DECOUPLING GROWTH FROM CO_2 EMISSION IN SELECTED ECOWAS COUNTRIES

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ABSTRACT

This study investigated the link between GDP, energy consumption and CO_2 emission and examined the role of decoupling CO_2 from GDP and energy consumption in reducing climate change in six ECOWAS countries. Using data on real GDP per capita, energy consumption per capita, and CO_2 emission for Benin, Côte d'Ivoire, Ghana, Nigeria, Senegal and Togo between 1970 and 2015, panel autoregressive distributed lag (PARDL), the study found evidence of a strong and positive link between CO_2 and energy and growth for all six countries. Furthermore, the growth hypothesis was found to hold in the entire region in the long run while the conservation hypothesis held in the short run. The main implication of these findings is that these countries are more amenable to conservation policies in the short run. In the long run, however, attempts to conserve energy consumption may harm growth. Increased decoupling of CO_2 from energy consumption was found to lead to higher energy intensity, thereby validating the energy rebound effect in these countries. However, increased decoupling of CO_2 from economic activity was found to reduce energy intensity in the entire region in the long run. It is recommended that the need to pursue greater growth in these countries ought to factor in the link between energy and growth and between energy and CO_2 emission as well as the limitation of conservation as a reliable long-term strategy for curbing CO_2 emission.

JEL classification: Q43, Q56

1. Introduction

The focus of this paper is to investigate the sustainability of economic growth in selected ECOWAS countries despite the reliance of these economies on energy use and its emission implications. Daly (1990) proposes that sustainable economic development entails maintaining a balance between economic growth, energy consumption and the environment (the three Es) and requires fulfilling three conditions: the consumption rate of renewable resources is not higher than its recovery rate; the consumption rate of non-renewable resources is not higher than the rate of increase in renewable resource supply; and the emission of pollutants is within the absorption capacity of the environment. Daly's recommendation essentially underscores the need to decouple economic growth from carbon dioxide (CO_2) emission, which is the most widely acknowledged and major contributor to global warming. But CO_2 is an inevitable by-product of economic growth powered by combustion of fossil fuel energy sources. Indeed, the environmental Kuznets hypothesis (EKH), which proposes an inverted U-shape relation between income per capita and environmental degradation, suggests the existence of a possible tie between economic growth and CO_2 emission in developing countries.

The motivation for this study rests on the need for ECOWAS countries, that have greater need for energy to power economic growth and poverty reduction but have been excluded from most efforts to mitigate climate change resulting from CO_2 emission due to combustion of fossil fuel energy sources, to devise ways of mitigating the negative consequences of pursuing greater growth on the environment. This motivation stems from the observation that developing countries appear to have taken a cue of a clean bill of health in terms of CO_2 emission from the EKH. In other words, one indirect consequence of the EKH has been the tendency of developing countries to view CO_2 emission as a necessary part of growth and implicitly excuse themselves from the responsibility of its abatement. For instance, even though Article 28 (Section 1) of the revised ECOWAS Treaty of 1993 provides for the co-ordination and harmonization of members' policy and programmes in the field of energy, there is no specific provision for mitigating the effects of climate change due to CO_2 emission in the region.

The EKH may also have been an instrumental factor in the exclusion of developing countries in the Kyoto protocol (Stern, 2004) that led to the exit of the United States and other countries from the Kyoto accord. Meanwhile, data from the least developed and middle-income countries on CO_2 emission in the past four decades shows that CO_2 emission has been on the increase in these regions (see figure 1). Nevertheless, efforts towards abatement appear to be more concentrated in developed countries than in developing countries, perhaps based on an unwritten 'polluter pays' principle. Indeed, developing countries which accounted for 9.6% of world per capita CO_2 emissions in 1987 accounted for 15.6% in 2000 (Baumert et al., 2005), reflecting higher energy intensity in developing countries than developed countries as the former pursue rapid economic growth.

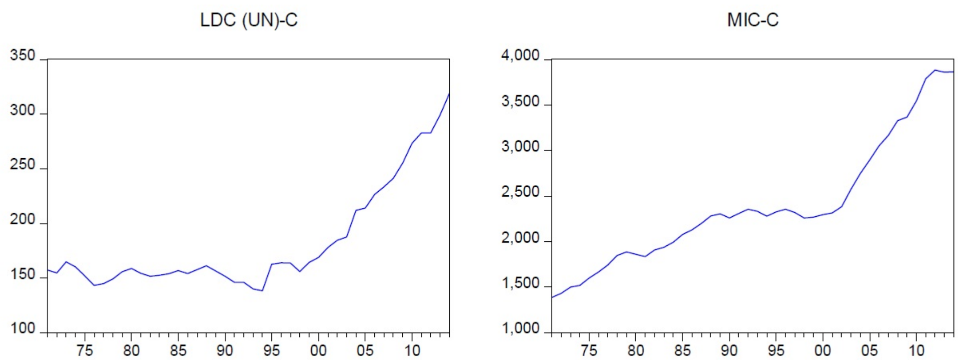

Figure 1. CO_2 Emission (Kt per capita) in LDCs and MICs
Author's computation, 2019.

Generally, expressing a pollutant as a ratio of economic activity measures the intensity of the pollutant associated with economic activity. Reductions in such intensities are a useful indicator of decoupling of economic activity from negative environmental impacts. For instance, indicators of energy intensity (ratio of energy use to output), the most widely used indicators for assessing the environmental impacts of economic activity in recent times, have been touted as very useful and necessary instruments for climate change negotiations and policy-making (Eichhammer & Mannsbart, 1997). This definition of decoupling matches that of the Organization for Economic Co-operation and Development (OECD, 2002), which defines decoupling as the process of breaking the relationship between environmental damages and economic benefits or between environmental pressures and economic performance. Indeed, since the ratification of the Kyoto protocol in 1997, the use of energy intensity indicators as a basis for policy-making has been on the increase. The basis for this is that trends in both energy intensity, and the major factors that affect it can provide climate change policy-makers with the information needed to set CO_2 targets for various industries, as well as design appropriate CO_2 abatement strategies (Mallika, 1998).

Despite notable increases in aggregate gross output and energy use over the past decade, energy intensity has declined globally (Allcott & Greenstone, 2012 & IEA, 2011) as well as in four of the selected ECOWAS countries (Senegal, Nigeria, Benin, and Ghana, except in Côte d'Ivoire and Togo: See Figure 1). In principle, reduction in energy intensity is desirable since it means that output has grown faster than energy use, thereby implying an improvement in energy efficiency and reduction in the negative environmental impacts of economic growth in the affected countries. However, the concern arising from the observed trends is whether the observed reductions in energy intensity would be sustainable in developing countries whose economic situations require that they vigorously pursue economic growth. This concern is further heightened by the energy rebound theory, which holds that greater energy efficiency results in greater energy consumption since efficiency drives down energy costs and raises its demand. The implication from the energy rebound theory is that reductions in CO_2 intensity (ratio of CO_2 emission to energy use) would be a more suitable approach towards abatement, especially for developing countries.

Bruns and Gross (2013) hold that, overall, the decline in CO_2 intensity over the past decades is mainly driven by lower energy intensity and as such cannot be sustained if energy use and economic activity are tied. The implication of this is that if the negative environmental impacts of energy use have to be mitigated, focus has to shift to reductions in CO_2 intensity, thereby underscoring the need to investigate the tie between energy and growth as well as to decouple CO_2 emission from economic activity towards achieving emission abatement in developing countries. However, owing to a number of reasons, ranging from the variable omission problem to differences in methodology, studies on the connection between economic growth and CO_2 emission have shown mixed results, especially for countries in the Economic Community of West African States (ECOWAS), thereby highlighting the need for a study to untangle the issue of connection between economic growth and CO_2 emission in these countries. Therefore, the focus of this study is to investigate the tie between CO_2 emission and economic growth and to establish whether decarbonization of energy use would be more sustainable in the selected countries.

2. Literature Review

The environmental implications of the linkage between economic activity and CO_2 emission due to energy use has been the subject of much debate. The mainstream view of the relationship between economic growth and the environment is that environment and economy have conflicting goals (Stern, 2004) as environmental degradation is often a direct or accidental consequence of economic growth. This implies that energy use ought to be reduced to preserve the environment. On the other hand, the ecological school considers energy as the only primary factor that all value derives from, including capital and labour which are intermediate inputs created and maintained through energy use (see Costanza, 1980; Cleveland et al., 1984; Hall et al., 2003; Ayres & Warr, 2005). The resource school, however, has incorporated the role of other resources apart from energy into the growth process. Even though the three schools differ on the importance of energy in the growth process, they do not dispute the connection between economic activity and the environment, nor do they detract from the need to decouple economic activity from negative environmental impacts, especially in developing countries where a positive association has been hypothesized to exist between economic growth and environmental degradation.

Extensive empirical work has examined the role of energy in the growth process with diverse findings as regards the relationship between energy use and relevant macroeconomic variables, including GDP, population, CPI, CO_2 emissions, among others. A review of the energy economics literature reveals mixed evidence on the connection between energy variables and non-energy variables, especially economic growth. A set of studies shows a causal relationship flowing from energy to economic growth (Fatai et al., 2004; Odhiambo, 2010; Tsani, 2010) while another set finds a causal relationship running from output to energy (Zachariadis, 2007; Zamani, 2007; Mehrara, 2007; Barleet & Gounder, 2010; Kapusuzoglu & Karan, 2010). A third set of studies indicates a bidirectional flow of causality between energy and economic growth (Mahadevan & Asafu-Adjaye, 2007; Erdal et al., 2008; Belloumi, 2009; Mishra et al, 2009) while a fourth set shows absence of a causal relationship between energy consumption and economic growth (Murry & Nan, 1996; Jobert & Karanfil, 2007; Soytas & Sari, 2009; Wolde-Rufael, 2009).

Indeed, each of the growth, conservation, feedback, and neutrality hypotheses has been empirically found to hold in different countries at different times. The growth hypothesis proposes that causality flows from energy use to economic growth while the conservation hypothesis proposes the reverse. The feedback hypothesis proposes a bidirectional causal relationship between energy use and economic growth while the neutrality hypothesis proposes absence of any causal relationship between the two. Each of these hypotheses bears implications for attempts to reduce emissions from energy use. Stern (1993), after observing that results of the early studies that tested for Granger causality using a bivariate model of energy and GDP were generally inconclusive, tested for Granger causality in a multivariate setting using a vector autoregression (VAR) model of GDP, capital and labour inputs, and a Divisia index of quality adjusted energy use (in place of gross energy use). He found that, in many cases, results differed depending on the samples used and the countries investigated. Stern (2000) also estimated a dynamic cointegration model for GDP, quality weighted energy, labour, and capital, using the Johansen methodology. He found a cointegrating relation between the four variables; and that energy Granger caused GDP either unidirectionally or possibly through a mutually causative relationship, depending on which version of the model is used.

Lee and Chang (2008) used panel data cointegration methods to examine the relationship between energy, GDP, and capital in 16 Asian and 22 OECD countries over a three and four decade period respectively. Lee and Chang (2008) found a long-run causal relationship from energy to GDP in the group of Asian countries while Lee and Chang (2008) found a bi-directional relationship in the OECD sample. Warr and Ayres (2010) replicated Stern's (2000) model for the US using their measures of exergy and useful work in place of Stern's Divisia index of energy use and found both short- and long-run causality from either exergy or useful work to GDP but not vice versa. Akinlo (2008), in a study of the relationship between energy consumption and economic growth for eleven countries in sub-Saharan Africa used the autoregressive distributed lag (ARDL) bounds test. The study found that energy consumption is co-integrated with economic growth in seven out of the eleven countries.

Esso (2010), using the Gregory and Hansen testing approach to threshold co-integration to investigate the long-run causality relationship between energy consumption and economic growth for seven sub-Saharan African countries during the period 1970–2007, found that energy consumption is co-integrated with economic growth in five out of the seven countries. Stern (2010) holds that the variable omission problem may explain the divergent and inconclusive nature of the early causality literature on energy and GDP. In this regard, some studies have included energy prices in the analysis of the energy-growth relationship. Stern, however, warns that that models using oil prices in place of energy quantities may not provide much evidence regarding the effects of energy use itself on economic growth. Olayeni (2012), using the asymmetric cointegration approach in order to account for a possible non-linear cointegration between energy and growth in twelve sub-Saharan African countries, also found confirmation for each of the growth, conservation, feedback, and neutrality hypotheses in different countries.

According to Smyth and Narayan (2014), in a review of the energy economics literature, the existence of a long-run relationship (cointegration) between energy variables and non-energy variables has become somewhat a stylized fact. They however submit that the mixed findings in the literature reflect several factors, including institutional differences between countries, model specification, and econometric approach. Indeed, they support the use of panel data for examining the unit root properties of energy variables as well as the Granger causality between energy variables and non-energy variables, warning however, that a panel Granger causality model will not reveal anything about the causality relationship for individual countries that make up the panel. In other words, a panel data model will not be appropriate if the research question and resulting policy implications focus on results for individual countries.

Similarly, most studies focusing on energy intensity have one main objective: to understand the drivers of changes in energy intensity. Gustavo and Francisco (2013), in their study of the drivers of energy intensity for European countries using the decomposition method, found that countries are classified into various groups based on drivers of changes in energy intensity. They therefore advocated that considering the change in the global energy intensity without decomposing it into its *technical* and *structural* components could lead to erroneous findings and inadequately conceived energy policies. To this end, a number of decomposition methods, broadly categorized into Structural Decomposition Analysis (SDA) and Index Decomposition Analysis (IDA), have been utilized to break down energy intensity into its technical and structural components (see Sinton & Levine, 1994; Garbaccio et al., 1999; Zhang, 2003; Fisher-Vanden et al., 2004). Findings in this area of energy research have generally been divided with some supporting that technical change within sectors accounted for most of the fall in the energy-output ratio while structural change actually increased the use of energy.

Cornillie and Fankhauser (2004) argued that the progress of technology improvements of energy efficiency may have contributed to a decline in energy intensity. Stern (2010) submitted that the reduction in energy intensity is due to both technological change and to a shift from poorer quality fuels such as coal to the use of higher quality fuels, and especially electricity. Other studies arrived at different conclusions, usually with controversies around the role of structural changes and technical changes on changes in energy intensity. In some countries energy intensity decreased because of improvements in both the structural and technical components. In other countries, the technical component resulted in reductions in energy intensity while structural changes increased it, although the technical component offset the structural component. In other countries yet, energy intensity increased despite changes in technical and structural components. While an analysis of the drivers of energy intensity using the decomposition method is highly important in order to identify the underlying dynamics of final energy consumption, Lightfoot and Green (2002) hold that a reduction in greenhouse gas emissions sufficient to stabilize the atmospheric concentration of CO_2 will require a combination of improvements in energy efficiency (technical) and increases in the availability and use of carbon-free sources of energy, including renewable energies and conservation (structural).

This study examines the effects of structural as well as technical components on energy intensity in selected ECOWAS countries

3. Methodology

Secondary time series data are on CO_2 emission in kilotons per capita, total energy use in kilograms of oil equivalent (kgoe) per capita and GDP per capita in constant 2010 US dollars, spanning the period 1971 to 2018. All data were obtained from the World Development Indicator (WDI) database. The use of per capita values brings the environmental impact of economic activity to the level of the individual energy user, thereby highlighting the role each individual can play in achieving emission abatement and energy conservation goals. The choice of countries is informed by lack of data for several years for the remaining ECOWAS countries. Equation 1 presents the general functional form of the model to capture the relation between economic growth, energy consumption and CO_2 emission.

$$G_{i,t} = f(E_{i,t}, C_{i,t}) \tag{1}$$

where:

$G_{i,t}$ is economic growth per capita;

$E_{i,t}$ is energy use per capita;

$C_{i,t}$ is CO_2 emission per capita;

the subscripts i ($i = 1, 2, \ldots, 6$) indicate the cross section of countries, while the subscripts t ($t = 1980, 1981, \ldots, 2012$) indicate the time dimension.

Following Yamaji et al. (1991), who used a modified form of the Kaya identity (see Equation 2) to illustrate the relationship between CO_2 emission and changes in energy per unit of GDP, CO_2 emission per unit of energy use, GDP per capita, and population, Equation 1 above can be transformed into a modified form of the Kaya identity (See Equation 3) which can be used to decompose the environmental impacts of energy use into energy intensity (structural) and CO_2 intensity (technical) components.

The Kaya identity is an application of the mathematical I = PAT equation, which describes the impact of human activity on the environment (I), via an interaction of three factors: population (P), affluence (A), and technology (T), to examine the environmental implications of energy use to power economic activity. Specifically, the modified Kaya identity expresses CO_2 emissions per unit of economic activity (GDP), expressed as a product of its structural (energy intensity) and technical (carbon intensity of energy) components. In addition to the effect of emission-reducing technological change, reductions in CO_2 intensity, i.e., decarbonization, can also be achieved through a shift from poorer quality energy sources such as coal to the use of higher quality sources such as natural gas (Stern, 2004).

$$CO_2 = \frac{CO_2}{Energy} \times \frac{Energy}{GDP} \times \frac{GDP}{Population} \times Population \tag{2}$$

Nhu and Pam (2012), in their economic analysis of end-use energy intensity in Australia, decomposed changes in energy consumption into three effects: the activity effect, which is based on the level of economic activity; the structural effect, based on the composition of economic activity; and the efficiency effect based on intensiveness of energy use. The implication of the foregoing is that energy consumption will change with changing economic activity as well as with changing need for energy in the growth process. Stern (2010) narrowed these effects down to two when he submitted that the observed reduction in energy intensities across the world over time is due to technological change, which could have dual effects on energy use and the environment. The first effect is that of energy-conserving technological change (structural effect) which reduces energy intensity while the second effect is that of emission-reducing technological change (technical effect) which reduces the emissions associated with energy use.

The structural effect entails reducing the CO_2 intensity of economic activity through the use of less energy per unit of output (conservation or de-intensification) while the technical effect entails reducing CO_2 intensity of energy use through the use of technology that reduces emission or through the use of more eco-friendly energy sources. The relevance of these two effects is that they constitute improvements in energy efficiency and mitigate the negative climate change implications of energy use. In this regard, the Kaya identity can be modified to decompose the decarbonization implications of changes in energy intensity into its structural and technical effects (Equation 3). Holding constant any direct effect of population changes on CO_2 emission (except through energy use and economic activity) and dividing both sides by GDP/Population (GDP per capita) yields:

$$CO_2 = \frac{CO_2}{Energy} \times \frac{Energy}{GDP} \times \frac{GDP}{Population} \times Population \tag{3}$$

where:

CO_2/GDP is the carbon intensity of output (CIO), which reflects the total environmental impact of economic activity in terms of CO_2 emission associated with energy consumption.

Energy/GDP is the energy intensity of output (EIO), which captures the extent of energy use in the growth process.

CO_2/Energy is the carbon intensity of energy use (CIE) and is used to capture the extent of CO_2 emissions associated with energy use. All variables are in per capita units.

The indicators in equation 3 offer a great opportunity for analysing the effects of CO_2 emission on the environment as well as for decoupling the economy from environmental degradation. Generally, reductions in these indicators imply decoupling of an economic 'bad' (the numerator) from an economic 'good' (the denominator). CIO implies decoupling of GDP from CO_2. Similarly, reductions in EIO imply decoupling GDP from energy while reductions in CIE imply decoupling energy from CO_2 emissions. However, for convenience, this study uses CIO to capture the *decoupling effect* while EIO and CIE capture, respectively, *the conservation effect* and the *decarbonization effect*.

The main concerns in the present study are to examine how these indicators have changed over the period of analysis and, more importantly, to investigate the impacts of the decarbonization and decoupling effects on the conservation effect in the selected countries. More specifically, given a possible tie between GDP and energy consumption as well as between energy and CO_2 emission, the striving towards higher economic growth in these countries may make conservation difficult, suggesting the need to explore the role of decoupling and decarbonization in achieving and sustaining conservation as well as improved environmental quality. Nakicenovic (1993) and Stern (2010) hold that reductions in energy intensity over time are associated with reductions in CO_2 intensity of energy use. This implies that the decarbonization effect is an important determinant of the conservation effect, especially when there is a tie between energy and GDP as well as between energy and CO_2. However, the decoupling effect is also a determinant of whether reductions in energy intensity would be sustainable over time since the efficiency gains from the decarbonization effect may lead to higher energy intensity. Therefore, reductions in CO_2 intensity of output are expected to combine with lower CO_2 intensity of energy to achieve lower energy intensity and, ultimately, better environmental quality. This relation is shown in figure 2.

Carbon Intensity of Energy↓ → Carbon Intensity of Output↓→ Energy Intensity↓

→ Environmental Quality↑

Figure 2. Hypothesized Relationship between CO_2 and Environment
Source: Agboola (2018).

Equation 3 can be re-written to enable an examination of the impacts of CO_2 intensity of energy as well as CO_2 intensity of output on energy intensity (see equation 4).

$$\frac{Energy}{GDP} = \frac{CO_2}{Energy} / \frac{CO_2}{GDP} \tag{4}$$

Equation 4 indicates that changes in energy intensity are influenced by CO_2 intensity of energy and CO_2 intensity of output. According to Stern (2010), a production function approach can be used to examine the factors that could weaken or strengthen the linkage between energy use and economic activity over time. By a similar reasoning, this study examines the environmental implications of the linkage between energy use and economic activity using a Cobb-Douglas specification (equation 5). The Cobb-Douglas specification is of importance since it enables us assess the extent of environmental impact of energy use as a result of each of energy intensity and carbon intensity of energy.

$$EIO_{i,t} = CIE_{i,t}^{\alpha} CIO_{i,t}^{\beta} \varepsilon^{\mu_{i,t}} \tag{5}$$

In equation 5, *EIO* denotes energy intensity of output, a measure of conservation effect (captured as reductions in energy intensity of output); *CIO* denotes CO_2 intensity of output, which captures the decoupling effect, while *CIE* denotes CO_2 intensity of energy. The parameter α measures the extent to which the decarbonization effect (captured by reductions in CO_2 intensity of energy) impacts the environment while β measures the extent to which the decoupling effect (captured as reductions in CO_2 intensity of output) impacts the environment; $\varepsilon^{\mu_{i,t}}$ captures other impacts on changes in CO_2 intensity of economic activity not explained by either of the conservation and decarbonization effects as captured above. In order to examine the dynamics of the relationship among the absolute values of the variables as well as the intensities, two separate sets of panel ARDL model, specified in equations 6 to 11, will be estimated to examine the tie between GDP, energy and CO_2 as well as between EIO, CIE and CIO. Equations 6 and 8 are to be estimated in case of the absolute values while Equations 9 to 11 are to be estimated in the case of the intensities.

Model 1. Impact of energy and CO_2 emission on GDP

$$\Delta LNGDP_{i,t} = \alpha + \sum_{j=1}^{\rho} \beta_i \Delta LNGDP_{i,t-j} + \sum_{j=0}^{\rho} \gamma_i \Delta LNENE_{i,t-j} + \sum_{j=0}^{\rho} \theta_i \Delta LNCO_{2_{i,t-j}} + \delta_1 LNGDP_{i,t-1} + \delta_2 LNENE_{i,t-1} + \delta_3 LNCO_{2_{i,t-1}} + \xi_{i,t} \quad (6)$$

$$LNGDP_{i,t} = \alpha_{i,1} + \sum_{j=1}^{\rho} \beta_{i,1} LNGDP_{i,t-j} + \sum_{j=0}^{\rho} \gamma_{i,1} LNENE_{i,t-j} + \sum_{j=0}^{\rho} \theta_{i,1} LNCO_{2_{i,t-j}} + \xi_{i,t} \quad (7)$$

$$\Delta LNGDP_{i,t} = \alpha_{i,2} + \sum_{j=1}^{\rho} \beta_{i,2} \Delta LNGDP_{i,t-j} + \sum_{j=0}^{\rho} \gamma_{i,2} \Delta LNENE_{i,t-j} + \sum_{j=0}^{\rho} \theta_{i,2} \Delta LNCO_{2_{i,t-j}} + \varphi_i ECT_{i,t-1} + \xi_{i,t} \quad (8)$$

Model 2. Impact of GDP and CO_2 emission on energy

$$\Delta LNENE_{i,t} = \alpha_{i,2} + \sum_{j=1}^{\rho} \beta_{i,2} \Delta LNENE_{i,t-j} + \sum_{j=0}^{\rho} \gamma_{i,2} \Delta LNGDP_{i,t-j} + \sum_{j=0}^{\rho} \theta_{i,2} \Delta LNCO_{2_{i,t-j}} + \varphi_i ECT_{i,t-1} + \xi_{i,t} \quad (9)$$

$$LNENE_{i,t} = \alpha_{i,1} + \sum_{j=1}^{\rho} \beta_{i,1} LNENE_{i,t-j} + \sum_{j=0}^{\rho} \gamma_{i,1} LNGDP_{i,t-j} + \sum_{j=0}^{\rho} \theta_{i,1} LNCO_{2_{i,t-j}} + \xi_{i,t} \quad (10)$$

$$\Delta LNENE_{i,t} = \alpha_{i,2} + \sum_{j=1}^{\rho} \beta_{i,2} \Delta LNENE_{i,t-j} + \sum_{j=0}^{\rho} \gamma_{i,2} \Delta LNGDP_{i,t-j} + \sum_{j=0}^{\rho} \theta_{i,2} \Delta LNCO_{2_{i,t-j}} + \varphi_i ECT_{i,t-1} + \xi_{i,t} \quad (11)$$

Model 3. Impact of GDP and energy on CO_2 emission

$$\Delta LNCO_{2_{i,t}} = \alpha + \sum_{j=1}^{\rho} \beta_i \Delta LNCO_{2_{i,t-j}} + \sum_{j=0}^{\rho} \gamma_i \Delta LNGDP_{i,t-j} + \sum_{j=0}^{\rho} \theta_i \Delta LNENE_{i,t-j} + \delta_1 LNGDP_{i,t-1} + \delta_2 LNENE_{i,t-1} + \delta_3 LNCO_{2_{i,t-1}} + \xi_{i,t} \quad (12)$$

$$LNCO_{2_{i,t}} = \alpha_{i,1} + \sum_{j=1}^{\rho} \beta_{i,1} LNCO_{2_{i,t-j}} + \sum_{j=0}^{\rho} \gamma_{i,1} LNGDP_{i,t-j} + \sum_{j=0}^{\rho} \theta_{i,1} LNENE_{i,t-j} + \xi_{i,t} \quad (13)$$

$$\Delta LNCO_{2_{i,t}} = \alpha_{i,2} + \sum_{j=1}^{\rho} \beta_{i,2} \Delta LNCO_{2_{i,t-j}} + \sum_{j=0}^{\rho} \gamma_{i,2} \Delta LNGDP_{i,t-j} + \sum_{j=0}^{\rho} \theta_{i,2} \Delta LNENE_{i,t-j} + \varphi_i ECT_{i,t-1} + \xi_{i,t} \tag{14}$$

Model 4. Impact of CIE and CIO on EIO

$$\Delta EIO_{i,t} = \alpha + \sum_{j=1}^{\rho} \beta_i \Delta EIO_{i,t-j} + \sum_{j=0}^{\rho} \gamma_i \Delta CIE_{i,t-j} + \sum_{j=0}^{\rho} \theta_i \Delta CIO_{2_{i,t-j}} + \delta_1 EIO_{i,t-1} + \delta_2 CIE_{i,t-1} + \delta_3 CIO_{i,t-1} + \xi_{i,t} \tag{15}$$

$$EIO_{i,t} = \alpha_{i,1} + \sum_{j=1}^{\rho} \beta_{i,1} EIO_{i,t-j} + \sum_{j=0}^{\rho} \gamma_{i,1} CIE_{i,t-j} + \sum_{j=0}^{\rho} \theta_{i,1} CIE_{i,t-j} + \xi_{i,t} \tag{16}$$

$$EIO_{i,t} = \alpha_{i,2} + \sum_{j=1}^{\rho} \beta_{i,2} EIO_{i,t-j} + \sum_{j=0}^{\rho} \gamma_{i,2} CIE_{i,t-j} + \sum_{j=0}^{\rho} \theta_{i,2} CIO_{i,t-j} + \varphi_i ECT_{i,t-1} + \xi_{i,t} \tag{17}$$

GDP is real GDP per capita, *ENE* is energy consumption per capita and CO_2 is CO_2 emission per capita. The intensities are as earlier defined. The parameter α_i is the intercept; β_i, θ_i and γ_i are the short run coefficients; φ_i are the short-run error covariances (ECT) while δ_i are the long run coefficients; ξ is the error term.

Equations 6 and 9 are the general panel ARDL specifications, equations 7 and 10 capture the long-run while equations 8 and 11 capture the short-run components. The panel ARDL or pooled mean group (PMG) estimator estimates the long run and short run separately but simultaneously. The panel ARDL or pooled mean group (PMG) proposed by Pesaran, Smith and Shin (1997), is an intermediate model that combines features of the random and fixed effects models. Specifically, the PMG model constrains long-run coefficients to be the same across the whole group while allowing short run intercepts, coefficients and error variances to vary among individual units. This feature of the PMG has economic justification on many accounts, especially when a similar or common steady state across the group is occasioned by economic fundamentals or policy while initial conditions, growth rates and speeds of adjustments differ among units in the short run. The PMG approach is especially appealing as it can combine variables whether they are all I(0) or I(1) series, regardless of whether they are cointegrated or not. The PMG also allows the simultaneous estimation of both short-run and long-run relationships.

4. Results

Four regressions are estimated. The first is estimated with the natural logarithms of GDP, energy (ENE) and CO_2 emission to investigate the tie among energy, CO_2 emission and economic activity while the second is estimated with energy and CO_2 intensities to examine the decoupling and decarbonization effects on energy conservation and hence on the environment. A good way to understand the behaviour of and relationship among a set of variables over time is to begin by examining the trend as well as the distribution properties of the chosen dataset. An observation of the graphs of the means of GDP, energy, CO_2, EIO, CIE and CIO among the six countries sampled for this study reveals an upward trend in all the six variables. This means that even though the variables fluctuate over time, they generally increased over the period of analysis. While the implication of an upward trend in GDP is desirable as it implies economic growth, that of energy consumption and CO_2 emission may not be desirable as they pose, respectively, challenges of energy conservation and increasing global temperatures. To further unravel the behaviour of these variables, a descriptive analysis is carried out.

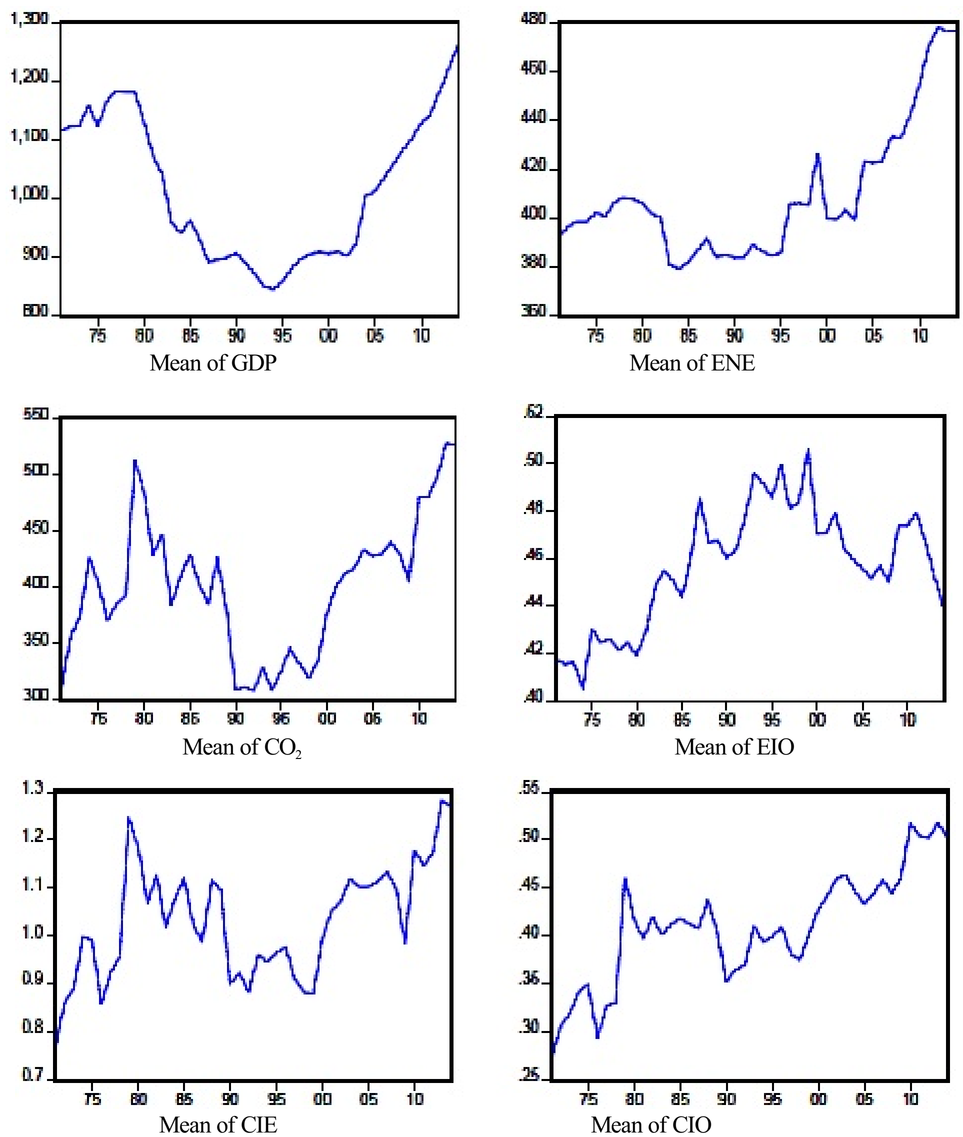

Figure 3. Graph of GDP, Energy CO_2 and Intensities
Source: Author's computation (2019).

Descriptive statistics such as mean, standard deviation, maximum and minimum values, skewness, kurtosis and the Jarque-Bera statistic provide information about the distributional properties of the data while trend analysis provides information about the behaviour of the variables over time. Information about the mean and standard deviation provides a theoretical distribution of the variable as a yardstick for assessing the maximum and minimum values which provide a hint regarding the empirical distribution of the variable. Any deviation of the empirical observation of distributional properties from theoretical expectation is a pointer to the need for further investigation. For a normally distributed dataset, 68%, 95% and 99.7% of the sample are expected to fall within one, two and three standard deviation units, respectively, around the mean. This means that the minimum and maximum values are expected to be close to one, two or three standard deviations (depending on whether the 68%, 95% and 99.7% rule, respectively, is used). Similarly the skewness and kurtosis values for a normally distributed dataset must be zero and three, respectively, while the null hypothesis of normal distribution in the Jarque-Bera test must not be rejected.

The results of the descriptive analysis (see table 1) show that, for all six variables, the minimum values are within the expected distance from the mean. However, the maximum values suggest a positive skewness as well as the presence of outliers, thereby implying that the data may not be normally distributed. The skewness values seem to confirm this as GDP and ENE are strongly positively skewed while CO_2, EIO, CIE and CIO are moderately positively skewed. Similarly, the kurtosis values show that GDP, ENE and CO_2 are fat-tailed and peaked, which implies an over-representation of extreme values while EIO, CIE and CIO are thin-tailed and flat, implying an under-representation of extreme values. Finally, the Jarque-Bera statistic for all variables indicate that there is no evidence that data not normally distributed as the null of normal distribution is rejected even at the 1% level.

Table 1. Descriptive Statistics

	GDP	ENE	CO2	EIO	CIE	CIO
Mean	1017.442	409.1063	400.3116	0.456749	1.030683	0.409201
Std. Dev.	504.2929	146.7715	194.233	0.178509	0.499646	0.140342
Maximum	2563.09	798.3	1010.017	1.021172	2.269306	0.912232
Minimum	411.18	206.87	77.78415	0.189413	0.215926	0.142686
Skewness	1.125929	1.12218	0.672678	0.656823	0.628146	0.677438
Kurtosis	3.394263	3.223662	3.01186	2.996154	2.463895	3.430133

	GDP	ENE	CO2	EIO	CIE	CIO
Jarque-Bera	57.48935	55.95892	19.91137	18.98246	20.52246	22.22775
Probability	0	0	0.00005	0.00008	0.00004	0.00002
Observations	264	264	264	264	264	264

Source: Author's computation, 2019.

The main concern of this study, however, is that the desired upward trend in GDP may be tied to the undesirable upward trend in energy consumption and CO_2 emission. Therefore, to investigate the relationship among these variables, correlation, unit root and panel regression analyses are conducted. Pairwise correlation shows the strength of linear association between two variables. One implication of conducting correlation analysis for this study is to determine the presence of linear dependence among the variables and as such the presence or otherwise of multicollinearity in the model. A rule of thumb is that a pairwise correlation coefficient in excess of 0.8 implies the presence of multicollinearity. The results of pairwise correlation conducted separately for the absolute values of the variables and their intensities are presented in table 2. A positive and significant linear association exists between GDP and CO_2 (0.75); GDP and energy (0.62); and energy and CO_2 (0.49). This further strengthens the suspicion of a tie between GDP and the duo of energy and CO_2 emission. Similarly, a positive and significant linear association exists between EIO and CIO (0.17) as well as between CIE and CIO (0.53). However, a negative and significant association exists between EIO and CIE (-0.69). Although all the correlation coefficients are significant at the 1% level, the values are not large enough (all coefficients < 0.8) to present any threat of multicollinearity.

Table 2. Pairwise Correlation Analysis

Correlation Analysis: Ordinary							
Variable	GDP	ENE	CO_2	Variable	CIO	EIO	CIE
GDP	1	-	-	CIO	1	-	-
ENE	0.622837**	1	-	EIO	0.169093**	1	-
CO_2	0.746508**	0.494620**	1	CIE	0.533873**	-0.692852**	1

Correlation in parenthesis; (**) significant at 1%

Source: Author's computation, 2019.

Table 3. Panel Unit Root Analyses

Panel Unit Root Analyses: Summary (with Constant & Trend, Maximum Lags)									
Absolute Values									
Variable	GDP			ENERGY			CO_2		
Method	Level	1st Diff.	Remark	Level	1st Diff.	Remark	Level	1st Diff.	Remark
IPS	2.5246	-8.0593**	I(1)	0.9328	-7.7897**	I(1)	-0.3967	-10.3702**	I(1)
LLC	0.8159	-6.6757**	I(1)	6827	-6.4416**	I(1)	0.7521	-8.1953**	I(1)
Breitung	1.7577	-5.5134**	I(1)	0.6392	-5.6072**	I(1)	-0.3104	-7.9177**	I(1)
Intensities									
Variable	ENERGY/GDP (EIO)			CO_2/ENERGY (CIE)			CO_2/GDP (CIO)		
Method	Level	1st Diff.	Remark	Level	1st Diff.	Remark	Level	1st Diff.	Remark
IPS	-0.2298	-9.0356**	I(1)	-1.216	-10.3173**	I(1)	-2.2919*	-	I(0)
LLC	-1.3878	-7.7121**	I(1)	-1.9742*	-	I(0)	-2.6458**	-	I(0)
Breitung	0.423	-6.2539**	I(1)	-1.5041	-7.9321**	I(1)	-2.1253*	-	I(0)

(**): $p < 0.01$, Significant at 1%; (*): $p < 0.05$, Significant at 5%

Source: Author's computation, 2019.

The integration properties of the data are examined using the Im-Pesaran-Shin (IPS), the Levin-Lin-Chu (LLC) as well as the Breitung unit root analyses. Results from all three tests unanimously show that four of the six variables (GDP, ENE, CO_2 and EIO) become stationary only after first difference while CIO is stationary at level. However, results from the LLC panel unit root test differs from those from IPS and Breitung only on account of CIE. Both the IPS and Breitung CIE become stationary only after first difference while the LLC shows that CIE is stationary at level. All results are significant at the 5% level. Since cointegration can be inferred from the panel ARDL estimation, no cointegration tests are conducted in this study.

Having determined the order of integration of the series, the test to obtain the optimal lag selection for the panel ARDL model is conducted to determine how many lags to include in the regression. The panel ARDL framework incorporates the mean group (MG), pooled mean group (PMG) and the dynamic fixed effect (DFE) models among which the Hausman test can be conducted to determine the more efficient model between the MG and PMG as well as between PMG and DFE. The MG model assumes both short run and long run heterogeneity among individual countries in the panel while the DFE assumes both short-run and long-run homogeneity among them. However, the PMG assumes short-run heterogeneity but long-run homogeneity among the individual countries. Four models are estimated. The first three examine the relationship between GDP, energy and CO_2 with each used as dependent variable in each regression to determine the flow of causality among them. The fourth model examines the effects of the decarbonization effect (CIE) and the decoupling effect (CIO) on the conservation effect (EIO). Results indicate that ARDL (1, 0, 0) is optimal in each case.

Results of the Hausman test reveal that the PMG is the more efficient model in the first, third and fourth regressions while the DFE is found to be more efficient in the second regression (see tables 4 to 7). The first regression is estimated to investigate the relationship between energy consumption and CO_2 emission, with a view to determining the flow of causality among the variables. The pooled mean group estimate indicates a positive and significant long-run relationship between each of energy consumption per capita and CO_2 emission per capita on per capita real GDP in the countries of focus. Specifically, a percentage increase (decrease) in each of energy consumption and CO_2 emission is expected to result, respectively, in an increase (decrease) of approximately 0.5 per cent and 0.2 per cent increase (decrease) in GDP in the group as a whole. This implies a long-run causal relationship flowing from both energy and CO_2 emission to economic growth in the region.

Table 4. Panel ARDL Estimation of Impact of Energy and CO_2 on GDP

Regression 1 - Estimator: Pooled Mean Group (PMG)						
Long Run Dependent: LNGDP						
Regressors			Coefficient			
LNENE			0.4907***			
$LNCO_2$			0.1951***			
Short Run						
Regressors	Benin	Côte d'Ivoire	Ghana	Nigeria	Senegal	Togo
ECT(-1)	-0.1512*	-0.059*	0.0529	-0.0101	-0.2634**	-0.04
D(LNENE)	-0.1234	0.0137	0.1641	-0.0202	0.092	0.4063*
DLN(CO_2)	0.0425	0.0302	0.018	0.0742	-0.0396	-0.0786**
C	0.3913	0.1778	-0.1287	0.0379	0.7675*	-0.0901

Note: Hausman (MG vs PMG) 1.84; p = 0.3976; Hausman (PMG vs DFE) 0.95; p = 0.6230

(***): $p < 0.01$; (**): $p < 0.05$; (*): $p < 0.10$

Source: Author's computation, 2019.

The short-run dynamics differ across the countries. The adjustment process to long run, as indicated by the error correction term, is negative and significant only for Senegal at the 5% level. This means that short-run deviations from the path to long-run equilibrium will be corrected at a rate of 26% per period in Senegal. There is no evidence (at the 5% level) of short-run adjustment to long-run equilibrium in the remaining five countries. The results also reveal that there is no evidence of a short-run causal relationship between energy and CO_2 in all six countries, while only Togo shows evidence of negative and significant short run impact of CO_2 on GDP. The results from the dynamic fixed effects regression conducted to examine the impact of GDP and CO_2 on energy consumption (table 5) indicate that there is no evidence of long-run causal relationship from each of GDP and CO_2 to energy. However, the short-run adjustment coefficient is negative and significant even at the 1% level.

Furthermore, results indicate statistical evidence of a short-run causal relationship from GDP and CO_2 to energy.

Table 5. Panel ARDL Estimation of Impact of GDP and CO_2 on Energy

Regression 2 - Estimator: Dynamic Fixed Effects (DFE)	
Long Run - Dependent: LNENE	
Regressors	Coefficients
LNENE	-0.4097
$LNCO_2$	0.1206
Short Run	
ECT(-1)	-0.0737***
LNENE	0.1557**
LNCO2	0.0607***
C	0.5951***
Note: Hausman (MG vs PMG) 25.76; p = 0.0000; Hausman (MG vs DFE) 0.00; p = 0.9995	
(***): p < 0.01; (**): p < 0.05; (*): p < 0.10	

Source: Author's computation, 2019.

The main implication of the results from the first and second regressions is that the growth hypothesis (which holds that energy causes growth) characterizes the group of countries under study in the long run while the conservation hypothesis (which proposes that growth causes energy) characterizes the region in the short run. This means that energy and economic growth may be tied in the long run and attempts to conserve energy consumption would harm growth in the region in the long run. This poses a challenge for attempts to combat the negative impacts of energy and CO_2 emission on the environment in this region. However, evidence suggests that conservation may be used to promote growth in the short run.

Given the evidence that energy conservation may not be a viable long-run solution to the emission implications of economic growth in the countries of focus, an attempt is made to explore the impact of energy consumption and economic growth on CO_2 emission, with a view to decoupling emission from energy and GDP. The pooled mean group regression (table 6) to examine the impact of GDP and energy on CO_2 shows that only energy shows evidence of a long-run causal effect on CO_2 emission in the entire region. Specifically, a one per cent increase (decrease) in energy consumption is expected to result in approximately one per cent increase (decrease) in CO_2 emission in the long run. However, the adjustment process to a long-run relationship is significant (and rather fast) for four countries: Côte d'Ivoire, Ghana, Senegal and Togo, but not significant for Benin and Nigeria. Furthermore, there is evidence of a positive and significant short-run causal relationship flowing from GDP to CO_2 in Benin, Nigeria and Togo while only Togo shows evidence of a significant but negative short-run causal relationship from energy to CO_2.

Table 6. Panel ARDL Estimation of Impact of GDP and Energy on CO_2

Regression 3 - Estimator: Pooled Mean Group (PMG)						
Long Run - Dependent: LNCO_2						
Regressors			Coefficient			
LNGDP			0.3045			
LNENE			0.9928***			
Short Run						
Independent	Benin	Côte d'Ivoire	Ghana	Nigeria	Senegal	Togo
ECT(-1)	-0.0633	-0.4211***	-0.5106***	-0.1399*	-0.4722***	-0.3042***
D(LNGDP)	1.5939***	0.5115	-0.4311	2.9399**	-0.7223	2.8741***
D(LNENE)	1.3199*	0.0314	0.2997	0.2516	-0.2277	-1.4800**
C	-0.1595	-2.2460	-1.3124	0.4289	-1.0982	-0.7920

Note: Hausman (MG vs PMG) 0.20; $p = 0.9068$; Hausman (PMG vs DFE) 0.10; $p = 0.9529$
(***): $p < 0.01$; (**): $p < 0.05$; (*): $p < 0.10$

Source: Author's computation, 2019.

These findings indicate that energy and CO_2 cause economic growth while only energy causes CO_2 emission in the long run. In the short run, GDP and CO_2 cause energy consumption while GDP causes CO_2 emission in three countries. These results depict a tie among GDP, energy and CO_2 emission, thereby further highlighting the need to decouple CO_2 emission from energy consumption as well as from GDP. Results of a pooled mean regression conducted to examine the impact of decoupling CO_2 from GDP and energy on energy conservation (table 7) indicate that there exists a negative and significant long-run causal relationship between CO_2 intensity of energy (CIE) and energy intensity of output (EIO) while CO_2 intensity of output (CIO) shows evidence of a positive long-run causal effect on EIO. This implies that, in the long run, increased decoupling of CO_2 from energy use (decarbonization of energy use, i.e., reductions in CIE) would lead to increased energy intensity while increased decoupling of CO_2 from economic activity (reductions in CIO) would lead to reduced energy intensity. These results are confirmed in the short run. CIE is found to have a negative and significant causal effect on EIO in all six countries while CIO has a positive and significant causal effect on EIO in five countries, except in Senegal where it has a positive and significant effect.

Table 7. Panel ARDL Estimation of Impact of CIE and CIO on EIO

Regression 4 - Estimator: Pooled Mean Group (PMG)						
Long Run - Dependent: EIO						
Regressors			Coefficient			
CIE			-0.3755***			
CIO			0.7207***			
Short Run						
Independent	Benin	Côte d'Ivoire	Ghana	Nigeria	Senegal	Togo
ECT(-1)	-0.0948**	-0.0658*	-0.3148***	-0.0428	-0.0078	-0.0300
D(CIE)	-0.7134***	-0.2305***	-0.2803***	-0.2664***	-0.1464***	-0.4636***
D(CIO)	1.2819***	0.9832***	0.6337***	0.6278***	-0.5176***	0.8776***
C	0.0517**	0.0340**	0.1693***	0.0209	0.0045	0.0197

Note: Hausman (MG vs PMG) 4.35; $p = 0.1136$; Hausman (PMG vs DFE) 0.00; $p = 0.9999$

(***): $p < 0.01$; (**): $p < 0.05$; (*): $p < 0.10$

Source: Author's computation, 2019.

5. Conclusion

This study set out to investigate the tie between GDP and energy consumption and CO_2 emission, and how changes in CO_2 intensity of energy and CO_2 intensity of output would impact energy intensity in six ECOWAS countries. GDP, energy consumption and CO_2 emission trended upwards over the period of analysis. Pairwise correlation suggests the presence of a tie between GDP and the duo of energy and CO_2 emission. A long-run causal relationship is found to run from both energy and CO_2 emission to GDP in the region but there is no evidence of a long-run causal relationship running from each of GDP and CO_2

to energy. In other words, the growth hypothesis is found to hold in the long run while the conservation hypothesis holds in the short run. The main implication of these findings is that these countries are more amenable to conservation policies in the short run. In the long run, however, attempts to conserve energy consumption may harm growth. This means that, given the tie between energy and GDP in the long run, decoupling energy consumption from GDP would not be a viable long run option for reducing CO_2 emission in the countries of focus. There is, therefore, the need for alternative long-run solutions to the climate change implications of energy consumption and CO_2 emission in the region. One viable option is to decouple CO_2 emission from economic growth. However, the findings that energy consumption (but not GDP) was also found to have a long-run causal effect on CO_2 emission in the entire region implies the need to also decouple CO_2 emission from energy consumption through decarbonization.

Decarbonization (increased decoupling of CO_2 from energy use) was found to lead to higher energy intensity in the long run, thereby validating the energy rebound effect in these countries. The energy rebound effect was also confirmed for all six countries in the short run. However, increased decoupling of CO_2 from economic activity was found to reduce energy intensity in the long run for the entire region but only in five countries (except in Senegal where it reduces energy intensity) in the short run. Following the findings of this study, the following recommendations are made for policy towards emission reduction in the countries of focus. The need to pursue greater growth in these countries ought to factor in the tie between energy and growth and between energy and CO_2 emission as well as the limitation of conservation as a reliable long-term strategy for curbing CO_2 emission. Furthermore, policies of decarbonization should be complemented with policies to achieve decoupling of CO_2 emission from economic growth through sourcing for alternatives to CO_2-emitting energy sources.

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