and energy consumption was observed in the study.

Ref. [12] estimated the STIRPAT model using Asian data from 1990 to 2019 and found that economic growth can accelerate environmental degradation and that innovation can result in achieving the environmental Kuznets curve (EKC) at a lower growth level. Ref. [35] used the STIRPAT model to examine the effects of natural resource extraction on the quality of the environment of Ghana in the long run from 1971 to 2013 and discovered that natural resource extraction, urbanization, and income increased the energy consumption and emission of carbon, thereby accelerating the environmental deterioration of Ghana, while carbon emission was found to be reduced by international trade. Ref. [15], using a "peak-and-decline" panel of 18 economies, investigated decomposition analysis on $CO_2$ emissions with 6 contributing factors using an extended STIRPAT model and found that the shift from unclean energy to clean energy and variations in energy intensity and fossil $CO_2$ intensity were the primary factors that reduced $CO_2$ emissions. Ref. [36], employing the STIRPAT approach, found that institutional quality, trade openness, and income mitigate the emission of carbon in Ghana, but urbanization accelerates the emission of carbon in Ghana.

Among the other studies that did not employ the STIRPAT, such as [10,11,16,18,37–46] discovered that improvements in trade openness and economic complexity promote environmental quality in Brazil, Russia, India, China, and South Africa (BRICS) economies. Ref. [38] explored the causal link between the growth of tourism and the real income level for emerging industrialized nations (E7) and discovered that an increase in nonrenewable energy and real GDP per capita leads to higher $CO_2$ emissions in E7 economies. Refs. [47,48] discovered that natural resource extraction, trade openness, industrialization, urbanization, and income, among others, have a significant impact on emissions of carbon dioxide. For example, ref. [37] in their study of economic growth, coal rent, and carbon emissions in countries in the BRICS, found that coal rent has a significant negative influence on $CO_2$ emissions. The empirical studies of [49–62] discovered that energy consumption is influenced by several factors at the macro and micro levels; however, these studies did not utilize the STIRPAT approach.

Ref. [41] examine the income-environment relationship in oil-producing countries, employing advanced panel cointegration techniques and nonparametric estimators. They find that key drivers of $CO_2$ emissions include per capita income, oil rents, fossil fuel-based electricity, and the manufacturing sector. In contrast, tertiarization and political rights reduce emissions. The environmental Kuznets curve hypothesis is rejected, supporting a monotonically increasing relationship between income and emissions. Ref. [42] present a three-sector decision model to analyze the net GHG footprint of oil in abundant settings, revealing opposing effects on atmospheric pollution. Using multivariate panel cointegration techniques and two-stage fixed effects estimations for 38 oil-producing countries, essential factors determining GHG emissions are identified, departing from the black-box approach that relies solely on per capita income. Ref. [43] examine the effect of foreign direct investment, economic development, and energy consumption on greenhouse gas emissions in some developing countries, finding that energy consumption strongly affects emissions, the environmental Kuznets curve hypothesis is valid for China and Indonesia, and investments in clean technology and energy efficiency are recommended for achieving sustainable development goals.

Nevertheless, out of the literature reviewed above, none examined the linkages of natural resource extraction, population, affluence, and trade openness with $CO_2$ emissions and energy consumption in an exclusive regression in sub-Saharan Africa. Thus, to address the gap observed in the literature, this paper scrutinized these environmental measures incorporating natural resource extraction in an exclusive regression using data from sub-Saharan Africa.

Therefore, this paper is aimed at scrutinizing the environmental deterioration effects of extraction of natural resources activities in SSA using a STIRPAT model. According to [35,63], natural resource extraction, a high level of international trade, population growth, consumption of energy, and economic growth can be linked to the recent high trend of carbon emissions globally. Additionally, in the quest for economic growth, natural resources, especially in third-world (developing) nations, are excessively used; all this requires more energy consumption, which leads to an upsurge in the emission of carbon dioxide ($CO_2$) [12]. One argument, on the contrary, argues that natural resource rent has the likelihood of shielding the environment and helping in the mitigation of carbon emissions. According to [63], natural resources, when employed in state capacity building, can mitigate the possibility of carbon dioxide emissions.

The study is novel in the sense that, to the best of the researchers' knowledge, it is the first to investigate the impact of natural resource extraction (proxied by total natural resource rent), population, affluence, and trade openness on $CO_2$ emissions and energy consumption in SSA countries in an exclusive regression using the STIRPAT model and the above-mentioned econometric techniques. Thus, it will contribute to the literature, particularly in the SSA region, as there is a dearth of reviews of related literature on linkages among natural resource extraction, energy consumption, and carbon emissions in SSA. Empirical studies e.g., [33,37,64–68] considered natural resources rent along with other variables in the regression using other economies as a case study and also did not employ the STIRPAT model as they utilized other models. Therefore, the outcome of this study is likely to inform better and more reliable policy directions.

The contributions from the study will help policymakers understand the connection between natural resource rent and carbon emissions and the need to establish policies, procedures, and strong institutions that will facilitate the transition from antique automation that exploits many natural resources to contemporary automation that absorbs value-addition, recycling, and unnatural resources.

The study's remaining parts are structured as follows: data and methodology are contained in Section 2; Section 3 comprises methodology and empirical results; conclusions and the policy implications of the study are found in Section 4.

## 2. Data and Techniques

### *2.1. Data*

The study employs balanced panel data sourced from the World Bank Development Indicator [22] for 17 sub-Saharan African countries, namely, Zimbabwe, Zambia, Togo, South Africa, Sudan, Senegal, Nigeria, Mauritius, Kenya, Ghana, Gabon, Cote d'Ivoire, Congo Republic of Brazzaville, Congo Democratic Republic, Cameroon, Botswana, and Benin, for a period of 1971–2019. The panel model was used due to the fact that nations diverge in disparate facets and to control for heterogeneity differences. According to [69], there would be outcomes' misspecification if diversity differences were not elucidated. Furthermore, panel data hold an extra degree of freedom, have less collinearity, extra estimates that are efficient, have greater variability, and are more informative. In this study, the study's dependent variable is the environmental impact, which is proxied by carbon dioxide emissions and energy consumption. The study's independent variables are natural resource extraction, trade openness, and population, which are measured by urban population (% of total) and affluence (income). The summary of the variables, their symbols, and their measurements are listed in Table 1.

According to Figure 1, the increment in energy usage and emissions of carbon in sub-Saharan Africa exhibit a likely pattern with the regions' natural resource rent, urban population (urbanization), affluence (income), and the rate of trade openness [6]. For instance, the SSA region's natural resource extraction proxied by the total natural resources rent rose from 4.11 in 1971 to 7.39 in 2019, and income measured by GDP per capita increased from 1445.39 in 1971 to 1656.70 in 2019. Energy consumption in SSA rose from 677.31 kg in 1971 to 687.23 kg (oil equivalent per capita) in 2019. The urban population of SSA increased from 18% in 1971 to 40% in 2019.

**Table 1.** Variables used in the study and their definitions.

| Symbols | Variables | Definition/Proxy |
|---|---|---|
| AFF | Affluence | Income—Gross domestic product (GDP) per capita |
| TNRR | Natural resource extraction | Natural resources rent (total) |
| TRD | Trade openness | Percentage of GDP of the sum of imports and exports |
| ENRC | Energy consumption | Kilogram (oil equivalent per capita) |
| URBN | Population | Urban population (% of total population) |
| CO2E | Carbon emissions | Metric per tons per capita |

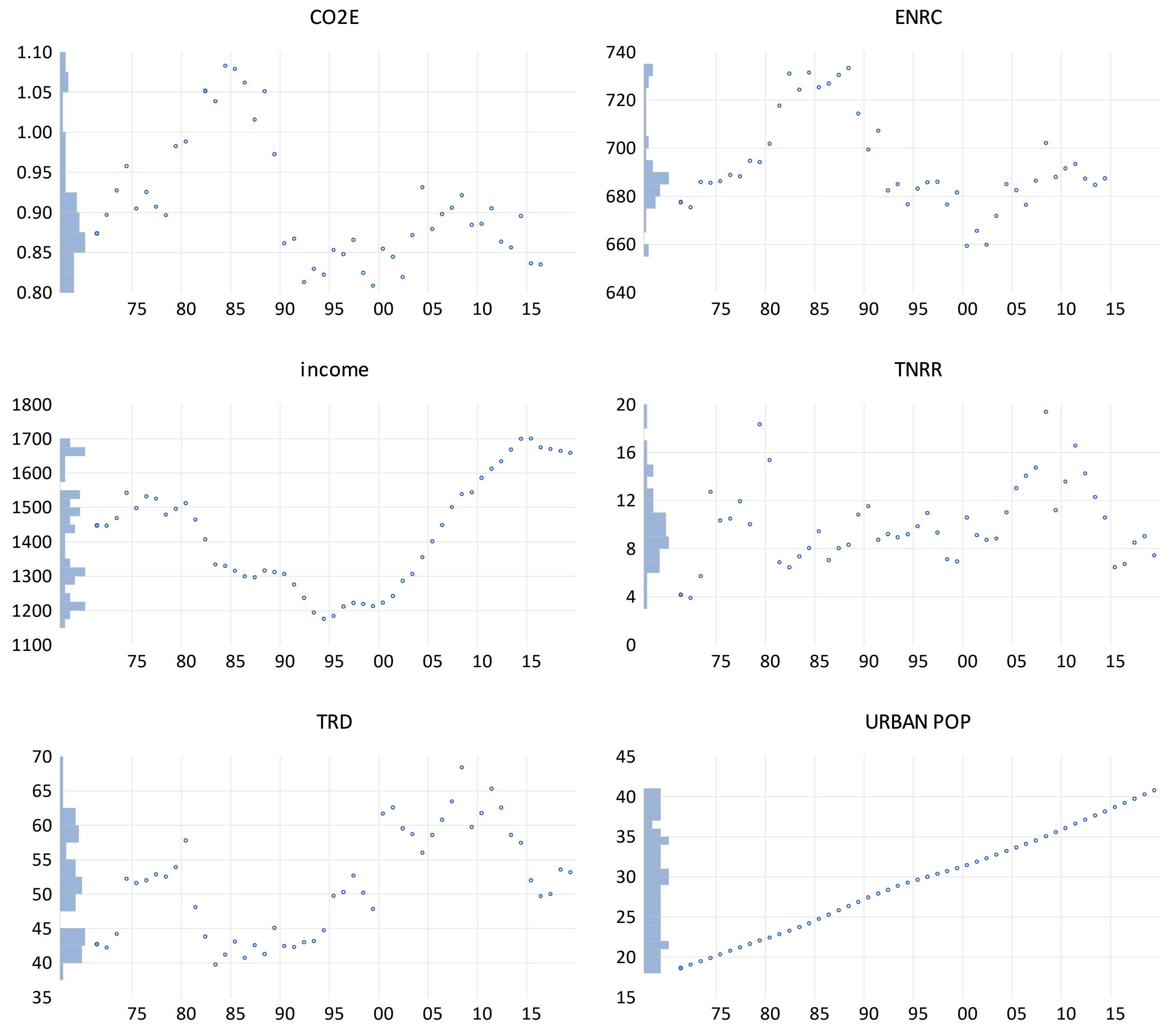


**Figure 1.** SSA regional data on natural resources rent (TNRR), urbanization (URBAN POP), energy consumption (ENRC), income, trade openness (TRD), and carbon dioxide emission (CO2E). Source: World Bank Development indicators (WDI), 2022; authors' computation.

Figure 2 illustrates the natural logarithm of per capita $CO_2$ emissions for the sub-Saharan African countries examined in this study during the period from 1971 to 2019. Given that $CO_2$ emissions are measured in natural logarithms, the slopes of the lines in these plots represent the corresponding percentage growth rates. The analysis of the data depicted in Figure 2 reveals that the $CO_2$ emission trends across SSA countries are diverse, albeit with a general increasing tendency, particularly during the post-2000 period. Over the course of the study, $CO_2$ emissions levels have been almost continuously rising in Benin, Botswana, Ghana, Mauritius, and Togo. In contrast, the Republic of Congo, Kenya, Nigeria, Senegal, and South Africa exhibit comparatively steadier rates or mild increases in $CO_2$ emissions. Furthermore, observed trends in Cameroon, the Democratic Republic of Congo, Sudan, and Zambia showed a decline in $CO_2$ emissions until the 2000s, followed by an increase. In a divergence from this pattern, Cote d'Ivoire, Gabon, and Zimbabwe demonstrate an overall decreasing trend in $CO_2$ emissions throughout the study period.


**Figure 2.** *Cont.*

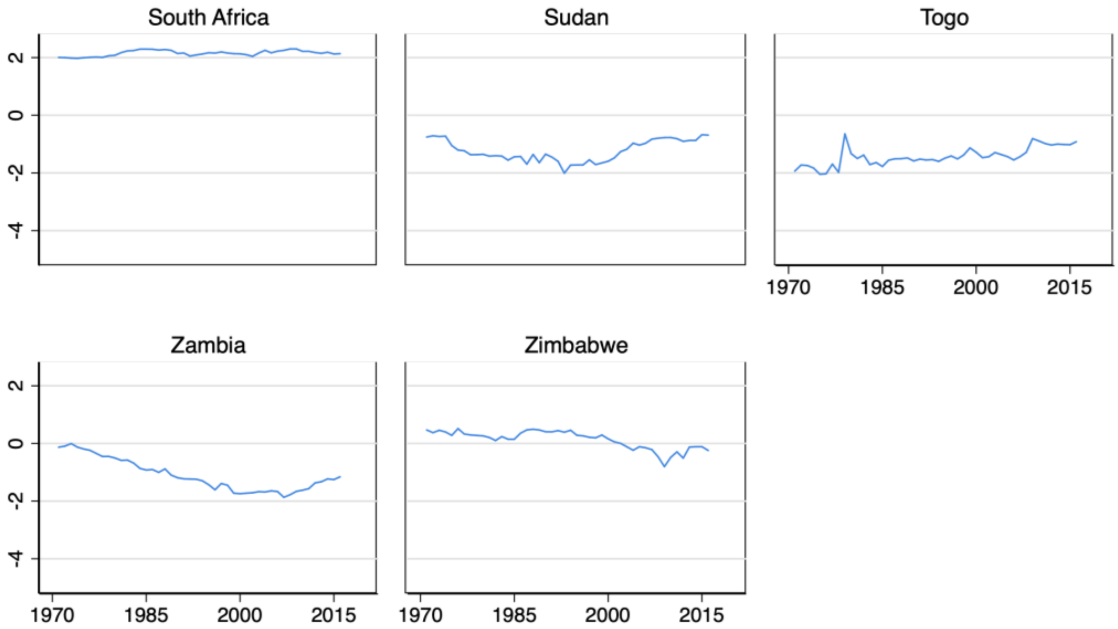


**Figure 2.** Per capita carbon dioxide emissions for the SSA courtiers over the period 1971–2019.

The primary research objective of this study is to investigate the impact of natural resource extraction on carbon dioxide emissions in sub-Saharan African countries. In order to obtain a comprehensive understanding of the relationship between the variables of carbon dioxide emission and natural resource extraction (proxied by natural resource rents), Figure 3 juxtaposes the natural logarithms of per capita carbon dioxide emissions (measured in metric tons) with the corresponding natural resource rents for each of the SSA countries considered in this study. While the general observation from Figure 3 indicates a positive relationship between these variables, substantial variation exists across countries. A distinctly positive association between $CO_2$ emissions and natural resource rents is observed for Cameroon, Ghana, Nigeria, Senegal, South Africa, Sudan, Togo, and Zambia. In contrast, Botswana, the Republic of Congo, and Gabon do not exhibit a definite direction for this relationship. Furthermore, Benin, the Democratic Republic of Congo, Cote d'Ivoire, Kenya, Mauritius, and Zimbabwe display a seemingly negative correlation between the variables. The observed variability across countries underpins the motivation for this study to incorporate additional covariates that influence $CO_2$ emissions within a multivariate regression framework. This approach allows for a more accurate estimation of the overall relationship between carbon dioxide emissions and natural resource extraction.

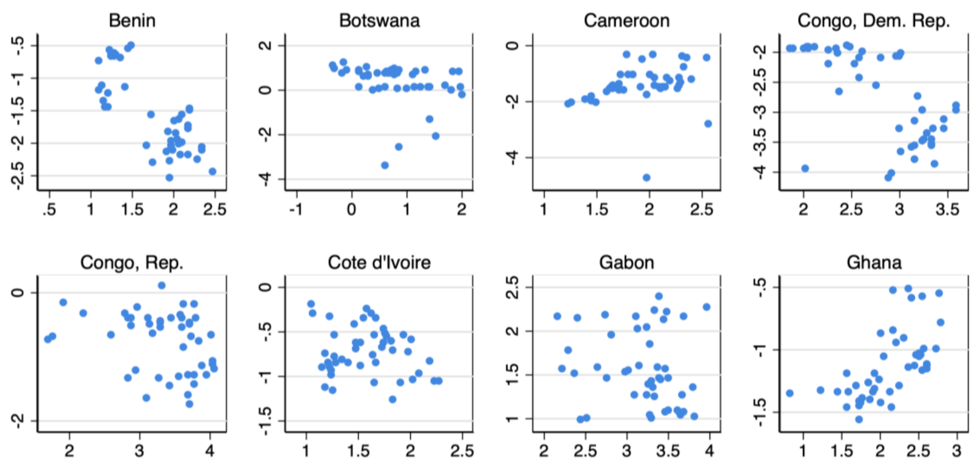


**Figure 3.** *Cont.*

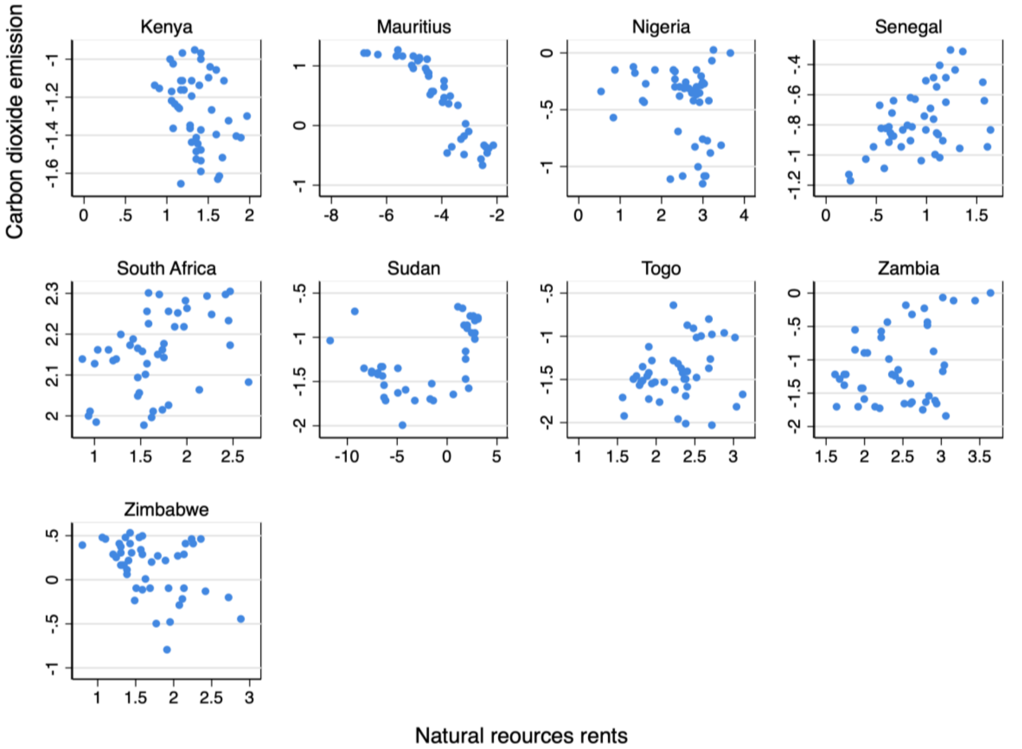


**Figure 3.** Scatterplot of per capita carbon dioxide emissions in natural logarithms against natural.

*2.2. Model Specification*

The long-lived perspective among the models and theories used in the analysis of the effect of human activities on environmental quality is the equation of IPAT, which is a framework to study the environmental impact ($I$) of the population ($P$), affluence ($A$), and technology ($T$) with its refinement. This model (equation), credited to [70,71], postulates that the environmental impact is dependent on the magnitude of technology, affluence, and population.

The IPAT model was revised to the stochastic impacts on population, affluence, and technology (STIRPAT) model by [72] with the introduction of a stochastic term into the former model. This advancement of the model permits the estimation and testing of the hypothesis of undue effects from the environmental prime mover. Since its introduction, the STIRPAT model has been utilized by numerous studies, such as [12,15,35,63,73–75], to examine the likely drivers of $CO_2$ emissions for countries. The STIRPAT model was also utilized to analyze the drivers of energy consumption in other studies such as [29,31,35,76–80] Nevertheless, the outcome of these studies has not been consistent.

This study is theoretically based on the STIRPAT framework. As stipulated above, with the introduction of a random term, the IPAT equation was refined to the STIRPAT framework (model) by [72] to investigate the influence of affluence, technology, and population on the environment. Below is the mathematical expression of the model:

$$I_t = e^D P_t^{\alpha_1} A_t^{\alpha_2} T_t^{\alpha_3} e^{\varepsilon_t} \quad (1)$$

where $T$ denotes technology, $A$ denotes affluence, $P$ denotes population, $e^D$ is the intercept or constant term with $e$ denoting the natural base, the stochastic term is the $e^{\varepsilon_t}$, the period is denoted by $t$, and the parameters to be analyzed are denoted by $\alpha_i$, $i = 1,2,3$. The technological level (that is, efficiently converting inputs) has been measured by numerous variables, of which trade openness is fundamental. The population can be represented by urbanization and/or total population, but for this study, urbanization is used to measure population. Affluence has been represented by income, while energy consumption and carbon dioxide emissions are used to measure environmental impact in much empirical research. Significant variables that are worthy of consideration are added to the above equation, given that its nature permits the modification of the model. Hence, the natural resource extraction ($R$) is included in the model, which gave rise to Equation (2) below:

$$I_t = e^D P_t^{\alpha_1} A_t^{\alpha_2} T_t^{\alpha_3} R_t^{\alpha_4} e^{\varepsilon_t} \quad (2)$$

All the variables were converted to natural logarithms, and thus the model's functional form is broadened and stated below:

$$\ln I_t = D + \alpha_1 \ln P_t + \alpha_2 \ln A_t + \alpha_3 \ln T_t + \alpha_4 \ln R_t + \varepsilon_t \quad (3)$$

STIRPAT is a coordinated program of research devoted to understanding the dynamic couplings between human systems and the ecosystems upon which they depend. The STIRPAT model not only allows each coefficient as a parameter to be estimated but also allows the proper decomposition of each factor, which means new influencing factors can be added to the STIRPAT model framework according to each study's characteristics. The STIRPAT model not only analyzes the fundamental science of environmental change but also pinpoints the factors that may be most responsive to policy.

### 2.3. Econometric Approach

This section discusses the econometric techniques employed in this study. To determine whether the data exhibit cross-sectional dependence (CD), the study adopt the CD and scaled Lagrange multiplier (LM) test proposed by Pesaran [81], and Breusch and Pagan [82] LM test. The stationarity of the series is examined to ensure an absence of unit roots at the latest first difference in order to prevent the estimation of Equation (3) from yielding spurious results [83]. Second-generation unit root tests, which allow for cross-sectionally dependent data, are utilized. The cross-sectionally augmented Dicker–Fuller (CADF) test, proposed by Pesaran [84], is applied in this study to ascertain the stationarity of the series. Subsequently, Westerlund [31] second-generation error-correction-based panel cointegration test for unobserved factors is employed to determine the presence of long-term relationships among the series. The [31] Westerlund error-correction model accounts for both heterogeneity and cross-dependence. To assess the long-run multiplier of carbon emission and energy consumption from Equation (3), the study employs the pooled mean group, the dimension group-mean panel dynamic ordinary least square techniques, and the fully modified ordinary least square method.

The PMG-ARDL model was also employed to investigate both short-run and long-run relationships among the variables. A key feature of the PMG-ARDL model is its allowance for heterogeneity across short-run coefficients (including intercepts, speed of adjustment to long-run equilibrium values, and error variances) while constraining long-run slope coefficients to be homogeneous across countries. The PMG-ARDL model is considered an effective alternative to the generalized method of moments (GMM) because it utilizes the cointegration form of the standard autoregressive distributed lag (ARDL) model developed by [81]. The PMG-ARDL model, although extensively utilized in panel data analysis, does possess certain drawbacks as well. A significant limitation that holds particular relevance to this discourse is the model's incapacity to account for nonlinearity. Approaches such as nonlinear ARDL (NARDL) and panel nonlinear ARDL (PNARDL) serve as supplementary models, addressing nonlinearity manifested through asymmetry in coefficients (see, e.g., [41]). To examine the long-run multiplier of carbon emission and energy consumption from Equation (3), the study applied the latest version of Hansen and Phillips' [73] FMOLS method, as proposed by Pedroni [85] for estimating heterogeneous panel data models. This FMOLS method is deemed robust against nonstationary variables and endogenous variables.

## 3. Empirical Results and Discussions

The outcomes of the study utilizing some econometrics methods are discussed in this section.

### *3.1. Descriptive Analysis*

Table 2 presents the descriptive statistics for all variables measured in natural logarithms, including carbon emissions (LNCO2E), energy consumption (LNENRC), affluence (LNAFF), total natural resource rent (LNTNRR), trade (LNTRD), and urbanization (LNURBN). The LNCO2E mean value is 0.60, with fluctuations in carbon emission levels demonstrated by maximum and minimum values of 2.39 and −4.77, respectively. This indicates that sub-Saharan African countries have comparatively lower carbon emissions than other regions in Africa and the world. The energy consumption mean value is 6.32, which is relatively large. Variability in energy consumption levels is represented by maximum and minimum values of 8.04 and 5.33, respectively. The mean, maximum, and minimum values for LNAFF, LNTNRR, LNTRD, and LNURBN suggest considerable variations over time.

**Table 2.** Summary of descriptive statistics.

| Statistics | LNCO2E | LNENRC | LNAFF | LNTNRR | LNTRD | LNURBN |
|---|---|---|---|---|---|---|
| Mean | −0.60 | 6.32 | 7.41 | 1.47 | 4.11 | 3.61 |
| Median | −1.87 | 6.16 | 7.17 | 1.86 | 4.13 | 3.65 |
| Maximum | 2.39 | 8.04 | 9.88 | 4.07 | 5.05 | 4.49 |
| Minimum | −4.77 | 5.33 | 5.62 | 11.59 | 1.84 | 2.19 |
| Std. Dev. | 1.26 | 0.62 | 0.86 | 2.08 | 0.50 | 0.38 |

Figure 4 displays pairwise matrix scatter plots for the variables LNCO2E, LNTNRR, LNAFF, LNENRC, LNTRD, and LNURBN, providing a visual representation of the direction and strength of associations between pairs of variables. A primary point of interest is the positive relationship observed between all variables and carbon dioxide emissions. While the strength of these associations varies, each variable exhibits a direct connection with $CO_2$ emissions. The direction and strength of these relationships depend on how they manifest within individual countries, resulting in the overall associations seen in Figure 4 being determined by variations across nations. Notably, a relatively strong direct association can be observed between affluence and energy consumption and $CO_2$ emissions. Conversely, associations with natural resource rents and trade openness appear comparatively weaker.

The Pearson correlation coefficient estimates presented in Table 3 illustrate the relationships among the series, which are consistent with established economic theories. For example, affluence (income), population (urbanization), and trade are expected to exhibit a positive correlation with carbon emissions.

**Table 3.** Pearson correlation coefficient estimates.

| Correlation | LNCO2 | LNENRC | LNAFF | LNTNRR | LNTRD | LNURBN |
|---|---|---|---|---|---|---|
| LNCO2E | 1.0000 | | | | | |
| *t*-statistic | – | | | | | |
| *p*-value | – | | | | | |
| LNENRC | 0.8371 | 1.0000 | | | | |
| *t*-statistic | 39.7085 | – | | | | |
| *p*-value | 0.0000 * | – | | | | |
| LNAFF | 0.8836 | 0.7627 | 1.0000 | | | |
| *t*-statistic | 48.9672 | 30.5970 | – | | | |
| *p*-value | 0.0000 *** | 0.0000 *** | – | | | |

**Table 3.** *Cont.*

| Correlation | LNCO2 | LNENRC | LNAFF | LNTNRR | LNTRD | LNURBN |
|---|---|---|---|---|---|---|
| LNTNRR | −0.0763 | −0.0316 | −0.0463 | 1.0000 | | |
| *t*-statistic | −1.9872 | −0.8206 | −1.2045 | – | | |
| *p*-value | 0.0473 ** | 0.4121 | 0.2288 | – | | |
| LNTRD | 0.2483 | 0.0733 | 0.3638 | 0.1074 | 1.0000 | |
| *t*-statistic | 6.6523 | 1.9068 | 10.1332 | 2.8040 | – | |
| *p*-value | 0.0000 *** | 0.0570 * | 0.0000 *** | 0.0052 *** | – | |
| LNURBN | 0.4668 | 0.3600 | 0.6295 | 0.1999 | 0.3735 | 1.0000 |
| *t*-statistic | 13.6956 | 10.0121 | 21.019 | 5.2949 | 10.4462 | – |
| *p*-value | 0.0000 *** | 0.0000 *** | 0.0000 *** | 0.0000 *** | 0.0000 *** | – |

Notes: *, **, and *** represent statistical rejection at 10%, 5%, and 1% significance levels, respectively.

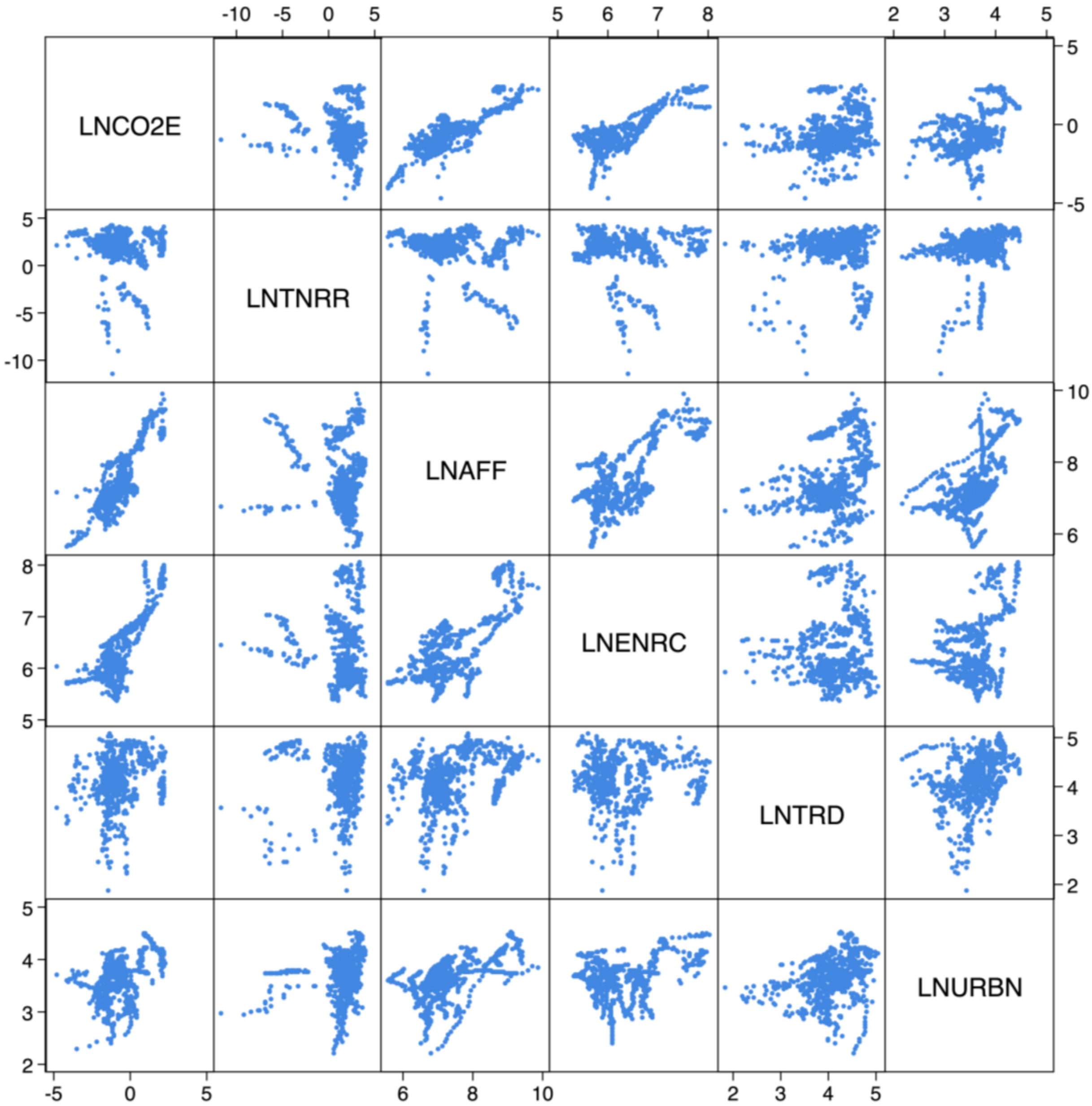


**Figure 4.** Matrix scatter plots of pairs of variables.

### 3.2. Cross-Sectional Dependence Testss

To diagnose whether the data exhibit cross-sectional dependence, the CD and scaled LM tests proposed by Pesaran [81] are employed, as well as the LM test of Breusch and Pagan [82]. The results of these tests are displayed in Table 4.

**Table 4.** CD tests outcome.

| | $CO_2$ Emission Series | | Energy Consumption Series | |
|---|---|---|---|---|
| Test | Statistic | *p*-value | Statistic | *p*-value |
| Breusch-Pagan LM | 1097.068 | 0.0000 * | 5648.363 | 0.0000 * |
| Pesaran scaled LM | 58.273 | 0.0000 * | 334.236 | 0.0000 * |
| Pesaran CD | 6.001 | 0.0000 * | 74.112 | 0.0000 * |

Notes: * denotes significance at the 1% level.

As depicted in Table 4, the null hypothesis of no cross-sectional dependence is rejected by all tests at a 1% significance level. Consequently, cross-sectional dependence exists among the sampled panel units.

### 3.3. Unit Root Tests

Considering that the panel data used in the study are cross-sectionally dependent, the first-generation panel unit root tests cannot be used because they tend to reject the null hypothesis of nonstationarity in the presence of cross-sectional dependence. Thus, the second-generation CADF unit root test proposed by Pesaran (2007), which allows for cross-sectional dependence in the data, was utilized to ascertain the stationarity of the variables under study. The outcome of the second-generation panel unit root tests is presented in Table 5.

**Table 5.** Panel unit root tests.

| Variables | Levels | | First Differences | |
|---|---|---|---|---|
| | Intercept | Intercept and Trend | Intercept | Intercept and Trend |
| | *t*-Bar *p*-Value | *t*-Bar *p*-Value | *t*-Bar *p*-Value | *t*-Bar *p*-Value |
| LNCO2E | −1.237 (0.108) | −0.355 (0.361) | −8.471 * (0.000) | −7.645 * (0.000) |
| LNTNRR | −0.856 (0.145) | −1.057 (0.145) | −6.123 * (0.000) | −3.776 * (0.000) |
| LNAFF | 0.467 (0.680) | 0.426 (0.665) | −5.407 * (0.000) | −4.565 * (0.000) |
| LNENRC | 1.718 (0.957) | 1.317 (0.990) | −7.520 * (0.000) | −5.139 * (0.000) |
| LNTRD | 0.878 (0.810) | 0.172 (0.568) | −8.838 * (0.000) | −6.947 * (0.000) |
| LNURBN | −2.832 * (0.000) | −3.988 * (0.000) | – | – |

Notes: * denotes significance at the 1% level. *p*-values are reported in brackets.

The findings presented in Table 5 demonstrate that all six series are nonstationary, with the exception of LNURBN, which exhibits stationarity at the level. Further analysis reveals that the series LNCO2E, LNTNRR, LNENRC, LNAFF, and LNTRD attain stationarity at the first difference with a significance level of 5%. Consequently, it can be inferred that LNURBN is integrated in the order of zero, I(0), while the other variables are integrated in the order one, I(1).

### 3.4. Cointegration Tests

Westerlund [85] cointegration tests are utilized to ascertain if there is a relationship among the series in the long run. The model finds out whether cointegration is present or not using four panel cointegration test statistics (group mean tests $G_a$ and $G_t$ and panel tests $P_a$ and $P_t$). The results presented in Table 6 show that Model 1 (with LNCO2E as the dependent and LNTNRR, LNTRD, LNAFF, and LNURBN as independent variables) rejected the null hypothesis of an absence of cointegration, except for $G_a$, while for Model

2 (with LNENRC as the dependent and LNTNRR, LNTRD, LNAFF, and LNURBN as independent variables), the null hypothesis of no cointegration is rejected by $G_t$. The robustness of the existence of cointegration among the variables in both models was also confirmed by the Kao [86] cointegration test outcome in Table 7 beneath. Thus, it can be concluded that an association exists between LNCO2E, LNTNRR, LNAFF, LNTRD, and LNURBN and between LNENRC, LNTNRR, LNAFF, LNTRD, and LNURBN in the long run.

**Table 6.** Westerlund panel cointegration tests.

| | Model 1: Dependent Variable Is LNCO2E | | Model 2: Dependent Variable Is LNENRC | |
|---|---|---|---|---|
| **Statistics** | **Value** | ***z*-Value** | **Value** | ***z*-Value** |
| $G_t$ | −3.033 * | −2.539 (0.006) | −3.195 ** | −1.506 (0.066) |
| $G_a$ | −9.701 | 1.752 (0.960) | −8.705 | 4.130 (1.000) |
| $P_t$ | −13.008 * | −3.831 (0.000) | −10.150 | 0.684 (0.753) |
| $P_a$ | −13.471 | −2.265 (0.012) | −9.822 | 1.948 (0.974) |

Notes: $G_a$ and $G_t$ denote group mean tests, while $P_t$ and $P_a$ denote panel tests. *, and ** represent statistical rejection at 1% and 10% significance levels, respectively.

**Table 7.** Kao panel cointegration tests.

| | Dependent Variable: LNCO2E | | Dependent Variable: LNENRC | |
|---|---|---|---|---|
| **Statistics** | ***t*-Statistic** | ***p*-Value** | ***t*-Statistic** | ***p*-Value** |
| ADF | −5.8327 * | 0.0000 | 1.4791 † | 0.0696 |
| Residual variance | 0.0630 | | 0.0027 | |
| HAC variance | 0.0358 | | 0.0026 | |

Notes: * and † denote significance at 1% and 10% levels, respectively.

### *3.5. Estimates of the Long-Run Parameters*

Having determined that the series are cointegrated in the long run, the DOLS and FMOLS estimations were undertaken to obtain estimates of the long-run parameters (elasticities in this study's particular specification). The outcomes are presented in Table 8.

**Table 8.** Long-run parameter estimates.

| Variable | FMOLS: LNCO2E | DOLS: LNCO2E | FMOLS: LNENRC | DOLS: LNENRC |
|---|---|---|---|---|
| LNAFF | 0.3838 * (0.0000) | 0.3002 * (0.0000) | 0.3340 * (0.0000) | 0.2882 * (0.0009) |
| LNTNRR | 0.1032 † (0.0441) | 0.0623 * (0.0396) | 0.0342 * (0.0014) | 0.0176 * (0.0013) |
| LNTRD | −0.3102 * (0.0000) | −0.2726 * (0.0000) | −0.0560 † (0.0120) | −0.0901 † (0.0119) |
| LNURBN | 0.8382 † (0.0136) | 0.9044 * (0.0061) | 0.3677 † (0.0374) | 0.3428 (0.1969) |

Notes: * and † denote significance at 1% and 5% levels, respectively.

The output of the FMOLS and DOLS in Table 8 reveals that, in the long run, income has a positive impact on the emission of $CO_2$. A 1% increase in income will lead to a 0.30–0.38% increase in carbon emissions. This implies that environmental deterioration increases with an increase in affluence (income). Excessive affluence can accelerate the manufacturing and consumption of goods, which in turn will result in pollution, a rise in waste generation, and overutilization of natural resources that may deteriorate the environment. This result is in accordance with the outcomes of [35] With regard to energy, the output of the FMOLS and DOLS in Table 8 reveals that income has a positive impact on the use of energy in SSA; this suggests that an increase in income by 1% will lead to a 0.33% increase in energy consumption. This means that a rise in income will accelerate energy consumption in sub-Sahara Africa. This is rational since an increase in consumption accelerates the demand for high-energy-consuming commodities as the economy grows.

Recently, in the majority of the sampled SSA countries, such as Ghana, Nigeria, Benin, etc., the demand for cars and other commodities that consume energy appears to have increased. People tend to buy commodities that will make their lives enjoyable as their income increases. Thus, seeing individuals buy washing machines and private cars in addition to other things when their income appreciates is not unconventional. Similarly, the desire to acquire additional income can make others buy commercial vehicles. This leads to a rise in the number of imported vehicles in these countries, which consequently increases $CO_2$ emissions indirectly by increasing energy consumption.

Natural resource extraction has a positive influence on carbon emissions in SSA countries in the long run. This means that in the long run, a 1% rise in natural resource rent will amount to a 0.06–0.10% increase in the emission of carbon in the SSA countries under study. The deterioration impact of extracting natural resources on the environment of SSA countries can be attributed to the increasing oil exploration in the oil-producing SSA countries and the illegal and legal mining activities in these countries. For example, the activities of illegal mining in countries such as Nigeria and Ghana do not satisfy the minimum environmental regulations and thus deteriorate the environment [35]. Similarly, exploration of oil and gas degrades the environment through the tumultuous exploration linked with the coastal oil and gas industry, ship traffic, construction work, and drilling, which produces noise pollution that affects the sea ecosystem's stability and that of its habitat. Additionally, the progressive exploration of oil utilizes an enormous amount of energy, which produces carbon, which deteriorates the environment. Additionally, disposing of gas through the burning of natural gas produces photochemical agents, carbon dioxide and nitrogen dioxide, which deteriorate the environment. This result is in accordance with [35,80]. Thus, there is a need to have renewable resources, which will drastically reduce the emission of carbon in SSA countries, and this can only be achieved by transitioning from antique automation that exploits increased natural resources to contemporary automation that absorbs value addition, recycling, and unnatural resources. Hence, decreasing environmental pollutants will enhance environmental quality and promote economic development.

Regarding the energy model, in the long run, natural resource extraction has a significant positive influence on energy consumption in SSA countries. This means that a 1% rise in natural resource rent will amount to a 0.01–0.03% increase in energy consumption in the long run. This outcome is in line with a priori expectations because the incessant exploitation of natural resources is largely dependent on energy-consuming machinery, which cannot operate without energy. Hence, energy consumption rises with an increase in natural resource activities in SSA countries. This result is insightful on the need for policymakers in SSA countries to pay attention to the activities of natural resource extraction when setting strategies to handle the energy security issues of their countries.

The output of the FMOLS and DOLS in Table 8 reveals that, in the long run, urbanization has a significant positive impact on the emission of $CO_2$. A 1% increase in urbanization will lead to a 0.83–0.90% increase in carbon emissions. This implies that environmental deterioration increases with an increase in urbanization. This suggests that urbanization accelerates pollutant emissions, which in turn deteriorates the environment of countries in the SSA region in the long run. The fast-moving rate of urbanization comes with numerous problems, such as the removal of vegetation cover to construct infrastructure to satisfy the expanding urban population's needs and heavy traffic jams, which result in a constant rise in the utilization of fossil fuels. Hence, this incident mitigates environmental quality. Additionally, there is a rise in the generation of waste as a result of the recent uncontrollable increase in the urban population of the SSA countries, especially in Nigeria, Ghana, Kenya, and Zimbabwe, which has surpassed the local government capacity in these countries to sustainably handle it. This has made these countries rank among the top six dirtiest countries in Africa in 2020 [6]. This result is in accordance with [11,68].

Concerning energy consumption, in the long run, the output of the FMOLS in Table 8 shows the impact of urbanization on the use of energy is positive and statistically significant. This suggests that in the long run, a 1% rise in the rate of urbanization enhances energy consumption by 0.36–0.38%. This is rationally based on the fact that the erection, functioning, and sustenance of urban infrastructure, such as the transportation system, accelerate the use of energy. Additionally, swift urbanization leads to a rise in the utilization of services and goods, which, in turn, results in a rise in the energy utilized for their manufacturing. This result is in accordance with [33,34].

The output of the FMOLS and DOLS in Table 8 reveals that, in the long run, trade openness has a significant negative influence on carbon emissions in SSA countries. An increment in trade openness of 1% will amount to a 0.27–0.1% reduction in carbon emissions. This implies that environmental deterioration decreases with an increase in trade openness in the long run. The argument in the literature regarding the influence of trade on the environment is complicated. The pollution haven hypothesis (PHH) supporters believe that trade openness influences the quality of the environment of poor nations negatively because they are forced to reduce environmental regulations in their bid to attract foreign companies. Consequently, negative externalities emerge to the disadvantage of the poor host nation [35]. Further, others believe that receptivity to trade degenerates the environment by stirring nations to extricate extra resources that do not possess an explicit property right [87]. Additionally, trade openness through "the scale effect, technique effect, and composition effect" influences environmental quality. The quality of the environment is enhanced by the technique effect, which empowers nations to import low-pollution manufacturing techniques. Trade, through its composition effect, assists in the transformation of the economy from agricultural-based to industrial-based and finally to service-based, which has relatively low pollution. The trade scale effect degrades the environment as it facilitates the expansion of manufacturing and consumption activities [58]. This implies that the aftermaths of trade are outpaced by the environmental-improving effects of trade openness in SSA countries. This result is in accordance with [88] who revealed that international trade can result in $CO_2$ emissions abatement in China as having ecofriendly trade policies helps to conserve the environment and promote economic growth.

Concerning energy, in the long run, the impact of trade openness on the use of energy is negative and statistically significant. This suggests that in the long run, a 1% increase in trade openness reduces energy usage by 0.05–0.09%. This result is in accordance with [89] who discovered in the case of Ghana that trade has a negative impact on energy intensity in the long run. A similar result was reported by [79]. The impact of trade on the demand for energy may be debated depending on the level of economic development. Trade openness implies that a country eases up on taxes and other procedures to enlarge foreign trade and enhance the foreign trade to GDP (gross domestic product) ratio. Trade openness, in return, is anticipated to contribute positively to economic growth. Subsequently, this initial growth in the economy might enhance energy usage owing to soaring economic activities such as outrageous government spending, production, and consumption, which is known as the scale effect. The country may grow enough in the later phase of economic growth to transition its manufacturing techniques from energy-intensive industries to the service sector and/or install technologies that are energy efficient, which are referred to as composition and technique effects, respectively. Thus, at later stages of economic growth, energy consumption may be reduced.

### *3.6. Diagnostic Tests*

In order to verify the validity of the obtained results, the estimates derived from the FMOLS and the DOLS models were assessed for the potential issue of multicollinearity. The variance inflation factor (VIF) was utilized as a diagnostic tool to detect the presence of multicollinearity among the regressors. According to the existing literature, a VIF value of one signifies the absence of correlation among regressors, necessitating further investigation if the VIF value exceeds four. Clear evidence of multicollinearity is indicated by a VIF value greater than 10. The results of the VIF estimation, presented in Table 9, demonstrate no signs of multicollinearity among the regressors, as the values in both models fall within the range of 1.13 to 1.30. It is noteworthy that a serial correlation test was not conducted, as the FMOLS and DOLS methodologies inherently account for serial correlation.

**Table 9.** Variance inflator factor estimates.

| | Model 1: CO2E as Dependent Variable | | Model 2: ENRC as Dependent Variable | |
|---|---|---|---|---|
| **Variables** | **Coefficient Variance** | **Uncentered VIF** | **Coefficient Variance** | **Uncentered VIF** |
| LNINCOME | 0.0087 | 1.3065 | 0.0031 | 1.1370 |
| LNTNRR | 0.0003 | 1.0909 | 0.0001 | 1.2616 |
| LNTRD | 0.0053 | 1.1018 | 0.0004 | 1.2455 |
| LNURBN | 0.0090 | 1.3067 | 0.0310 | 1.1313 |

### 3.7. *Pooled Mean Group ARDL Estimation*

The outcomes of the long-run estimation utilizing the PMG-ARDL approach for the energy model, as displayed in Table 10, exhibit a resemblance to the findings obtained from the FMOLS and DOLS estimations concerning income and natural resource extraction presented in Table 8. However, trade openness and urbanization do not hold statistical significance in this case. In the long run, income and natural resource extraction exert a substantial positive impact on carbon emissions in SSA countries. A 1% escalation in income and natural resource extraction results in a 0.98% and 0.04% augmentation in carbon emissions, respectively. The convergence parameter, also known as the error correction coefficient, is negative and statistically significant for the panel, indicating an adjustment towards long-run equilibrium. Moreover, the convergence parameter for individual countries proved to be significant across the entire nation.

**Table 10.** Estimation output of the pooled mean group with dynamic ARDL (dependent variable: LNCO2E).

| | LNAFF | LNTNRR | LNTRD | LNURBN | Adjustment Parameter |
|---|---|---|---|---|---|
| Long-run | 0.9850 ***<br>(0.0000) | 0.0464 *<br>(0.0917) | 0.0812<br>(0.1101) | −0.1761<br>(0.1220) | −0.3241 ***<br>(0.0000) |
| Short-run of cross-sections | | | | | |
| Benin | 0.6188<br>(0.4951) | −0.0394 **<br>(0.0475) | 0.2833 **<br>(0.0210) | −2.9848<br>(0.5337) | −0.0851 ***<br>(0.0001) |
| Botswana | −0.3299<br>(0.6325) | −1.0356 ***<br>(0.0080) | 0.3857<br>(0.1363) | −0.1328<br>(0.8924) | −0.3207 ***<br>(0.0000) |
| Cote d'Voire | 0.4480 **<br>(0.0253) | −0.1101 ***<br>(0.0080) | 0.0296<br>(0.7538) | −5.9163<br>(0.6317) | −0.5918 ***<br>(0.0001) |
| Cameroun | 3.2383<br>(0.3137) | 0.4586 **<br>(0.0220) | 0.3960<br>(0.4864) | −7.9326<br>(0.8599) | −0.7061 ***<br>(0.0000) |
| Congo Dem. Rep | 4.1516 **<br>(0.0150) | −0.0595 ***<br>(0.0057) | −0.0031<br>(0.8426) | −0.0031<br>(0.8426) | −0.6961 ***<br>(0.0004) |
| Congo Rep. | 1.6242<br>(0.1361) | 0.1242 ***<br>(0.0022) | 0.3213 *<br>(0.0317) | −7.5518<br>(0.9388) | −0.2130 ***<br>(0.0004) |
| Gabon | −0.2774 ***<br>(0.0065) | 0.0143 ***<br>(0.0028) | −0.1576 **<br>(0.0146) | 6.5496 *<br>(0.0742) | −0.3662 ***<br>(0.0000) |
| Ghana | −0.1602<br>(0.4364) | −0.1618 ***<br>(0.0001) | −0.0435 ***<br>(0.0037) | 4.3060<br>(0.8185) | −0.5771 ***<br>(0.0001) |
| Kenya | 0.7499<br>(0.1199) | −0.1642 ***<br>(0.0003) | 0.1358 ***<br>(0.0094) | 2.8817<br>(0.3537) | −0.3006 ***<br>(0.0001) |
| Mauritius | 0.6224 *<br>(0.0720) | −0.0137 ***<br>(0.0012) | 0.0240<br>(0.6581) | 7.4872<br>(0.6891) | −0.0040<br>(0.2019) |

**Table 10.** *Cont.*

| | LNAFF | LNTNRR | LNTRD | LNURBN | Adjustment Parameter |
|---|---|---|---|---|---|
| Nigeria | 0.4774<br>(0.1515) | 0.0978 ***<br>(0.0001) | −0.1296 ***<br>(0.0012) | 13.9980<br>(0.9026) | −0.3865 ***<br>(0.0007) |
| Sudan | −1.4317 ***<br>(0.0083) | −0.0264 ***<br>(0.0000) | 0.0248<br>(0.1337) | −0.5166<br>(0.8821) | −0.2669 ***<br>(0.0003) |
| Senegal | 0.0373<br>(0.9202) | 0.0521 ***<br>(0.0047) | −0.0034<br>(0.9237) | −4.4362<br>(0.8069) | −0.4010 ***<br>(0.0001) |
| Togo | −0.6603<br>(0.1374) | 0.0564 ***<br>(0.0091) | −0.5258 ***<br>(0.0072) | −295.66<br>(0.9506) | −0.7028 ***<br>(0.0000) |
| South Africa | 0.6144 **<br>(0.0216) | 0.0229 ***<br>(0.0001) | −0.1821 ***<br>(0.0011) | −0.9166<br>(0.9286) | −0.0771 ***<br>(0.0014) |
| Zambia | −2.2703<br>(0.1176) | −0.0396 ***<br>(0.0056) | −0.4950 ***<br>(0.0012) | −1.1769<br>(0.8731) | −0.4474 ***<br>(0.0002) |
| Zimbabwe | −0.0571<br>(0.4960) | 0.1123 ***<br>(0.0005) | 0.0981 **<br>(0.0213) | 7.3176<br>(0.2444) | −0.5479 ***<br>(0.0000) |

Notes: *, **, and *** represent statistical rejection at 10%, 5%, and 1% significance levels, respectively. The numbers in parentheses are the *p*-values. The model is specified with an ARDL (1, 1, 1, 1, 1).

Further, the estimations of the short-run coefficients of the individual countries are shown in Table 10. In the short run, income has a significant positive impact on the emission of carbon in Cote d'Ivoire, the Congo Democratic Republic, Mauritius, and South Africa, while its impact is negative in Gabon and Sudan. In the short run, natural resource extraction has a negative impact on carbon emissions in Benin, Botswana, the Congo Democratic Republic, Ghana, Kenya, Mauritius, Sudan, and Zambia, while its impact is positive in Zimbabwe, South Africa, Togo, Senegal, Nigeria, Gabon, the Congo Republic, and Cameroun. In the short run, trade openness has a negative impact on carbon emissions in Zimbabwe, Zambia, and South Africa. Togo, Nigeria, and Ghana, while its impact is positive in Kenya, Gabon, the Congo Republic, and Benin. The impact of urbanization in the short run is not significant in all the countries except Gabon, where the impact is positive and statistically significant.

The outcome of the long-run estimation of the PMG-ARDL of the energy model in Table 11 is similar to the outcome of the FMOLS and DOLS estimations in Table 8, except for natural resource extraction. Income has an insignificant positive influence on energy consumption in SSA countries. In the long run, the impact of trade openness and natural resource extraction on energy consumption is significantly negative. The convergence parameter, or error correction coefficient, is negative and statistically significant for the panel, showing adjustment to the long-run equilibrium. Additionally, for the individual countries, the convergence parameter for the entire nation was significant.

**Table 11.** Estimation output of the pooled mean group with dynamic ARDL (dependent variable: LNENRC).

| | LNAFF | LNURBN | LNTNRR | LNTRD | Adjustment Parameter |
|---|---|---|---|---|---|
| Long-run | 0.0077<br>(0.7691) | 0.2562 ***<br>(0.0000) | −0.0261 ***<br>(0.0060) | −0.1371 ***<br>(0.0000) | −0.1722 ***<br>(0.0002) |
| Short-run of cross-sections | | | | | |
| Benin | −0.6616<br>(0.2191) | 0.8218<br>(0.2734) | −0.0151 ***<br>(0.0006) | 0.0818 ***<br>(0.0005) | −0.1699 ***<br>(0.0005) |
| Botswana | 0.6616 ***<br>(0.0009) | −0.9545 ***<br>(0.0029) | −0.0063 ***<br>(0.0001) | −0.3455 ***<br>(0.0001) | −0.6046 ***<br>(0.0001) |
| Cote d'Voire | 0.4671 ***<br>(0.0095) | −0.0607<br>(0.9720) | 0.0183 **<br>(0.0145) | 0.0585 *<br>(0.0669) | −0.1517 ***<br>(0.0003) |
| Cameroun | 0.1045<br>(0.0002) | 0.1197<br>(0.3142) | −0.0013 ***<br>(0.0067) | −0.0254 ***<br>(0.0001) | −0.0152 ***<br>(0.0007) |

**Table 11.** *Cont.*

| | LNAFF | LNURBN | LNTNRR | LNTRD | Adjustment Parameter |
|---|---|---|---|---|---|
| Congo Dem. Rep | 0.6019 ***<br>(0.0021) | 0.0075 ***<br>(0.0005) | −0.0504 ***<br>(0.0000) | 65.626<br>(0.9764) | −0.1292 ***<br>(0.0047) |
| Congo Rep. | 0.5635 ***<br>(0.0009) | −3.4114<br>(0.5706) | 0.0161 ***<br>(0.0003) | −0.0982 ***<br>(0.0003) | −0.0176 ***<br>(0.0093) |
| Gabon | −0.1195 **<br>(0.0408) | 0.1988<br>(0.8767) | −0.0149 ***<br>(0.0033) | −0.1891 ***<br>(0.0094) | −0.0623 ***<br>(0.0005) |
| Ghana | 0.2699 **<br>(0.0130) | 1.1633<br>(0.7587) | −0.0201 ***<br>(0.0006) | −0.0806 ***<br>(0.0000) | −0.0057 ***<br>(0.0845) |
| Kenya | 0.2520 ***<br>(0.0001) | −0.0670<br>(0.3115) | −0.0004<br>(0.1510) | −3.6978 **<br>(0.0343) | −0.3006 ***<br>(0.0001) |
| Mauritius | 0.5235 ***<br>(0.0015) | 2.3604<br>(0.5155) | −0.0139 ***<br>(0.0000) | 0.0823 ***<br>(0.0039) | −0.0097 ***<br>(0.0001) |
| Nigeria | −0.0855 ***<br>(0.0001) | 2.3970 **<br>(0.0120) | 0.0058 ***<br>(0.0000) | 0.0003 **<br>(0.0415) | −0.2245 ***<br>(0.0000) |
| Sudan | −0.5147 ***<br>(0.0002) | −0.4425<br>(0.1329) | −0.0026 ***<br>(0.0000) | 0.0617 ***<br>(0.0000) | −0.1410 ***<br>(0.0019) |
| Senegal | 0.1665 **<br>(0.0153) | 1.1510<br>(0.6900) | 0.0364 ***<br>(0.0000) | −0.0946 ***<br>(0.0001) | −0.1111 ***<br>(0.0004) |
| Togo | 0.1772 ***<br>(0.0005) | −56.426<br>(0.8514) | −0.0003<br>(0.3518) | −0.0028<br>(0.3484) | −0.3455 ***<br>(0.0001) |
| South Africa | 0.6241 **<br>(0.0216) | −1.4222<br>(0.7616) | 0.0134 ***<br>(0.0001) | −0.1177 ***<br>(0.0005) | −0.0704 ***<br>(0.0016) |
| Zambia | −0.2392<br>(0.0005) | 0.3739 **<br>(0.0190) | 0.0107 ***<br>(0.0000) | −0.0792 ***<br>(0.0000) | −0.6143 ***<br>(0.0000) |
| Zimbabwe | 0.1886 ***<br>(0.0000) | 1.7205 **<br>(0.0483) | 0.0457 ***<br>(0.0000) | −0.0841 ***<br>(0.0000) | −0.2239 ***<br>(0.0000) |

Notes: *, **, and *** represent statistical rejection at 10%, 5%, and 1% significance levels, respectively. The numbers in parentheses are the *p*-values. The model is specified with an ARDL (1, 1, 1, 1, 1).

Further, the estimations of the short-run coefficients of the individual countries are shown in Table 11. In the short run, income has a significant positive impact on energy usage in Zimbabwe, South Africa, Togo, Senegal, Mauritius, Kenya, Ghana, Cote d'Ivoire, the Congo Republic, the Congo Democratic Republic, Cameroun, and Botswana, while its impact is negative in Nigeria, Gabon, and Sudan. In the short run, natural resource extraction has a negative impact on energy consumption in Sudan, Mauritius, Ghana, Gabon, Benin, Botswana, Cameroun, and the Congo Democratic Republic, while its impact is positive in Zimbabwe, Zambia, South Africa, Senegal, Nigeria, the Congo Republic, and Cote d'Ivoire. In the short run, trade openness has a negative impact on carbon emissions in Zimbabwe, Zambia, South Africa, Senegal, Kenya, Ghana, Gabon, the Congo Republic, Cameroun, and Botswana, while its impact is positive in Sudan, Nigeria, Mauritius, Cote d'Ivoire, and Benin. In the short run, the impact of urbanization on energy consumption in Botswana is negative, whereas its influence is positive in Zimbabwe, Zambia, Nigeria, Gabon, and the Congo Democratic Republic.

## 4. Conclusion and Policy Implications

The present study employed the STIRPAT framework to investigate the effects of natural resource extraction (proxied by total natural resource rent), population (proxied by urbanization), affluence (income), and trade openness on $CO_2$ emissions and energy consumption in 17 SSA countries over the period of 1971–2019. The motivation behind conducting this research lies in the limited contributions of existing literature to the econometric analysis of the impact of natural resource extraction on the drivers of environmental degradation, specifically carbon dioxide emissions. SSA was chosen as the subject of this investigation due to its high vulnerability to climate change and natural disasters stemming from the region's heavy reliance on natural resources. Moreover, economies in SSA are characterized by rapid urbanization, natural resource extraction, trade, economic growth, and 21 population growth, which may collectively contribute to increased pollution levels. To determine the presence of long-run relationships among the series, the Westerlund and Kao cointegration techniques were employed. Furthermore, the PMG-ARDL, panel FMOLS, and group mean panel DOLS approaches were utilized to assess the long-run multipliers for carbon emissions and energy consumption.

The findings from the FMOLS and DOLS estimations indicate that, in the long run, a 1% increase in income corresponds to a 0.30–0.38% rise in carbon emissions and a 0.33% growth in energy consumption. This suggests that an augmentation in income may stimulate energy usage and exacerbate environmental degradation. In the long run, natural resource extraction exerts a positive influence on carbon emissions and energy consumption in SSA countries. Specifically, a 1% increase in natural resource rent can lead to a 0.06–0.10% expansion in carbon emissions and a 0.01–0.03% enhancement in energy consumption. Urbanization has a substantial and positive impact on $CO_2$ emissions and energy consumption, with a 1% upsurge in urbanization resulting in a 0.83–0.90% growth in carbon emissions and a 0.36–0.38% increase in energy usage in the long run. Conversely, trade openness demonstrates a significant negative influence on carbon emissions and energy consumption in SSA countries over the long term. For instance, a 1% increment in trade openness amounts to a 0.27–0.1% reduction in carbon emissions and a 0.05–0.09% decrease in energy consumption.

The outcomes of the long-run estimation using the PMG-ARDL approach for the energy model are consistent with the findings from the FMOLS and DOLS estimations with regard to income and natural resource extraction. However, trade openness and urbanization do not display statistical significance in this case. In the long run, income and natural resource extraction have a considerable positive impact on carbon emissions in SSA countries. A 1% increase in income and natural resource extraction leads to a 0.98% and 0.04% growth in carbon emissions, respectively.

Additionally, the short-run coefficient estimations for individual countries reveal that income exerts a positive, significant influence on carbon emissions in Cote d'Ivoire, the Democratic Republic of Congo, Mauritius, and South Africa, while its effect is negative in Gabon and Sudan. In the short run, natural resource extraction demonstrates a negative impact on carbon emissions in Benin, Botswana, the Democratic Republic of Congo, Ghana, Kenya, Mauritius, Sudan, and Zambia; conversely, a positive effect is observed in Zimbabwe, South Africa, Togo, Senegal, Nigeria, Gabon, the Republic of Congo, and Cameroon. Furthermore, trade openness exhibits a negative influence on carbon emissions in Zimbabwe, Zambia, South Africa, Togo, Nigeria, and Ghana, whereas its effect is positive in Kenya, Gabon, the Republic of Congo, and Benin. In terms of urbanization, no statistically significant impact is found in the short run for all countries, with the exception of Gabon, where the influence is both positive and statistically significant.

In the short run, income has a significant positive impact on energy usage in Zimbabwe, South Africa, Togo, Senegal, Mauritius, Kenya, Ghana, Cote d'Ivoire, the Congo Republic, the Congo Democratic Republic, Cameroun, and Botswana, while its impact is negative in Nigeria, Gabon, and Sudan. In the short run, natural resource extraction has a negative impact on energy consumption in Sudan, Mauritius, Ghana, Gabon, Benin, Botswana, Cameroun, and the Congo Democratic Republic, while its impact is positive in Zimbabwe, Zambia, South Africa, Senegal, Nigeria, the Congo Republic, and Cote d'Ivoire. In the short run, trade openness has a negative impact on carbon emissions in Zimbabwe, Zambia, South Africa, Senegal, Kenya, Ghana, Gabon, the Congo Republic, Cameroun, and Botswana, while its impact is positive in Sudan, Nigeria, Mauritius, Cote d'Ivoire, and Benin. In the short run, the impact of urbanization on energy consumption in Botswana is negative, whereas its influence is positive in Zimbabwe, Zambia, Nigeria, Gabon, and the Congo Democratic Republic.

These findings suggest that environmental degradation decreases as foreign trade expands. The improvement in environmental quality can be attributed to the technique effect, which enables nations to import low-pollution manufacturing technologies. Trade, via its composition effect, facilitates the economic transition from agriculture-based to industry-based and ultimately to service-based sectors. These shifts typically exhibit lower pollution levels and adopt energy-efficient technologies, subsequently reducing energy demand.

Based on the results of this study, several policy implications can be deduced. Given that natural resource extraction activities contribute to environmental degradation, it is crucial for policymakers in the region to implement more stringent ecofriendly regulations that foster resource extraction in a financially prudent manner. Strict enforcement of legislation governing oil production and mining activities is essential. Furthermore, in addressing energy security challenges, it is vital for policymakers to focus on natural resource extraction ventures.

Considering that urbanization and income were found to increase energy consumption and carbon emissions, it is imperative for policymakers to encourage the transition towards renewable energy sources and stimulate the development and utilization of low-$CO_2$-emitting technologies. This approach will facilitate urban development and energy secur and foster sustainable green development in the region.

Lastly, as trade is determined to mitigate carbon emissions, there is a need for the governments of SSA countries to lower tariffs on environmentally friendly commodities and raise both tariff and nontariff barriers on goods that are detrimental to ecological quality.

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## References

1. Balcilar, M.; Usman, O.; Ike, G.N. Investing green for sustainable development without ditching economic growth. *Sustain. Dev.* **2023**, *31*, 728–743. [CrossRef]
2. Agan, B.; Balcilar, M. Unraveling the Green Growth Matrix: Exploring the Impact of Green Technology, Climate Change Adaptation, and Macroeconomic Factors on Sustainable Development. *Sustainability* **2023**, *15*, 8530. [CrossRef]
3. Agan, B.; Balcilar, M. On the Determinants of Green Technology Diffusion: An Empirical Analysis of Economic, Social, Political, and Environmental Factors. *Sustainability* **2022**, *14*, 2008. [CrossRef]
4. Zoaka, J.D.; Ekwueme, D.C.; Güngör, H.; Alola, A.A. Will financial development and clean energy utilization rejuvenate the environment in BRICS economies? *Bus. Strategy Environ.* **2022**, *31*, 2156–2170. [CrossRef]
5. Carbon Footprint. Climate Change. 2018. Available online: https://www.carbonfootprint.com/warming.html (accessed on 6 June 2022).
6. World Bank. *Update on World Bank Environmental and Social Framework (ESF)*; The World Bank: Washington, DC, USA, 2022.
7. Djalante, R. Key assessments from the IPCC special report on global warming of 1.5 C and the implications for the Sendai framework for disaster risk reduction. *Prog. Disaster Sci.* **2019**, *1*, 100001. [CrossRef]
8. Al-Mulali, U.; Ozturk, I.; Lean, H.H. The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe. *Nat. Hazards* **2015**, *79*, 621–644. [CrossRef]
9. Asumadu-Sarkodie, S.A.; Owusu, P.A. Carbon dioxide emissions, GDP, energy use, and population growth: A multivariate and causality analysis for Ghana, 1971–2013. *Environ. Sci. Pollut. Res.* **2016**, *23*, 13508–13520. [CrossRef]
10. Ekwueme, D.C.; Zoaka, J.D.; Alola, A.A. Carbon emission effect of renewable energy utilization, fiscal development, and foreign direct investment in South Africa. *Environ. Sci. Pollut. Res.* **2021**, *28*, 41821–41833. [CrossRef]
11. Ekwueme, D.C.; Zoaka, J.D. Emissions of carbon dioxide in MENA countries: Inference of financial development, trade receptivity, and energy utilization. *Environ. Sci. Pollut. Res.* **2020**, *27*, 12449–12460. [CrossRef]
12. Yu, H.; Nazir, R.; Huang, J.; Li, H. Linkages between renewable energy, financial development, and environmental sustainability in Asian countries. *Econ. Res. Ekon. Istraživanja* **2023**, *36*, 2192764. [CrossRef]

13. Yu, S.; Zhang, Q.; Hao, J.L.; Ma, W.; Sun, Y.; Wang, X.; Song, Y. Development of an extended STIRPAT model to assess the driving factors of household carbon dioxide emissions in China. *J. Environ. Manag.* **2023**, *325*, 116502. [CrossRef] [PubMed]
14. Adedoyin, F.F.; Gumede, M.I.; Bekun, F.V.; Etokakpan, M.U.; Balsalobre-lorente, D. Modelling coal rent, economic growth and $CO_2$ emissions: Does regulatory quality matter in BRICS economies? *Sci. Total Environ.* **2020**, *710*, 136284. [CrossRef] [PubMed]
15. Xing, L.; Khan, Y.A.; Arshed, N.; Iqbal, M. Investigating the impact of economic growth on environment degradation in developing economies through STIRPAT model approach. *Renew. Sustain. Energy Rev.* **2023**, *182*, 113365. [CrossRef]
16. Zongjie, D.; Shanliang, Z.; Wei, S.; Shulin, S. Study on energy consumption of hotel based on extended STIRPAT model. In Proceedings of the 2016 Chinese Control and Decision Conference (CCDC), Yinchuan, China, 28–30 May 2016; pp. 2052–2056.
17. Ekwueme, D.C. Footprint of Inexhaustible Energy Usage and Financial Development on Carbon Outrush of Eurasian Countries. In Proceedings of the International Conference on Eurasian Economies 2020, Baku, Azerbaijan, 2–4 September 2020. [CrossRef]
18. Uddin, I.; Khan, M.A.; Tariq, M.; Khan, F.; Malik, Z.K. Revisiting the determinants of life expectancy in Asia—Exploring the role of institutional quality, financial development, and environmental degradation. *Environ. Dev. Sustain.* **2023**, 1–21. [CrossRef]
19. World Bank. The World Bank Environmental and Social Framework. 2017. Available online: https://thedocs.worldbank.org/en/doc/837721522762050108-0290022018/original/ESFFramework.pdf (accessed on 6 June 2023).
20. World Bank. *The World Bank Environmental and Social Framework (ESF)*; The World Bank: Washington, DC, USA, 2020.
21. World Bank. Implementation Update. 2020. Available online: https://thedocs.worldbank.org/en/doc/982711602165538091-0290022020/original/ESFImplementationUpdateOctober2020.pdf (accessed on 6 June 2023).
22. World Bank. World Development Indicators. 2022. Available online: http://data.worldbank.org/country (accessed on 6 June 2022).
23. Wu, R.; Wang, J.; Wang, S.; Feng, K. The drivers of declining $CO_2$ emissions trends in developed nations using an extended STIRPAT model: A historical and prospective analysis. *Renew. Sustain. Energy Rev.* **2021**, *149*, 111328. [CrossRef]
24. Elkington, J. *Cannibals with Forks: The Triple Bottom Line of 21st-Century Business*; Capstone Publishing Ltd.: Oxford, UK, 1997.
25. Singh, R.K.; Murty, H.R.; Gupta, S.K.; Dikshit, A.K. An overview of sustainability assessment methodologies. *Ecol. Indic.* **2009**, *9*, 189–212. [CrossRef]
26. Azapagic, A. Systems approach to corporate sustainability: A general management framework. *Process Saf. Environ. Prot.* **2003**, *81*, 303–316. [CrossRef]
27. Waas, T.; Hugé, J.; Verbruggen, A.; Wright, T. Sustainable development: A bird's eye view. *Sustainability* **2011**, *3*, 1637–1661. [CrossRef]
28. Seuring, S.; Müller, M. From a literature review to a conceptual framework for sustainable supply chain management. *J. Clean. Prod.* **2008**, *16*, 1699–1710. [CrossRef]
29. Ma, M.; Pan, T.; Ma, Z. Examining the Driving Factors of Chinese Commercial Building Energy Consumption from 2000 to 2015: A STIRPAT Model Approach. *J. Eng. Sci. Technol. Rev.* **2017**, *10*, 28–38. [CrossRef]
30. Cai, W.G.; Ren, H.; Cao, S.P.; Lu, H.J. Analysis of the Major Drivers of Building Energy Consumption Using the STIRPAT Model—A Case Study in China. In *Applied Mechanics and Materials*; Trans Tech Publications Ltd.: Bach, Switzerland, 2012; Volume 193, pp. 57–61.
31. Westerlund, J. Testing for error correction in panel data. *Oxf. Bull. Econ. Stat.* **2007**, *69*, 709–748. [CrossRef]
32. Shahbaz, M.; Chaudhary, A.R.; Ozturk, I. Does urbanization cause increasing energy demand in Pakistan? Empirical evidence from STIRPAT model. *Energy* **2017**, *122*, 83–93. [CrossRef]
33. Shahbaz, M.; Loganathan, N.; Muzaffar, A.T.; Ahmed, K.; Jabran, M.A. How urbanization affects $CO_2$ emissions in Malaysia? The application of STIRPAT model. *Renew. Sustain. Energy Rev.* **2016**, *57*, 83–93. [CrossRef]
34. Inglesi-Lotz, R.; Morales, L.D.D.C. The effect of education on a country's energy consumption: Evidence from developed and developing countries. *ERSA Work. Pap* **2017**, *678*.
35. Kwakwa, P.A.; Alhassan, H.; Adu, G. Effect of natural resources extraction on energy consumption and carbon dioxide emission in Ghana. *Int. J. Energy Sect. Manag.* **2020**, *14*, 20–39. [CrossRef]
36. Adams, S.; Adom, P.K.; Klobodu, E.K.M. Urbanization, regime type and durability, and environmental degradation in Ghana. *Environ. Sci. Pollut. Res.* **2016**, *23*, 23825–23839. [CrossRef]
37. Adedoyin, F.F.; Agboola, P.O.; Ozturk, I.; Bekun, F.V.; Agboola, M.O. Environmental consequences of economic complexities in the EU amidst a booming tourism industry: Accounting for the role of Brexit and other crisis events. *J. Clean. Prod.* **2021**, *305*, 127117. [CrossRef]
38. Bekun, F.V.; Adedoyin, F.F.; Etokakpan, M.U.; Gyamfi, B.A. Exploring the tourism-$CO_2$ emissions-real income nexus in E7 countries: Accounting for the role of institutional quality. *J. Policy Res. Tour. Leis. Events* **2022**, *14*, 1–19. [CrossRef]
39. Caglar, A.E.; Zafar, M.W.; Bekun, F.V.; Mert, M. Determinants of $CO_2$ emissions in the BRICS economies: The role of partnerships investment in energy and economic complexity. *Sustain. Energy Technol. Assess.* **2022**, *51*, 101907. [CrossRef]
40. Rahman, M.M.; Alam, K. $CO_2$ emissions in Asia-Pacific region: Do energy use, economic growth, financial development, and international trade have detrimental effects? *Sustainability* **2022**, *14*, 5420. [CrossRef]
41. Sadik-Zada, E.R.; Loewenstein, W. Drivers of $CO_2$-Emissions in Fossil Fuel abundant settings:(Pooled) mean group and nonparametric panel analyses. *Energies* **2020**, *13*, 3956. [CrossRef]
42. Sadik-Zada, E.R.; Gatto, A. The puzzle of greenhouse gas footprints of oil abundance. *Socio-Econ. Plan. Sci.* **2021**, *75*, 100936. [CrossRef]

43. Sarkodie, S.A.; Strezov, V. Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. *Sci. Total Environ.* **2019**, *646*, 862–871. [CrossRef] [PubMed]
44. Udemba, E.N. Implication of energy expansion via the interaction of coal, industrialization, and agriculture towards climate goal: Dual sustainability analysis. *Environ. Sci. Pollut. Res.* **2022**, *29*, 25605–25622. [CrossRef]
45. Udemba, E.N.; Tosun, M. Energy transition and diversification: A pathway to achieve sustainable development goals (SDGs) in Brazil. *Energy* **2022**, *239*, 122199. [CrossRef]
46. Wang, Z.; Shi, C.; Li, Q.; Wang, G. Impact of heavy industrialization on the carbon emissions: An empirical study of China. *Energy Procedia* **2011**, *5*, 2610–2616. [CrossRef]
47. Dong, K.; Sun, R.; Li, H.; Liao, H. Does natural gas consumption mitigate $CO_2$ emissions: Testing the environmental Kuznets curve hypothesis for 14 Asia-Pacific countries. *Renew. Sust. Energy Rev.* **2018**, *94*, 419–429. [CrossRef]
48. Sinha, A.; Shahbaz, M. Estimation of Environmental Kuznets Curve for $CO_2$ emission: Role of renewable energy generation in India. *Renew. Energy* **2018**, *119*, 703–711. [CrossRef]
49. Aboagye, S. The policy implications of the relationship between energy consumption, energy intensity and economic growth in Ghana. *OPEC Energy Rev.* **2017**, *41*, 344–363. [CrossRef]
50. Adom, P.K. Time-varying analysis of aggregate electricity demand in Ghana: A rolling analysis. *OPEC Energy Rev.* **2013**, *37*, 63–80. [CrossRef]
51. Adom, P.K.; Bekoe, W. Modelling electricity demand in Ghana revisited: The role of policy regime changes. *Energy Policy* **2013**, *61*, 42–50. [CrossRef]
52. Alper, A.; Onur, G. Environmental Kuznets curve hypothesis for sub-elements of the carbon emissions in China. *Nat. Hazards* **2016**, *82*, 1327–1340. [CrossRef]
53. Asongu, S.A.; Odhiambo, N.M. Basic formal education quality, information Technology, and inclusive human development in sub-Saharan Africa. *Sustain. Dev.* **2019**, *27*, 419–428. [CrossRef]
54. Bekun, F.V.; Alola, A.A.; Sarkodie, S.A. Toward a sustainable environment: Nexus between $CO_2$ emissions, resources rent, renewable and nonrenewable energy in 16-EU countries. *Sci. Total Environ.* **2019**, *657*, 1023–1029. [CrossRef]
55. Ekwueme, D.C.; Lasisi, T.T.; Eluwole, K.K. Environmental sustainability in Asian countries: Understanding the criticality of economic growth, industrialization, tourism import, and energy use. *Energy Environ.* **2022**, 0958305X221091543. [CrossRef]
56. Kwakwa, P.A.; Aboagye, S.; Alhassan, H. Towards energy sustainability in Ghana: A review of the empirics on determinants of energy consumption. In *Sustainable Utilization and Management of Natural Resources in the Era of Climate Change*; Nova Publisher: New York, NY, USA, 2015; pp. 93–111.
57. Kwakwa, P.A.; Alhassan, H.; Aboagye, S. *Environmental Kuznets Curve Hypothesis in a Financial Development and Natural Resource Extraction Context: Evidence from Tunisia*; Aims Press: Springfield, MO, USA, 2018; Volume 2.
58. Kwakwa, P.A.; Aboagye, S. Energy consumption in Ghana and the story of economic growth, industrialization, trade openness and urbanization. *Asian Bull. Energy Econ. Technol.* **2014**, *1*, 1–5.
59. Mashhoodi, B.; Stead, D.; van Timmeren, A. Spatial homogeneity and heterogeneity of energy poverty: A neglected dimension. *Ann. GIS* **2019**, *25*, 19–31. [CrossRef]
60. Owusu, P.; Asumadu, S.S. A review of renewable energy sources, sustainability issues and climate change mitigation. *Adv. Hum. Perform. Cogn. Eng. Res.* **2016**, *3*, 1167990. [CrossRef]
61. Salahuddin, M.; Alam, K.; Ozturk, I.; Sohag, K. The effects of electricity consumption, economic growth, financial development and foreign direct investment on $CO_2$ emissions in Kuwait. *Renew. Sustain. Energy Rev.* **2018**, *81*, 2002–2010. [CrossRef]
62. Udemba, E.N.; Emir, F.; Philip, L.D. Mitigating poor environmental quality with technology, renewable and entrepreneur policies: A symmetric and asymmetric approaches. *Renew. Energy* **2022**, *189*, 997–1006. [CrossRef]
63. Jiang, Q.; Rahman, Z.U.; Zhang, X.; Guo, Z.; Xie, Q. An assessment of the impact of natural resources, energy, institutional quality, and financial development on $CO_2$ emissions: Evidence from the B&R nations. *Resour. Policy* **2022**, *76*, 102716.
64. Ahmed, K.; Mahalik, M.K.; Shahbaz, M. Dynamics between economic growth, labor, capital and natural resources abundance in Iran: An application of the combined cointegration approach. *Res. Policy* **2016**, *49*, 213–221. [CrossRef]
65. Badeeb, R.A.; Lean, H.H.; Clark, J. The evolution of the natural resources curse thesis: A critical literature survey. *Res. Policy* **2017**, *51*, 123–134. [CrossRef]
66. Balsalobre Lorente, D.; Shahbaz, M.; Roubaud, D.; Farhani, S. How economic growth, Renewable electricity and natural resources contribute to $CO_2$ emissions? *Energy Policy* **2018**, *113*, 356–367. [CrossRef]
67. Ben-Salha, O.; Dachraoui, H.; Sebri, M. Natural resource rents and economic growth in the top resource-abundant countries: A PMG estimation. *Resour. Policy* **2018**, *74*, 101229. [CrossRef]
68. Ulucak, R.; Khan, S.U.D. Determinants of the ecological footprint: Role of renewable energy, natural resources, and urbanization. *Sustain. Cities Soc.* **2020**, *54*, 101996.
69. Klevmarken, N.A. Panel Studies: What can we Learn from them? *Eur. Econ. Rev.* **1989**, *33*, 523–529. [CrossRef]
70. Commoner, B. The environmental cost of economic growth. *Popul. Resour. Environ.* **1972**, *3*, 343–363.
71. Ehrlich, P.R.; Holdren, J.P. Impact of population growth. *Science* **1971**, *171*, 1212–1217. [CrossRef]
72. Dietz, T.; Rosa, E.A. Rethinking the environmental impacts of population, affluence and technology. *Hum. Ecol. Rev.* **1994**, *1*, 277–300.

73. Hassan, M. Urbanization and $CO_2$ emission in Bangladesh: The Application of STIRPAT model. *A Pap. Presented Insearch* **2016**, *2016*, 3rd.
74. Li, K.; Lin, B. Impacts of urbanization and industrialization on energy consumption/$CO_2$ emissions: Does the level of development matter? *Renew. Sustain. Energy Rev.* **2015**, *52*, 1107–1122. [CrossRef]
75. Uddin, G.A.; Alam, K.; Gow, G. Estimating the major contributors to environmental impacts in Australia. *Int. J. Ecol. Econ. Stat.* **2016**, *37*, 1–14.
76. Ahmed, M.; Shuai, C.; Ahmed, M. Influencing factors of carbon emissions and their trends in China and India: A machine learning method. *Environ. Sci. Pollut. Res.* **2022**, *29*, 48424–48437. [CrossRef] [PubMed]
77. Aziz, S.; Chowdhury, S.A. Analysis of agricultural greenhouse gas emissions using the STIRPAT model: A case study of Bangladesh. *Environ. Dev. Sustain.* **2022**, *25*, 3945–3965. [CrossRef]
78. Salim, R.A.; Shafiei, S. Urbanization and renewable and non-renewable energy consumption in OECD countries: An empirical analysis. *Econ. Model.* **2014**, *38*, 581–591. [CrossRef]
79. Wang, D.; Han, B. The impact of ICT investment on energy intensity across different regions of China. *J. Renew. Sustain. Energy* **2016**, *8*, 055901. [CrossRef]
80. Ziyuan, C.; Yibo, Y.; Simayi, Z.; Shengtian, Y.; Abulimiti, M.; Yuqing, W. Carbon emissions index decomposition and carbon emissions prediction in Xinjiang from the perspective of population-related factors, based on the combination of STIRPAT model and neural network. *Environ. Sci. Pollut. Res.* **2022**, *29*, 31781–31796. [CrossRef]
81. Pesaran, M.H. General Diagnostic Tests for Cross Section Dependence in Panels. 2004, pp. 1–41. Available online: https://ssrn.com/abstract=572504 (accessed on 10 February 2019).
82. Breusch, T.S.; Pagan, A.R. The Lagrange multiplier test and its applications to model specification in econometrics. *Rev. Econ. Stud.* **1980**, *47*, 239–253. [CrossRef]
83. Phillips, P.C.; Hansen, B.E. Statistical inference in instrumental variables regression with I (1) processes. *Rev. Econ. Stud.* **1990**, *57*, 99–125. [CrossRef]
84. Pesaran, M.H. A simple panel unit root test in the presence of cross-section dependence. *J. Appl. Econom.* **2007**, *22*, 265–312. [CrossRef]
85. Pedroni, P. Fully modified OLS for the heterogeneous cointegrated panels. *Adv. Econom.* **2000**, *15*, 93–130.
86. Kao, C. Spurious regression and residual-based tests for cointegration in panel data. *J. Econom.* **1999**, *90*, 1–44. [CrossRef]
87. Amuakwa-Mensah, F.; Adom, P.K. Quality of institution and the FEG (forest, energy intensity, and globalization)-environment relationships in sub-Saharan Africa. *Environ. Sci. Pollut. Res.* **2017**, *24*, 17455–17473. [CrossRef] [PubMed]
88. López, L.A.; Arce, G.; Kronenberg, T.; Rodrigues, J.F. Trade from resource-rich countries avoids the existence of a global pollution haven hypothesis. *J. Clean. Prod.* **2018**, *175*, 599–611. [CrossRef]
89. Adom, P.K.; Kwakwa, P.A. Effects of changing trade structure and technical characteristics of the manufacturing sector on energy intensity in Ghana. *Renew. Sustain. Energy Rev.* **2014**, *35*, 475–483. [CrossRef]