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# Impact of Agriculture and Energy on $CO_2$ Emissions in Zambia

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**Abstract:** The world has experienced increased impacts of anthropogenic global warming due to increased emissions of greenhouse gases (GHGs), which include carbon dioxide ($CO_2$). Anthropogenic activities that contribute to $CO_2$ emissions include deforestation, usage of fertilizers, and activities related to mining and energy production. The main objective of this paper was to assess the impacts of agriculture and energy production on $CO_2$ emissions in Zambia. This research used econometric analysis, specifically the Autoregressive-Distributed Lag (ARDL) Bounds Test, to analyze the relationship between $CO_2$ emissions and GDP, electricity consumption, agricultural production, and industry value added. The results showed the presence of cointegration, where the variables of $CO_2$ emissions, GDP, electricity, and agriculture converge to a long-run equilibrium at the rate of 74%. Further, there was a short-run causality towards $CO_2$ emissions running from agriculture and the consumption of energy as indicated by the Wald test. This is the first study of its kind that empirically shows the impact of agricultural activities and energy consumption on the Zambian environment through their contribution to $CO_2$ emissions at a macro (country) level. This paper also presents recommendations that are pertinent to mitigate these effects. To deescalate environmental degradation, we propose increasing the number of access points for multiple renewable energy sources across the country; discouraging deforestation, the usage of conventional fertilizers, and the burning of vegetation for fertilizers; encouraging afforestation and reforestation, in addition to providing subsidies, training, and financial support to farmers and entrepreneurs who decide to use environmentally friendly agricultural methods and renewable energy. This research highlights the serious impacts of anthropogenic activities on $CO_2$ emissions. The study was intended to assist Zambian policymakers in formulating and implementing environmentally friendly policy measures or systems that will contribute towards environmental protection commitments and sustainable economic development.

**Keywords:** agriculture; energy; carbon emissions; ARDL bounds test; Zambia



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## 1. Introduction

The world has experienced increased impacts of anthropogenic global warming, resulting mainly from increased emissions of greenhouse gases (GHGs), including carbon dioxide ($CO_2$). The continuous increase in demand for energy, food production, and Gross Domestic Product (GDP) per capita has led to a rise in GHG emissions [1]. The surge in GHG emissions has contributed to climate change and has adverse impacts on societies and the environment. Because of this, the contribution of different economic sectors to GHG emissions and climate change mitigation is an issue that has come under increasing scrutiny [2]. Increased global warming has also led to a global climate agreement, namely, the 2015 Paris Agreement, which binds member states to maintain global warming below 2 °C [3]. Energy or electricity consumption and agricultural production play a key role in increasing economic development. Thus, they have been highlighted as important contributors to environmental degradation [4–13].

Electricity generation and consumption contribute about 40% of global $CO_2$ emissions [14]. Agriculture production [2,15–19] and mining [11] are some of the main contributors to GHG emissions. In 2000 and 2010, the annual GHG emissions from agricultural production and changes in land use were 5.0–5.8 $GtCO_2eq/yr$ and 4.3–5.5 $GtCO_2eq/yr$, respectively [20]. According to the Food and Agriculture Organization (FAO) [21], global GHG emissions from agricultural production, mainly livestock and crop production, grew from 4.7 billion tonnes of carbon dioxide equivalents ($CO_2$ eq) to more than 5.3 billion tonnes between 2001 and 2011. Agriculture-related $CO_2$ emissions are mainly associated with energy consumption (e.g., through the operation of machinery; fertilizer application) [1] and land use-related $CO_2$ emissions (e.g., land clearing for crop production) [2]. Agriculture is also deemed to be among the economic sectors with the largest environmental impacts [22,23].

In developing areas of the world, such as Africa, increases in GHGs result from agriculture and energy consumption [21]. For example, the southern African region has seen major economic developments towards improving human livelihoods. These developments have led to a rise in the demand for agricultural production and energy consumption, with electricity as the main source of energy, which plays a vital role in the region's economic growth [24]. This is due to increased demand for food production to sustain the constantly growing population, technological change, economic growth, and cost/price demands. However, these economic developments have negative impacts on the environment. For example, because of a lack of alternative environmentally friendly agricultural practices and energy sources, these actions contribute significantly to GHGs emissions [19,25].

Africa, because of its high social vulnerability, is among the continents most affected by the impacts of climate change resulting from increased GHG emissions [26]. For example, a greater portion of the population in Africa is directly and indirectly threatened by climate change because of poor socio-economic conditions, high dependence on natural resources, and low capacity to undertake efficient adaptation actions [27,28]. Some parts of Africa, such as the Sub-Saharan African region, account for about 4% of global electricity consumption; however, the overall energy demand of the African population is projected to increase by the year 2040 [25]. In addition, Africa has seen an annual increase of about 1.6% in GHG emissions from agriculture (livestock and crop production), contributing about 15% of the global emissions between 2005 and 2014 [21]. The biggest agricultural-related contributors to GHG emissions in Africa are enteric fermentation (39%), manure on pasture (28%), and wildfires (21%) [21].

Historically, the Zambian economy has been reliant on the mining (mainly copper) and agriculture sectors, with the former immensely affected by frequent commodity price fluctuations and the latter experiencing exponential expansion due to rapid population growth [29,30]. These key economic activities, particularly mining, use a large amount of energy for their operations.

In 2000 and 2014, the Zambian population grew by a rate of 2.91 and 3.12% respectively. [31]. The growth in population has adversely impacted the Zambian environment, particularly the forestry sector; as a result, there has been a notable increase in deforestation [32]. The population growth also contributed to the expansion in agricultural practices, in addition to that in other economic activities, such as construction, services, and mining, which led to an increase in the production and consumption of energy, particularly electricity [33].

Zambia, like many other developing countries, has experienced increased $CO_2$ emissions. According to the World Bank [31], the country's $CO_2$ emission level stood at 4503 kilotons in 2014, compared to 1929 kilotons in 2007. In the period between 1975 and 2014, Zambia's levels of $CO_2$ emissions, energy (electricity) consumption, and agriculture production fluctuated (see Appendix A). However, because more than one-quarter of Zambia's energy consumption relies on electricity [32], coupled with the rapid expansion in agricultural production [30,34], there is significant concern regarding the potential contribution of these two economic sectors to the increase in $CO_2$ emissions and climate change. These factors are thus exerting substantial pressure on the environment, with detrimental consequences, including the loss of biodiversity and severe implications for tourism, which is an important source of income for many communities in the country [32]. Addressing these environmental risks, therefore, requires a profound understanding of the impacts of energy consumption and agricultural activities on $CO_2$ emissions in the country.

To the best of the authors' knowledge, research pertaining to the effect of agricultural activities and energy use on the environment through their impacts on $CO_2$ emissions has yet to be conducted at a macro level in Zambia; hence, the contribution of this article to the pool of knowledge. This information can be vital in the advocacy for the reduction in $CO_2$ emissions, through the promotion of environmentally friendly agricultural practices and the use of sustainable renewable energy.

In this study, we therefore aimed to assess the impact of agricultural expansion and energy consumption on the environment, that is, their contribution to $CO_2$ emissions. The study particularly focused on agriculture production and the consumption of electricity as a main source of energy. The further intention was to assist policymakers in formulating and implementing policies that will contribute to environmental commitments and Africa's Agenda 2063. This paper is arranged as follows: Section 1 contains the introduction and a review of the literature; Section 2 presents the data and methodology used; Section 3 looks at the results, discussion, and policy implications; and finally, Section 4 concludes the paper.

## 2. Materials and Methods

### *2.1. Study Area*

Zambia is a Sub-Saharan African lower-middle-income country, with a population of 17.86 million, and a GDP per capita of USD 1654 as of 2019 [31]. Zambia is classified into three main agro-ecological zones, based on pedological characteristics, climatic factors, rainfall patterns, and main agricultural practices (Figure 1). Zone I comprises the low rainfall (semi-arid, <800 mm), low altitude (400–900 m), hot and dry areas along the Luangwa and Zambezi Rift Valleys; Zone II is a high rainfall (>1000 mm) area in the north and on the plateau. The altitude in this Zone ranges between 1100 and 1500 m. The Zone is further categorized into two zones—Zone IIa comprises a sub-region of the medium rainfall (800–1000 mm) plateau including the main farming areas on the plateau of Central, Eastern, and Southern Provinces. The altitude in this Zone ranges between 900 and 1300 m. Zone IIb is a sub-region of the medium rainfall (800–1000 mm) plateau comprising the Kalahari sand plateau and the Zambezi flood plains. The altitude ranges between 900 and 1200 m. Zone III has the largest annual rainfall (1000 to 1500 mm). The country's annual temperature ranges between 7 and 37 °C. Figure 1 shows Zambia's agro-ecological zones and its geographical position in the region.

Agriculture is one of the most important economic sectors in Zambia. Most of the population depends on rainfall-dependent agriculture for their livelihoods. Agriculture also contributes about one-quarter of the country's GDP [30]. Approximately two-thirds of the country's total land area deemed to be arable land is suitable for poultry and pastoral farming [33]. Historically, the Zambian government has spent at least 60% of agriculture public spending on maize, which is cultivated by 98% of smallholder households who occupy 54% of agricultural land [33]. Recently, the country's electricity consumption increased from 565.439 KWh in 2009 to 717 KWh in 2014. In comparison to previous years, this is a significant increase [31].

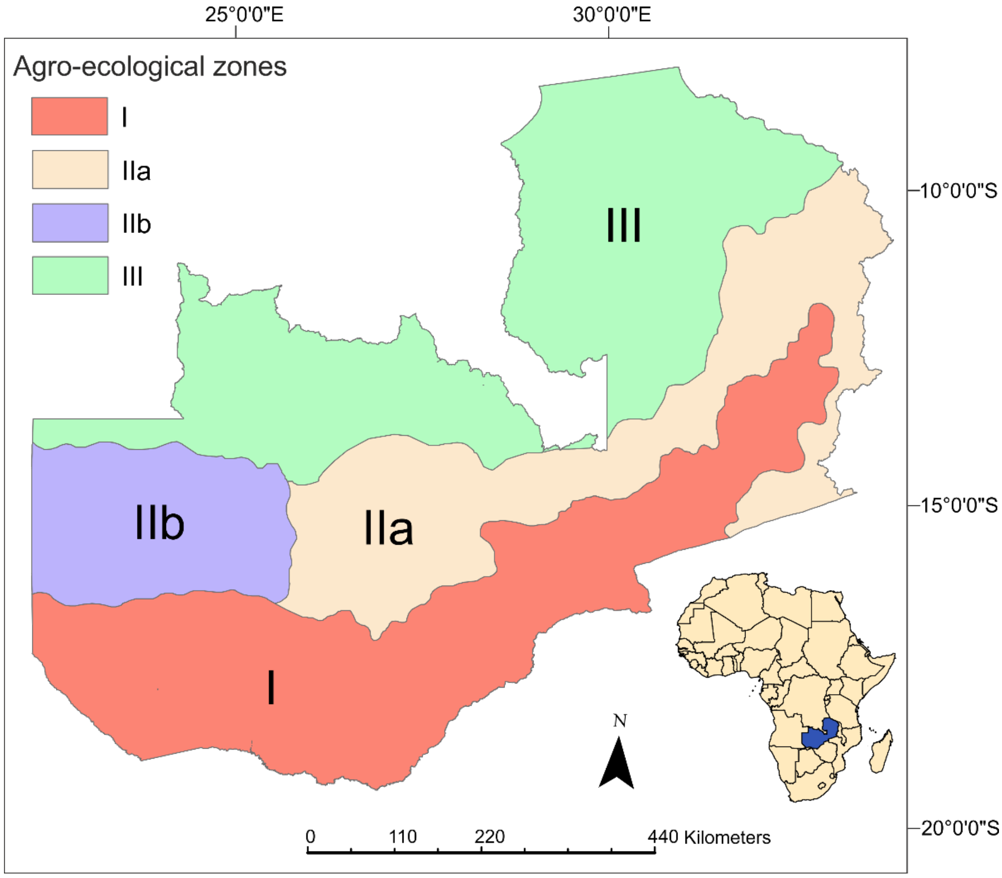


**Figure 1.** Agro-ecological zones of Zambia. The insert map shows the location of Zambia in the African continent.

### 2.2. Empirical and Econometric Steps

The annual data (1975 to 2014) for our empirical study was sourced from World Bank's World Development Indicators. We used EVIEWS 12 software to perform the econometric computations. The variables we used to conduct the econometric analysis included carbon emissions in kilotons, GDP constant 2010 in USD, electricity consumption in kilowatts, agriculture value-added constant 2010 in USD, and industry value added constant 2010 in USD. The variables of interest were converted to logarithms and interpreted as elasticities. The graphical representation of the variables in their normal form is shown in Appendix A. The general formulation of the model is:

$$CO_2 = F(GDP,ELEC,AGRIC,IND) \quad (1)$$

where $CO_2$, $GDP$, $ELEC$, $AGRIC$, and $IND$ represent carbon emissions, GDP, electricity, agriculture, and industry, respectively.

The stochastic form of the model is:

$$CO_2 = \alpha_0 + \alpha_1 + GDP + \alpha_2 ELEC + \alpha_3 AGRIC + \alpha_4 IND + \mu_t \quad (2)$$

where = $\alpha_0$, $\alpha_1$, $\alpha_2$, $\alpha_3$, and $\alpha_4$ are coefficients for intercept, $GDP$, electricity consumption, agriculture, and industry, respectively; and $\mu_t$ = the stochastic term (unobserved).

The general forms and procedures are similar to those adopted by Gokmenoglu et al. [8], Gokmenoglu and Taspinar [10], and Liu et al. [11], who used similar variables to assess the impact of energy and agriculture on carbon emissions. To the work of these researchers, we added the industryvariable. The novelty of this paper is that this is the first analysis to apply these econometric empirical steps to the Zambian context, particularly at a macro level.

Before proceeding with further econometric analysis, we checked for the existence of unitroots in our variables. This is significant because variables with a unitroot or non-stationary data are less effective in explaining a larger proportion of the results and can lead to misleading interpretations of the findings [35,36]. We applied the widely used Augmented Dickey–Fuller (ADF) test to check for the existence of a unitroot. The ADF test is widely preferred because it accounts for serial autocorrelation [37]. All the variables of interest seemed to exhibit some characteristics of structural breaks. As a result, the Zivot–Andrews (Z-A) unit root test was a better confirmatory test than the ADF test [38]. The test is superior to the ADF test and the Phillips and Perron test [39] which, in most instances, fail to account for shocks and structural breaks, recording them as unit root [38]. The general form of the ADF test is indicated below:

$$\Delta Y_t = \beta_1 + \beta_2 + \delta Y_{t-1} + \Delta Y_{t-i} + E_t \tag{3}$$

where $\Delta Y_t$ = related variable; $\beta_1$, $\beta_2$ parameters in the model; $i$ = lag order to which the Dickey–Fuller equation is augmented; $t$ time trend; $E_t$ is Gaussian white noise with zero mean and possible autocorrelation represented by time $t$.

The stationary results and levels of integration determine the next procedure. The Autoregressive-Distributive Lag (ARDL) Bounds Tests is appropriate when analyzing variables that have an order of integration I(0), I(1), or a combination of both, but without I(2) or higherorders [40]. This addresses the limitations of Engle and Granger [35] and Johansen and Jeselius [41], which limits the cointegration steps to variables of the same order of integration, I(1). We determined the optimal lags for each of the variables using the Akaike Information Criterion (AIC) [42]. This test is suitable in small sample sizes; in particular, it minimizes the risks of underestimation while increasing the chances of recovering the true lag length as compared to the Sequential modified LR test statistic, the final prediction error, the Schwarz information criterion, and the Hannan–Quinn information criterion. The model representation for the ARDL is:

$$\begin{aligned} \Delta CO2_t = \alpha_0 + \textstyle\sum_{i=1}^{p} \alpha_{1t} \Delta CO2_{t-1}\ \Delta CO2_{t-1} + \sum_{i=1}^{p} \alpha_{2t} \Delta GDP_{t-1+} + \sum_{i=1}^{p} \alpha_{3r} + \Delta ELEC_{t-1} \\ + \textstyle\sum_{i=1}^{p} \alpha_{4r} \Delta AGRIC_{t-1} + \sum_{i=1}^{p} \alpha_{5t} \Delta IND_{t-1} + \lambda_1 CO2_{t-1} + \lambda_2 GDP_{t-1} + \lambda_3 ELEC_{t-1} \\ + \lambda_4 AGRIC_{t-1} + \lambda_5 IND_{t-1} + E_t \end{aligned} \tag{4}$$

where $\Delta$ is the difference operator, $p$ denotes lag length; $\alpha_0$ is the constant term; $\alpha_{1i}$, $\alpha_{2i}$, $\alpha_{3i}$, $\alpha_{4i}$, $\alpha_{5i}$ are error correction dynamics; $\lambda_1$, $\lambda_2$, $\lambda_3$, $\lambda_4$ and $\lambda_5$ are long-term coefficients; and $E_t$ is the White noise disturbance term.

The F-statistic confirmed the test of cointegration for the ARDL Bounds Test. The null hypothesis of no cointegration is where the F-statistic lies below the lower bound I(0), whereas the rejection of the null hypothesis indicates the presence of cointegration with an F-statistic lying above the upper bound I(1) values. Inclusiveness of the cointegration test is indicated by the F-statistic value lying between I(0) and I(1) [42].

The post-estimation model diagnosis was conducted to test for the absence of autocorrelation, the absence of heteroskedasticity, and the presence normality, [42]. The stability of the model was also checked using the Cusum test [42]. The descriptive statistics of the variables used are shown in Table 1 as follows.

**Table 1.** Descriptive statistics of the variables used in this analysis.

| Variable | Mean | Median | Maximum | Minimum | Std. Dev. | Observations |
|---|---|---|---|---|---|---|
| $CO_2$ | 2781.05 | 2555.90 | 4503.08 | 1807.83 | 721.00 | 40 |
| GDP (000,000) | 11,286.52 | 8652.303 | 25,318.84 | 7340.42 | 5206.91 | 40 |
| Electricity | 798.78 | 734.48 | 1172.15 | 568.44 | 186.18 | 40 |
| Agriculture (000,000) | 1904.19 | 2024.21 | 2347.46 | 1283.43 | 320.15 | 40 |
| Industry (000,000) | 3464.619 | 2623.580 | 7405.307 | 2294.145 | 1614.762 | 40 |

Note: Units of the above variables are described at the empirical and econometric steps (Section 2.2).

# 3. Results and Discussion

## 3.1. Unit Root Results

The Table 2 below shows the results for stationarity using the ADF and Z-A tests.

**Table 2.** Unit root results.

| Variable | Test | Level | | 1st Difference | |
|---|---|---|---|---|---|
| | | Statistic | 5% Critical | Statistic | 5% Critical |
| $CO_2$ | ADF | 0.31 | −3.52 | −5.794 * | −3.53 |
| | Z-A | −2.07 (2008) | −4.85 | −7.28 * (1999) | −4.85 |
| GDP | ADF | 0.16 | −3.52 | −7.20 * | −3.53 |
| | Z-A | −3.40 (1995) | −4.85 | −7.97 * (1981) | −4.85 |
| Electricity | ADF | −1.65 | −3.53 | −4.64 * | −3.53 |
| | Z-A | −3.57 (1998) | −4.85 | −5.91 * (1989) | −4.85 |
| Agriculture | ADF | −1.75 | −3.53 | −12.69 * | −3.53 |
| | Z-A | −5.75 * (2006) | −4.85 | - | - |
| Industry | ADF | −1.31 | −3.53 | −4.37 * | −3.53 |
| | Z-A | −4.57 (1992) | −4.85 | −5.54 * (2000) | −4.45 |

Note: ADF is tested with a constant and trend. * Indicates significance at the 5% level. The year of the structural break is indicated in brackets for the Z-A test. Source: Authors' computations (2021).

### 3.1.1. Test Abbreviations

From the graphical illustration in Appendix A, all variables exhibited properties of some structural breaks at some point. Hence, the Z-A test for a unitroot was a good confirmatory test for the ADF test. Using the ADF and Z-A tests, all the variables were found to be stationary and significant in their first difference, except for agriculture which was stationary in level form using the Z-A test, although stationary in first difference using the ADF test. The rejection of the null hypothesis for a unit root (for both the ADF and Z-A tests) was indicated by the respective statistical values for each variable being greater than the critical value, with all the variables significant at the 5% level. Based on our unitroot tests, which contain a mixture of I(0) and I(1) orders of integration for all variables, the ARDL Bounds Test was used, and the AIC criterion established the maximum lags of 2, 4, 3, 2, and 0 for carbon emissions, GDP, electricity, agriculture, and industry, respectively. Table 3 shows the ARDL error correction regression results, and Table 4 indicates the long-run relationship and effects amongst the variables.

**Table 3.** ARDL error correction regression.

| Case 3: Unrestricted Constant and No Trend | | | | |
|---|---|---|---|---|
| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
| C | −12.80 | 2.02 | −6.31 | 0.00 |
| Δ LCO2(-1) | 0.32 | 0.13 | 2.44 | 0.02 |
| Δ LGDP | −1.91 | 0.44 | −4.29 | 0.00 |
| Δ LGDP(-1) | 0.45 | 0.46 | 0.98 | 0.33 |
| Δ LGDP(-2) | −1.43 | 0.43 | −3.33 | 0.00 |
| Δ LGDP(-3) | −1.90 | 0.32 | −5.88 | 0.00 |
| Δ LELEC | 1.50 | 0.229 | 6.58 | 0.00 |
| Δ LELEC(-1) | −1.02 | 0.27 | −3.78 | 0.00 |
| Δ LELEC(-2) | −0.61 | 0.23 | −2.62 | 0.01 |
| Δ LAGRIC | 0.22 | 0.11 | 1.98 | 0.06 |
| Δ LAGRIC(-1) | −0.48 | 0.12 | −3.89 | 0.00 |
| CointEq(-1)* | −0.74 | 0.11 | −6.30 | 0.00 |
| R-squared | 0.80 | Mean dependent var | | 0.00 |
| Adjusted R-squared | 0.72 | S.D. dependent var | | 0.10 |
| S.E. of regression | 0.057 | Akaike info criterion | | −2.60 |
| Sum squared resid | 0.079 | Schwarz criterion | | −2.07 |
| Log likelihood | 58.89 | Hannan-Quinn criter. | | −2.42 |
| F-statistic | 9.28 | Durbin-Watson stat | | 2.17 |
| Prob(F-statistic) | 0.00 | | | |
| F-Bounds Test | | | Null Hypothesis: No levels relationship | |
| Test Statistic | Value | Signif. | I(0) | I(1) |
| F-statistic | 6.63 | 10% | 2.45 | 3.52 |
| k | 4 | 5% | 2.86 | 4.01 |
| | | 2.5% | 3.25 | 4.49 |
| | | 1% | 3.74 | 5.06 |

* *p*-value incompatible with t-Bounds distribution.

**Table 4.** Long-run relationship and coefficients towards $CO_2$.

| Variable | Coefficient | Std. Error | t-Statistic | Prob. |
|---|---|---|---|---|
| LGDP | 1.31 | 0.28 | 4.60 | 0.00 |
| LELEC | 1.63 | 0.24 | 6.61 | 0.00 |
| LAGRIC | 0.56 | 0.33 | 1.67 | 0.10 |
| LIND | −0.25 | 0.24 | −1.01 | 0.32 |

Prior to computing the cointegrations and the long-run F-statistic as indicated in Tables 3 and 4, we confirmed their presence in the short-run ARDL estimation (see Appendix B). However, thesewere not examined further in the study because it was not among the main objectives. Nonetheless, the results indicated that agriculture practices and energy consumption do impact the environment in the short run through the emissions of carbon dioxide.

### 3.1.2. Variable Abbreviations

As the cointegration results in Table 3 reveal, $CO_2$ emissions, GDP, electricity consumption, and agriculture all converge to a long-run equilibrium at the speed of −0.74 (in absolute value) or 74.26%, which is statistically significant with a probability of less than 5%. This, when converted to time, means that these variables converge to a long-run equilibrium within 1.35 years. This was reaffirmed by the cointegration results, where the F-statistic of 6.64 was greater than the I(1) bounds of 3.52, 4.01, 4.49, and 5.06 at 10, 5, 2.5, and 1% respectively. The F-statistic was also greater than the respective I(0) bound value (at the same respective percentages as the I(1) bounds), which were 2.45, 2.86, 3.25, and 3.74, respectively. In the long run (as indicated in Table 4), the coefficients of GDP, electricity, and agriculture were all positive with values of 1.31, 1.63, and 0.56, respectively, except for that of agriculture. The coefficients of GDP and electricity were also statistically significant, whereas those of agriculture and industry were insignificant. This means that a one percent increase in GDP and electricity increases $CO_2$ emissions by 1.31% and 1.63%, respectively.

In the same period, the coefficient of the industry was −0.25 and not statistically significant, implying that the effect of industry on carbon emissions was not pronounced. This indicates that a one percent increase in industry decreases $CO_2$ emissions by 0.25%. The model was well fitted, as 80.97% of the variation in the variable ($CO_2$ emissions) was explained by the regressors of GDP, electricity, and agriculture, including their lagged values, as indicated by the R-squared value, which was 0.81 (see Table 3). The model was also well fitted because the F-statistic (indicated in Table 3) had a probability of less than 5%, implying statistical significance.

After the ARDL tests, we used the Wald test to further check the short-run direction of causality of our variables (see Table 5). Causality was inferred from GDP, electricity, and agriculture towards $CO_2$ with probability values of 0.00, 0.00, and 0.02, respectively. These probabilities were all less than 5% and statistically significant, signifying strong causality. Regarding industry, there was no evidence of causality running from industry to carbon emissions. The initial ARDL table, from which the Wald test and ARDL error correction regression (Table 3) were derived, is presented in Appendix B.

**Table 5.** Wald test for short-run causality towards $CO_2$.

| Variable | F-Statistic | Probability |
|---|---|---|
| GDP | 8.58 | 0.00 |
| Electricity | 7.11 | 0.00 |
| Agriculture | 3.79 | 0.02 |
| Industry | 0.89 | 0.35 |

Post-estimation diagnostic tests for autocorrelation, heteroskedasticity, and normality were checked; the findings are presented in Table 6.

**Table 6.** Diagnostic tests.

| Problem | Test | *p*-Value |
|---|---|---|
| Autocorrelation | Breusch-Godfrey LM | 0.27 |
| Heteroskedasticity | White's | 0.69 |
| Normality | Histogram | 0.09 |

As noted in Table 6, the null hypotheses for the lack of autocorrelation, homoskedasticity, and the presence of normality, which are all desirable, were not rejected with *p*-values of 0.27, 0.69, and 0.09, respectively. This showed that the model was good for our analysis and interpretation. Figure 2 shows the results of the tests for the stability of the model using the CUSUM test. As shown in the figure, the model was stable, having an output line within the 10% boundaries, as indicated by the blue line between the parallel red lines in the output figure.

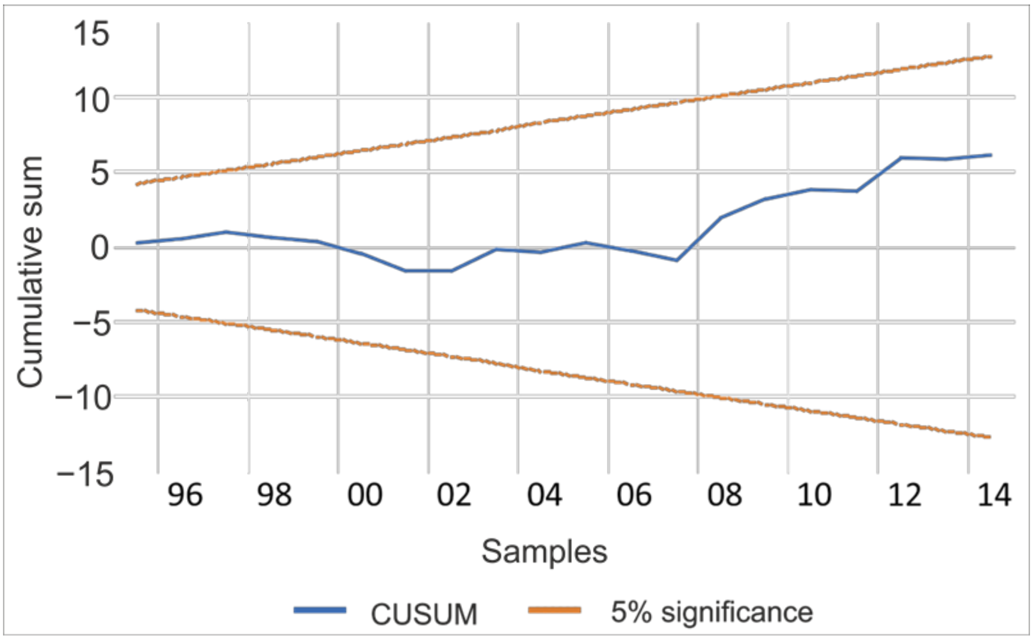


**Figure 2.** Stability test.

### *3.2. Discussion and Policy Implications*

The ARDL Bounds Test results (Table 3) showed the existence of cointegration amongst the variables $CO_2$, GDP, electricity, and agriculture, which converges to the long-run equilibrium at the rate of 74.26%. GDP growth and consumption of electricity culminated in an increase in the levels of carbon emissions, with the short-run causality observed running from electricity consumption to $CO_2$ emissions, as indicated by the Wald test (Table 5). The findings on the impact of energy consumption on $CO_2$ emissions are in line with several studies, including Balsalobre-Lorente et al. [5]; Chandran and Tang [7]; Gokmenoglu et al. [8]; Gökmenoğlu and Taspinar [10]; and Shahbaz [12]. Furthermore, Gokmenoglu and Taspinar [10] and Zhang and Cheng [13] observed a similar but unidirectional causal relationship between energy consumption and $CO_2$ emissions, and Begum et al. [43] and Liu [11] observed the opposite impact between energy consumption and carbon emissions. Shahbaz [12] acknowledged that public–private partnerships catalyze mitigation of the effects of energy use on the environment.

The short- and long-run effects of electricity on the emission of $CO_2$, and consequently the environment, can be attributed to population growth, which has put pressure on the economy through increased investment and other economic activities, such as construction, services, and mining. The country's mining of copper, cobalt, gold, silver, gemstones, coal, and industrial minerals, among others, has culminated in an increase in electricity demand. The use of electricity has increased the pressure on resources and the environment because the country's technology and machinery have limited capacity to sustain the growing demand. This is especially the case in the mining and construction industries, which are growing at an exponential rate, thus putting upward pressure on natural resources and consequently the environment. In addition, the country has experienced segregation of electricity usage, due to which only limited sections of the economy and country have access to power [32]. This compels the population in other parts of the country (particularly the rural parts) to use traditional energy sources, such as charcoal and firewood, which cause environmental degradation.

Although agriculture had an insignificant long-run impact (Table 5), it was found that it had a significant short-run impact on carbon emissionsas suggested by the Wald test results (Table 5). Concerning the impact of agriculture on carbon emissions, the findings of this paper agreed with several other studies, including those ofBalsalobre-Lorente et al. [5], Gokmenoglu et al. [8], Gokmenoglu and Taspinar [10], and Liu et al. [11]. A similar cointegration relationship was noted by Agboola and Bekun [4], and Chandio et al. [6], with the latter acknowledging that improvements in the quality of agriculture production methods help to preserve the environment. In a related finding, Gokmenoglu and Taspinar [10] observed a bi-directional causality amongst the target variables.

In the case of Zambia, the effects of agriculture on carbon emissions and, consequently, the environment, can be attributed to the engagement of people in most parts of the country in less environmentally friendly agricultural activities, including deforestation and traditional methods of cultivation such as combustion of vegetation for fertilizer, which result in the emission of more carbon dioxide. Due to the need for environmental sustainability, some studies have recommended the use of environmentally friendly energy sources, particularly renewable sources [6,7,13]. Similar to the results obtained by the above authors, Abdallah and El-Shennawy [14] further indicated that this can be achieved using smart electricity grids and solar, wind, and hydroelectricity, which are means to conserve and efficiently use energy; this approach was applied in Egypt. Diversifying the use of energy sources was further proposed as a viable policy alternative to mitigate the effects of environmental degradation [25]. Other policy advocates in a similar situation indicated the need to provide farmers with support and extension services, including training and subsidies for the use of environmentally friendly agricultural production and farming techniques with the aim of sustainability [44,45]. The need to reduce the use of less environmentally friendly farming and energy usage strategies cannot be overemphasized. From the Zambian perspective, the following actions are worth recommending:

1. Increase electricity access points to mitigate the effects of increasing power demand, including the use of smart electricity grids, and diversify the economy through alternative energy sources, including solar and wind
2. Discourage deforestation and burning of vegetation for fertilizers, and encourage afforestation or reforestation, in addition to the use of organic fertilizers such as animal dung, which has a minimal effect on the environment compared to burned and conventional fertilizers.
3. Provide agriculture subsidies to farmers and financial support to implement recommendation number 2, including offering training to farmers on environmentally friendly farming methods.

The strategies may require a significant investment by policymakers and other relevant stakeholders. However, they are worthwhile considering that environmental sustainability is a global challenge and mitigating the effect of environmental degradation will help the country in the future. Because future generations are likely to benefit, over time the benefits of implementing such policies will outweigh the costs.

## 4. Conclusions

The main objective of this study was to assess the impact of agriculture and energy production on the Zambian environment, where the environment was quantified using $CO_2$ emissions. In quantifying the effect of the above-mentioned indicators on the Zambian environment, the ARDL Bounds Test was used, and the results indicated that the variables of $CO_2$ emissions, GDP, electricity, and agriculture converge to a long-run equilibrium at a rate of 74.27% (Table 3). Furthermore, the results of this study showed that there was short-run causality towards $CO_2$ emissions culminating from agriculture and the consumption of energy (Table 5). The effect of agriculture on the environment can be attributed to poor agricultural practices and activities, such as deforestation, burning of vegetation for fertilizer, and the use of conventional fertilizers, which contribute to the harm of the ozone layer. Other factors, which are a combined effect of both agriculture and the use of energy, includethe rising population, which puts pressure on the economy through investments, and other activities such as construction and mining. These put pressure on natural resources and ultimately lead to environmental degradation because the country has limited technological capacity. The need to reduce the quantity of $CO_2$ emissions and their effect on the environment can be addressed by increasing the number of access points to multiple renewable energy sources across the country; discourage deforestation, the use of conventional fertilizers, and the combustion of fertilizers; encourage afforestation and reforestation; and finally provide subsidies, training, and financial support to farmers and entrepreneurs who decide to use environmentally friendly agricultural methods and renewable energy. These steps will make a positive contribution to Zambia's efforts, in conjunction with other countries, in achieving Sustainable Development Goals (SDGs), particularly SDG 7, 11, 13, 14, and 15, and their commitments under the 2015 Paris Agreement on Climate.

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## Appendix A

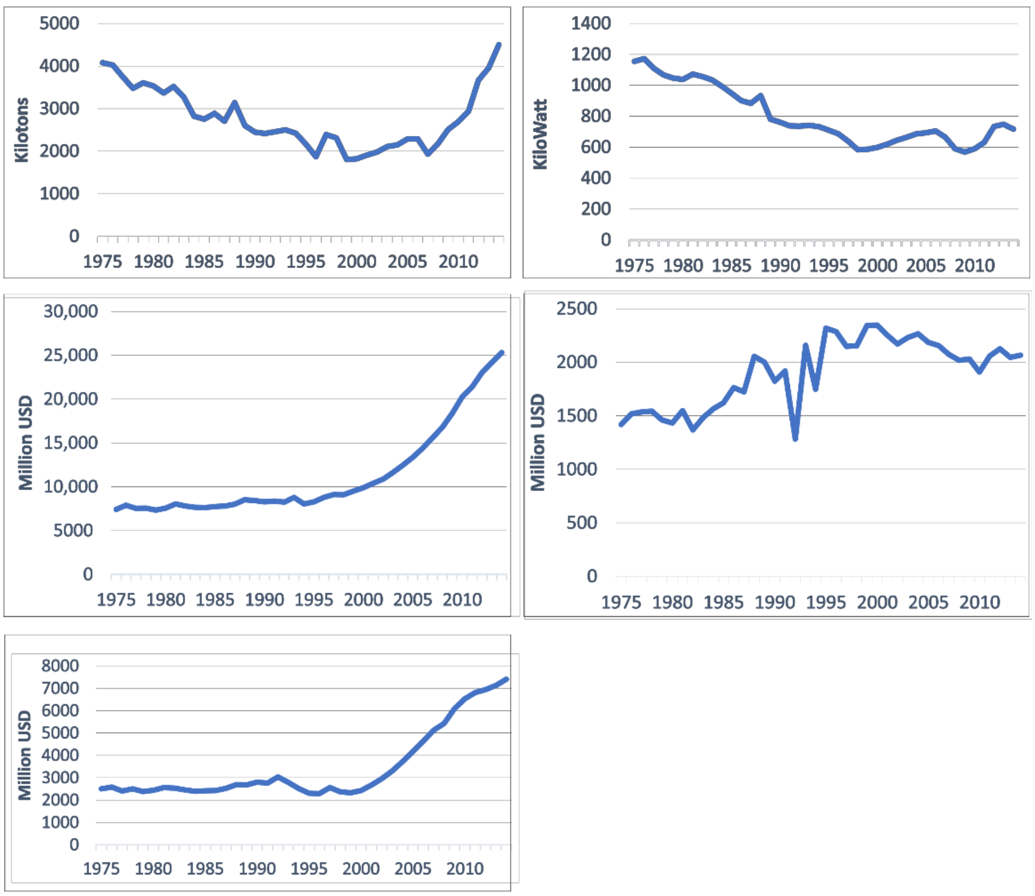


**Figure A1.** Variables used for the econometric analysis in this study: (**a**) $CO_2$ emissions; (**b**) electricity consumption; (**c**) GDP constant 2010 prices; (**d**) agriculture; (**e**) industry. Source: World Bank (2021).

**Appendix B**

**Table A1.** ARDL estimation output (results).

| Dependent Variable: LCO2<br>Number of Models Evaluated: 2500<br>Selected Model: ARDL (2, 4, 3, 2, 0) | | | | |
|---|---|---|---|---|
| Variable | Coefficient | Std. Error | t-Statistic | Prob. * |
| LCO2(-1) | 0.582992 | 0.149972 | 3.887349 | 0.0009 |
| LCO2(-2) | −0.325638 | 0.170691 | −1.907769 | 0.0709 |
| LGDP | −1.910476 | 0.564709 | −3.383117 | 0.0030 |
| LGDP(-1) | 3.341822 | 0.807545 | 4.138248 | 0.0005 |
| LGDP(-2) | −1.890799 | 0.723873 | −2.612060 | 0.0167 |
| LGDP(-3) | −0.470066 | 0.538798 | −0.872434 | 0.3933 |
| LGDP(-4) | 1.908158 | 0.377745 | 5.051449 | 0.0001 |
| LELEC | 1.509706 | 0.292682 | 5.158187 | 0.0000 |
| LELEC(-1) | −1.318802 | 0.405586 | −3.251598 | 0.0040 |
| LELEC(-2) | 0.411176 | 0.396006 | 1.038308 | 0.3115 |
| LELEC(-3) | 0.614014 | 0.273230 | 2.247240 | 0.0361 |
| LAGRIC | 0.222730 | 0.153986 | 1.446437 | 0.1635 |
| LAGRIC(-1) | −0.284192 | 0.155780 | −1.824313 | 0.0831 |
| LAGRIC(-2) | 0.484259 | 0.160797 | 3.011622 | 0.0069 |
| LIND | −0.187390 | 0.198014 | −0.946346 | 0.3553 |
| C | −12.80520 | 3.233001 | −3.960779 | 0.0008 |
| R-squared | 0.958488 | Mean dependent var | | 7.860142 |
| Adjusted R-squared | 0.927354 | S.D. dependent var | | 0.234568 |
| S.E. of regression | 0.063223 | Akaike info criterion | | −2.383200 |
| Sum squared resid | 0.079943 | Schwarz criterion | | −1.679414 |
| Log likelihood | 58.89760 | Hannan-Quinn criter. | | −2.137560 |
| F-statistic | 30.78596 | Durbin-Watson stat | | 2.172878 |
| Prob(F-statistic) | 0.000000 | | | |

* Note: $p$-values and any subsequent tests do not account for model selection.

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