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The Nexus between Energy Poverty and Environmental Change in Zimbabwe

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Abstract

Over the years, energy poverty has been seen as a major struggle in Zimbabwe and globally. This paper tries to find the relationship between energy poverty and environmental change. Ecological footprint represents a degradation in this paper. The findings showed an insignificant relationship between renewable energy and ecological footprint in Zimbabwe. This study employs the ARDL technique. This study employs time series data from 1990-2021. This study uses the ARDL framework to get robust results. The ARDL bound test and ECM are employed to find the short-run and long-run coefficients of the model. The significant findings of the results show that RE, NRE, GDP, and natural resources (NR) are not significant in the long run but in the short run, GDP, NRE, and NR negatively impact the ecological footprint (EFP), while RE promotes or improves the ecological footprint. The results show a negative correlation between energy poverty and ecological footprint. Zimbabwe should work towards promoting RE energy as an alternative energy source and should revise its policies to attract more investment.

Keywords
Economic growth; renewable resource; non-renewable resource; energy poverty; environmental change

1. Introduction

Energy poverty is a significant issue the Sub-Saharan African nationals are struggling with in order to achieve the "United Nations' Sustainable Development Goal (UN SDG7)", thus ensuring access to cost-effective, dependable, environmentally friendly, and proficient clean energy to all by 2030. Energy poverty has become one of the global challenges that Sub-Saharan African countries are struggling with a tremendous effect on the environment. The "International Energy Agency" postulates that energy poverty is insufficient access to modern, clean energy (clean fuel) and energy facilities in a country and strong dependence on conventional fuels. [1] explains the focal point of energy deprivation and environmental change in a way that both affect each other. There is little literature that has been made on the research on the nexus of energy poverty and environmental change, and several studies have used environmental quality and poverty. Thus, it is relevant for us to study the relationship. The relationship between the two is compatible; if the factors that add to the environmental quality and poverty/energy poverty (EP) are the same, then nations will be economically better focusing on maintaining the environment [2].

EP is the ineffectiveness of households in acquiring energy services. EP is the insufficiency of clean energy sources. Due to a lack of clean energy, people have resorted to using conventional energy sources (coal, oil, or gas), which poses serious health issues. Several countries have attempted to totally eliminate energy poverty by investing more in clean energy, and some of the countries have managed to achieve this goal as the global number of people deprived of clean energy has decreased [3]. Globally, the number of people not have access to clean energy has decreased from 1685 million to 775 million in 2019. Among the several scholars who have analyzed the effects of EP on the environment, we noticed that they have not yet reached a consensus on the uniform standard measure of energy poverty levels in developing countries [4]. The effects of carbon emission on socio-economic and environmental degradation have become of concern in most studies.

The unavailability of clean energy has led people to be more dependent on conventional energy sources (biofuel and kindling [5]. Countries with higher energy poverty have a substantial negative impact on energy growth and human development. A healthy life and comfort are unattainable to people with energy deficiency. This means that they require so much energy to escape the terrible predicament. Exacerbated energy consumption degrades the environment unless there is usage of non-renewable energy [6] which it's impossible as people experiencing EP cannot afford to acquire solar panels that can generate carbon-free energy [7]. SSA is feared to remain the largest emitters of air pollution globally, and they remain scrutinized.

The electricity production in Zimbabwe is not able to sustain the whole population. The country currently is undergoing electricity rationing, which is commonly known as "load shedding, "as a way for the whole country to be able to access electricity. Due to the load shedding, some places can be dark for many days than other places before they can get electricity compared to their neighboring countries such as Zambia, Botswana, and South Africa. This has led to people resorting to using firewood for cooking, resulting in deforestation, which has led to land degradation. In Zimbabwe, the issue of energy poverty is a reflection of a problem that hinders access to energy, which, if not addressed, discourages socioeconomic development. According to [8-10], Zimbabwe struggles with energy poverty with only a 44% electricity penetration rate, with mainly the rural areas being affected with only 20% electricity penetration. Statistically suggesting that about 75% of the country lacks sufficient energy sources to alleviate energy poverty, resulting in widespread darkness. Only 20% of the number of individuals in the rural area have electricity, which means that the large population relies on non-renewable sources of energy such as fossil fuel (wood, biomass), which are disastrous to the environment, and cause environmental degradation. This reflects the harsh disparities in energy provision. The problem worsens as the total installed electricity capacity is 1700 MW, which is insufficient considering Zimbabwe's population of 14.9 million [8].

The ZESA (Zimbabwe Electricity Supply Authority) quality of energy service and reliability is of deep concern as it is accompanied by numerous power cuts and some parts of the country experiencing two to three days of electricity outages. Power supply significantly affects the economy of the country by causing a 5% annual GDP (World Bank Data). This problem poses a burden on healthcare, education, the environment, and other services. One of the crucial causes of the power supply shortages is the decrease in hydroelectricity produced due to the declining level of water, investment, and vandalism of the electricity infrastructure. However, [11], postulated that solar energy can help to alleviate energy poverty in Zimbabwe. [12] postulate that the emphasis that clean energy supply can also be increased by bagasse-generated electricity. RE energy sources become crucial in reducing energy poverty and achieving the sustainability development goals (UNSDG7). Most of the studies that explored energy poverty have concentrated on the effects of energy poverty on education, vandalism of infrastructure, sanctions, and climate in Zimbabwe.

Energy poverty and environmental change have become a major concern in Zimbabwe. This paper aims to provide ways to eliminate EP and degradation. Several works of literature have used environmental degradation as their independent variable. This literature has used ecological footprint as the independent variable to represent environmental degradation because it encompasses the activities that can affect the environment, such as cropland, grazing land, fishing grounds, built-up areas, forest area, and carbon demand on the land. There is not much research done in Zimbabwe on EP and ED compared to other countries in its region. Prior literature has presented mixed findings on this subject. This may be due to different research methods or techniques used and regions. In this paper, we employed the ARDL because of its robust results. The findings show a negative relationship between EP and environmental issues due to the difficulty in getting financial funding in order to be able to increase renewable energy production. Gap exists in terms of exploring the relationship between EP and environmental changes in Zimbabwe. This research is conducted as follows: literature review, followed by the methods section and the data portion. Subsequently, the sequence of the study will consist of findings, followed by discussion, and ultimately, a conclusion.

2. Literature Review

The immersing and exacerbating impact of energy poverty globally has gained more attention from scholars; hence, the investigation of energy poverty within the realm of academia to assist lawmakers in discovering the most ideal policies in this study. EP has been on the rise, and the governments of SSA countries have been inevitably attempting to eliminate its effects but to no avail. The UNSDG is to ensure access to cost-effective, trusted, sustainable and modern energy. The mandate involves ensuring universal access to clean energy and clean cooking, doubling the classical levels of efficiency improvements, and remarkably soaring the quota of renewables in the global energy mix. Fulfilling this duty will have a more profound effect on the communities' health and fitness, protecting them from social and environmental hazards, including air pollution, and increasing their access to primary healthcare and services.

2.1 Theory

2.1.1 Environmental Kuznets Curve (EKC)

Prior studies [13-16] hinted at impact on the environment by human activities such as economic growth. EKC is named after [17], who investigated that a rise in per capita income is linked with an increase in income disparity until a stage is reached where there is a corresponding shift, thus when an increase in income is coupled with a reduction in income inequality. Consequently, the EKC proposition asserts that national economic growth will initially tend to worsen environmental conditions to a certain extent before environmental stress decreases as a result of a shift from environmentally harmful to sustainable practices [18]. The EKC's form is also a result of nations switching from using dirty energy to clean energy. Previously, countries depended on nonrenewable energy sources, but in the last few years, countries have begun adopting them. The EKC has analyzed the link that exists between environmental quality and economic growth, whilst other scholars have evaluated the connection between environmental quality and energy consumption [19]. Zimbabwe is considered to be one of the countries with the worst quality of air due to air pollution, which comes from using fossil fuels. The EKC exist

2.2 Environmental Impacts on Ecological Footprints (EF)

The Ef is the best predictor of environmental destruction compared to other measures [20]. [21] reveal that renewable energy eradicates environmental pollution and positively contributes to environmental sustainability. Their findings stated that coal-based energy significantly led to more ED than energy obtained from natural gas. This may be due to the smoke that comes from burning coal that sinks into the ground because of coal ashes. Strong evidence supporting the influence of air pollution on mortality, daily adjusted life years, and premature deaths was also reported by [22], who looked at the relationship between ambient particulate matter and ozone, welfare costs, and mortality for 195 nations. A common proxy for environmental degradation used in most investigations is carbon emissions. However, [23] created the environmental quality index, and its impact on the death rate was evaluated. This index was developed using five factors: built, air, water, and land.

By EF as a measure of environmental quality, [24] tried to close this gap. However, EF measures several other relatively static components, like forestry land, cropland, fisheries, and grazing area, in addition to the dynamic element of CO_2 emissions, so it is a more comprehensive and broader indicator of ambient quality. However, as ambient quality is an autonomous dynamic variable that predicts trends of sharp swings as a result of constantly growing environmental adversities, the static-dynamic combination that makes up environmental quality appears to be incorrect. This research tackles this issue by investigating how renewable energy affects environmental quality while accounting for three dynamic environmental changes.

Many scholars have shown interest in the study of the nexus between EP and pollution. [25] suggest that high firewood usage increases the risk of pollution. [26] proposes that water and land pollution are the major contributors to environmental degradation. Air pollution is caused by the continuous emission of greenhouse gases and the accumulation of matter in the air.

Deforestation has also been one of the leading causes of environmental change as there is an increase in the cutting down of trees to get firewood for energy. This has led to the deterioration of the environment as there is no corresponding afforestation by people regarding the number of trees cut down [26]. According to [27], about 4.2 × 108 hm^2 of forest area had been cleared by 1990. While deforestation rates are decreasing in many countries, they are growing in Sub-Saharan Africa (SSA). The source cited is the Food and Agriculture Organization (FAO) from 2020. From 2010 to 2020, nations in Sub-Saharan Africa (SSA) experienced the most significant yearly decrease in forest area, with around 3.9×10^7 hectares lost yearly. This increases from the 3.4×10^7 hectares cleared annually between 2000 and 2010 and the 3.3×10^7 hectares destroyed between 1990 and 2000.

2.3 Environmental Impact of EP

A few academics have looked into the connection between pollution and EP in light of the growing awareness of energy poverty in recent years. For example, a researcher [25] suggested that increasing the use of kindling/cordwood for heating can increase toxic fumes in Chile's context of significant EP. Furthermore, using biomass in insufficient cookstoves might result in significant indoor pollution levels. [28] also support this finding, suggesting that EP in developing nations has the opposite effect on the environment. Regarding the association between EP and CO_2, EP can worsen indoor air pollution, and its environmental repercussions account for greenhouse gas emissions. However, [29] argue that energy poverty assists in preserving the ecosystem and only negatively affects economic growth during the study of the correlation between EP, ecological footprint, and economic growth in SSA [29].

2.4 Economic Growth (EG)/GDP and Environmental Change

Energy is a major and important agent for stimulating and promoting economic expansion. Several studies have proved that energy has favorable substantial effects on the EG. Past studies have revealed energy consumption has a beneficial effect on EG [30]. GDP has a favorable effect on the ecosystem. [31] used the NARDL method to assess the link between ambient quality and GDP in Nigeria. [32, 33] support the results as they also used the NARDL, the asymmetric effect on growth and carbon emission, and obtained the same results. An increment in EG reduces CO_2, and the opposite is true; other researchers affirm that economic growth improves environmental quality. This could be attributed to increased energy efficiency, improved environmental information and training programs. Increased reliance on clean energy sources to multiple energy mixes and stringent environmental laws and regulations [34-36]. [37, 38] showed evidence of a bi-directional causal relationship between environmental parameters and economic advancement. However, other scholars have shown that there is no causative relationship between economic advancement and environmental quality [39, 40] as well as a one-way causal tie between the two [41, 42].

[43] argue that electricity availability on its own cannot have much impact on economic growth unless all potential explanations are included. However, as much as there are so many negative effects of energy consumption on EG, it increases environmental degradation. The United Nations Commission for Sustainable Development has discovered insufficient energy resources like electric power to hinder growth and development and has a significant impact on the environment. Energy poverty is always correlated with economic poverty, meaning that places that do not have access to electricity at all cannot have economic development or growth because they spend a great deal of their time collecting firewood. The use of fossil fuels like firewood, agricultural crop residue, and dung cake are contemporary examples that increase greenhouse gas and global warming. Zimbabwe, due to the power shortage problem, has low economic growth as a result of a decrease in production.

2.5 The Impact of Environmental Change on NRE and RE

Renewable resources are defined as resources that cannot be depleted by using them. NRE negatively affects the environment. NRE has a deleterious impact on the environment, excluding nuclear energy, another type of NRE that does not cause environmental degradation [44]. The research on the impact of urbanization and NRE on CO_2 in Africa explains that NRE is the primary factor responsible for environmental degradation in Africa [45]. NRE is one of the major catalysts for carbon emission. Past studies have suggested that non-renewable resources contribute to environmental change or environmental degradation [46]. moreover, other papers have proposed that renewable energy reduces carbon emissions, therefore leading to the improvement of the environment and air quality [47]. RE is argued to be environment benign [48-50]. Utilization of RE has been observed to reduce CO_2. The carbon emission elimination goal of the United Nations is achieved through utilizing RE instead of NRE. Alternative energy sources, like fossil fuels, are dirty and can potentially worsen the environment. The energy systems of less developed nations are carbonizing at a higher rate. Emerging economies are showing signs of a gradual shift towards weak decoupling. Emerging countries have remarkably low levels of decarbonization and decoupling compared to SSA nations. A renewable resource is primarily found to reduce environmental pollution and be environmentally friendly [21, 51]. SSA countries should collaborate in lowering carbon emission (CO_2) as it is believed CO_2 can travel from one country to another neighboring country [52]. This means that for countries to attain sustainable development goals by the year 2030, they have to work together and protect their environments as well as the health of the people.

2.6 The Research Gaps

The present study seeks to make a number of contributions to contemporary research on the correlation between energy poverty and environmental change in Zimbabwe. Zimbabwe is facing energy poverty, and environmental change is making the situation dire. Environmental degradation has caused climate change that, in turn, has led to drought affecting the electricity-generating reservoir, thus, energy poverty. Over the years, most of the Zimbabwean population has been in the dark due to power outages and no electricity for the whole country, with only 62% having electricity. When electricity generation increases, it will reduce energy poverty and increase productivity, thereby increasing EG. This study differs from the past study in that it employs environmental change and energy poverty to establish the nexus. Most of the research, to the best of my knowledge, focused more on RE technologies and power sector reforms [53-55]. This makes this research different. Although there are other researchers who have concentrated on energy poverty, they did not really focus on its impact or correlation with environmental change. For instance, [56] focused on the political-economic effects of energy poverty. Prior research focused on the nexus between carbon emission, EG, RE, and NRE resources [57]. Firstly, the relationship between energy poverty and environmental change is paucity explored in the energy literature. The present research contributes by providing new vigorous evidence on the interrelation between energy poverty and environmental change. This study, along with the proxies of environmental change, includes EG, RE and NRE resources, and EFP, in modeling EP in these third-world countries (SSA).

3. Methodology

3.1 Research Model

This research aims to make a comparison of the variables that impact ambient change and EP by utilizing EFP as the dependent variable. In this work, we use the ARDL limits test approach by [58], to investigate the short- and long-term causal relationship between EP and EFP. The ARDL model by [59, 60] is expanded upon by the ARDL bounds test technique. There is no requirement for pre-testing because the ARDL bounds test model enables the levels connection to be studied independently of whether the variables are I (0), I (1), or not mutually cointegrated [59, 61]. To ensure that no variable is I, we use the Phillips and Peron (PP) test by Phillips and Perron, 1988 and the Augmented Dickey-Fuller.

According to [58], the ARDL bound test is found on the t- and F- statistic test and is used for examining the importance of lagged levels of variables in a univariate equilibrium correction mechanism. According to the ARDL limits test null hypothesis, there is no level relationship even when the repressors are I (0) or I (1). Therefore, the ARDL limits test method checks for a relationship between variables even when they are cointegrated or integrated of different orders, I (0) and I (1). We specify the short-run ARDL and equilibrium error mechanism (ECM) to ascertain the long-run relationship if the relationship of the level between variables is determined to exist. If the results of the bound test show that there is no level of relationship, then only the short-term ARDL.

Equation 1 below depicts the statistical model of this research.

$$EFP = \beta_0 + \beta_1 EP + \beta_2 RE + \beta_3 NRE + \beta_4 NR + \beta_5 EG + \mu \tag{1}$$

One of the essential strengths of the ARDL model is that it jointly estimates both the short-run and the long-run dynamics between the dependent and independent variables. This aspect is very significant in the present study since the associations between Ecological Footprint and the explanatory variables, Energy Poverty, Renewable Energy, Non-Renewable Energy, Natural Resources, and Economic Growth, might change over time and are prone to immediate and long-term influences. However, like any econometric model, the ARDL approach has certain limitations. The primary limitation is that it cannot be applied if any variable in the model is integrated of order I (2), since such a thing would violate the underlying assumptions and result in spurious regression outcomes. In this regard, strict pre-estimation tests for stationarity, including the Augmented Dickey-Fuller and Phillips-Perron tests, were conducted to ensure the data met the required conditions.

Despite its limitations, the ARDL model remains the most appropriate choice for this study due to its flexibility with mixed-order integration and its efficiency in capturing both short- and long-run relationships. Alternative techniques, such as Vector Error Correction Models (VECM), require all variables to be integrated in the same order, which is not the case in this dataset. Similarly, nonlinear models such as the NARDL or SEM are not appropriate because the focal point of this study rests on the linear dynamics of the series. Thus, the application of the ARDL model ensures robust and reliable results. At the same time, its limitations are adequately controlled in a manner that assures the validity and relevance of the results in Zimbabwe.

3.2 Data

The data used is from Sub-Sahara Africa countries from 1990 to 2021. The ecological footprint data was gathered from the "Global Network Footprint database". The EFP represents the environmental change in this model. EFP indicates the eco-assets that a population needs to produce the natural resources it consumes. An index accumulated by considering six components supports human activities such as cropland, fishing ground, grazing land, carbon, forestland and built-up area (Global Network Footprint 2023[1]). The data NRE, RE, EC, EP and EP is accumulated from the World Bank database. Global Network and World Bank sources for data are mostly recommended for data collection as the information provided on the websites is more accurate. A country's annual GDP change indicates its economic growth; a positive figure indicates growth, whereas a negative value indicates a decrease [44]. RE and NRE are measured by the total percentage of energy use. Energy poverty is measured as the access to electricity. It indicates the number of households with access to electricity Additionally, Table 1 provides comprehensive details on the research variables. The EFP in this literature is measured using consumption per capita; EP is measured using access to electricity. Renewable energy is the percentage of the final energy consumption. NRE refers to the % of GDP based on market prices.

[1] https://data.footprintnetwork.org/?_ga=2.142353211.828576877.1735070425-982540431.1735070425#/

Table 1 Variable summary.

Variables	Abbreviation	Measurement	Source
Ecological Footprint	EFP	Consumption per capita	GFN
Energy Poverty	EP	Access to electricity	
Renewable Energy	RE	% total energy use	
Non-Renewable Energy	NRE	% total energy use	WB
Natural Resources	NR	% of GDP	
Economic Growth	EG	% of GDP	

Source: Author Compilation, GFN = Global Network Footprint (Licenses and Support - Global Footprint Network) and WB = World Bank (World Development Indicators | Databank (worldbank.org)).

Also, the EKC hypothesis assumes an inverted U-shaped relationship between environmental degradation and economic growth, suggesting that environmental damage increases during the early stages of economic growth but decreases as economies reach higher levels of development. This study explores the relevance of the EKC hypothesis in Zimbabwe, where economic growth, energy poverty, and natural resource utilization are critical factors influencing environmental outcomes. In sum, incorporating Ecological Footprint as the dependent variable captures a broad measure of environmental change. Further, including Renewable and Non-Renewable Energy reflects the dual energy dynamics that impinge on ecological sustainability. Natural Resources and Economic Growth are pivotal variables for testing the EKC hypothesis, given that Zimbabwe is an extractive economy and is on its economic development journey. This framework provides an opportunity to assess whether economic growth in Zimbabwe aligns with the EKC hypothesis or follows a different environmental-economic pathway due to the country's unique socio-economic and energy poverty challenges.

3.3 Method

3.3.1 Preliminary Test

This study begins by examining the preliminary test. Preliminary tests are essential as they allow us to identify the perfect model for our study, thereby enhancing the robust finding [44]. During the preliminary test, we begin by testing the unit root, heterogeneity test, and cointegration test in order to see the best method to use [62]. In this research, we apply the “Augmented Dicke Fuller (ADF)” and “Phillip Peron (PP)” tests to access the unit root outcomes [44, 63]. In a time series, the ADF is used for the stochastic and the trend [64]. PP is utilized alongside with ADF to test the unit root for the robustness of the results [44]. When the variables are stationed at the difference, we conducted the cointegration analysis to ascertain the long-term relationship of the variables formed as z_t.

$$z_t = Y_t - aX_{t\sim 1(0)}$$

Where $Z_t$is the cointegration relationship between Y_t and X_t that is stationary at the level and *a* is a unique constant term connecting Y_t and X_t in a cointegration relationship.

3.3.2 ARDL Techniques

The ARDL model exhibits higher efficacy in examining the long-term correlation between economic variables, as compared to conventional econometric methods. The ARDL model offers a dependable statistical method for assessing the connections between economic time series data. The estimator accurately measures the short-term and long-term effects, demonstrates strong performance even with limited data, and successfully addresses issues related to autocorrelation. The ARDL technique is an invaluable tool for comprehending the complex dynamics of economic concerns, as illustrated by the equation.

$$\begin{aligned} EFP_t = \beta_0 &+ \sum_{i=1}^{q} \beta_{1i} \Delta EFP_{t-i} \\ &+ \sum_{j=1}^{p} \beta_{2i} \Delta RE_{t-j} + \sum_{j=1}^{p} \beta_{3i} \Delta NRE_{t-j} + \sum_{j=1}^{p} \beta_{4i} \Delta EP_{t-j} + \sum_{j=1}^{p} \beta_{5i} \Delta NR_{t-j} \\ &+ \sum_{j=1}^{p} \beta_{6i} \Delta EG_{t-j} + \delta_{1i} RE_{t-1} + \delta_{2i} NRE_{t-1} + \delta_{3i} EP_{t-1} + \delta_{4i} NR_{t-1} + \delta_{5i} EG_{t-1} \\ &+ \delta_{6i} ECT_{t-1} + et \end{aligned} \tag{2}$$

Equation 2 above depicts the empirical depiction of the ARDL model in both the short-term and long-term to analyze the link amidst environmental change and energy poverty in Zimbabwe. Where the initial difference operator is *Δ* and the nation is indicated by *j*. The long-term influence is represented by the $\beta 1$-$\beta 6$ coefficients, whilst the short-term impacts are captured by the $\delta 1$-$\delta 6$ coefficients. Furthermore, *q* and *p* represent the ideal lag duration.

The existing study employs several diagnostic tests, including the "Breusch-Pagan-Godfrey heteroscedasticity test, Breusch-Godfrey Serial Correlation LM Test, and Ramsey RESET test", to confirm that the empirical analysis was conducted appropriately. Additionally, the study utilizes "CUSUM and CUSUM-square" evaluations to ensure the empirical analysis is adequately tested. "Granger causality" analysis is employed to ascertain causal association. The difference between short-term level deviations and long-term equilibrium level variances is defined in this study as (EC^{Term}). The following equations represent the ECM (3-8):

$$\begin{aligned} \Delta \mathrm{EFP_{it}} = \alpha_0 &+ \sum_{i=1}^{p} \beta_1 \Delta \mathrm{EFP_{t-j}} + \sum_{i=1}^{g} \beta_2 \Delta \mathrm{RE_{t-j}} + \sum_{i=1}^{g} \beta_3 \Delta NRE_{\mathrm{t-j}} \\ &+ \sum_{i=1}^{g} \beta_4 \Delta EP_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_5 \Delta \mathrm{NR_{t-j}} + \sum_{i=1}^{g} \beta_6 \Delta EG_{\mathrm{t-j}} + \gamma \mathrm{ECT_{t-1}} + \varepsilon_{1t} \end{aligned} \tag{3}$$

$$\begin{aligned} \Delta \mathrm{RE_{it}} = \alpha_0 &+ \sum_{i=1}^{p} \beta_1 \Delta \mathrm{RE_{it-J}} + \sum_{i=1}^{g} \beta_2 \Delta \mathrm{EFP_{it-J}} + \sum_{i=1}^{g} \beta_3 \Delta NRE_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_4 \Delta \mathrm{EP_{t-j}} \\ &+ \sum_{i=1}^{g} \beta_5 \Delta NR_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_6 \Delta \mathrm{lnEG_{t-j}} + \gamma \mathrm{ECT_{t-1}} + \varepsilon_{1t} \end{aligned} \tag{4}$$

$$\Delta NRE_{\mathrm{it}} = \alpha_0 + \sum_{i=1}^{p} \beta_1 \Delta \mathrm{lnNRE}_{\mathrm{it-J}} + \sum_{i=1}^{g} \beta_2 \Delta \mathrm{EFP}_{\mathrm{it-J}} + \sum_{i=1}^{g} \beta_3 \Delta RE_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_4 \Delta EP_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_5 \Delta NR_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_6 \Delta EG_{\mathrm{t-j}} + \gamma \mathrm{ECT}_{\mathrm{t-1}} + \varepsilon_{1\mathrm{t}} \tag{5}$$

$$\Delta EP_{\mathrm{t-j}_{\mathrm{it}}} = \alpha_0 + \sum_{i=1}^{p} \beta_1 \Delta EP_{\mathrm{t-j}_{\mathrm{it-J}}} + \sum_{i=1}^{g} \beta_2 \Delta EFP_{\mathrm{it-J}} + \sum_{i=1}^{g} \beta_3 \Delta RE_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_4 \Delta \mathrm{NRE}_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_5 \Delta NR_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_6 \Delta EG_{\mathrm{t-j}} + \gamma \mathrm{ECT}_{\mathrm{t-1}} + \varepsilon_{1\mathrm{t}} \tag{6}$$

$$\Delta \mathrm{NR}_{\mathrm{it}} = \alpha_0 + \sum_{i=1}^{p} \beta_1 \Delta NR_{\mathrm{it-J}} + \sum_{i=1}^{g} \beta_2 \Delta \mathrm{EFP}_{\mathrm{it-J}} + \sum_{i=1}^{g} \beta_3 \Delta RE_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_4 \Delta NRE_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_5 \Delta EP_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_6 \Delta EG_{\mathrm{t-j}} + \gamma \mathrm{ECT}_{\mathrm{t-1}} + \varepsilon_{1\mathrm{t}} \tag{7}$$

$$\Delta EG_{\mathrm{it}} = \alpha_0 + \sum_{i=1}^{p} \beta_1 \Delta EG_{\mathrm{it-J}} + \sum_{i=1}^{g} \beta_2 \Delta \mathrm{EFP}_{\mathrm{it-J}} + \sum_{i=1}^{g} \beta_3 \Delta \mathrm{RE}_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_4 \Delta NRE_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_5 \Delta EP_{\mathrm{t-j}} + \sum_{i=1}^{g} \beta_6 \Delta NR_{\mathrm{t-j}} + \gamma \mathrm{ECT}_{\mathrm{t-1}} + \varepsilon_{1\mathrm{t}} \tag{8}$$

Where $\gamma\mathrm{ECT}_{\mathrm{t-1}}$ represents the lagged ECT and Δ is the difference operator, the statistical analysis of the Wald test (F) is utilized to assess the causal relationship between the target variables at the short-term level.

4. Results

4.1 Preliminary Outcomes

Table 2 also presents descriptive statistics for key variables related to the analysis: ecological footprint, energy poverty, renewable energy, non-renewable energy, natural resources, and economic growth. These summary statistics were derived based on 31 observations; these describe centrality, dispersion, and the range of the data: the mean, median, and highest value are all attributed to RE; EG has the lowest value.

Table 2 Descriptive Results.

	EFP	EP	RE	NRE	NR	EG
Mean	1.30968	36.6039	75.0642	31.6407	7.19647	1.02034
Median	1.28786	35.622	78.01	29.0958	6.77604	1.43962
Maximum	1.63859	52.7477	84.36	47.3425	18.2366	21.4521
Minimum	1.08658	28.0239	63.74	15.7669	2.50321	-17.669
Std. Dev.	0.13464	6.00983	7.17641	9.92811	3.43049	8.84725
Observations	31	31	31	31	31	31

Source: Author compilation from EViews. EFP means ecological footprint, EP means energy poverty, RE means renewable energy, NRE means non-renewable energy, NR means natural resources and EG means economic growth.

The summary statistics give an initial sensation of the data by showcasing some central tendencies and dispersion within the variables. This becomes important as it provides the background against which the associations assessed in later sections are contextual, especially the changes associated with ecological footprint and environmental change in Zimbabwe.

Additionally, the study unit's root results are provided in Table 3. The outcomes of the stationarity test show that RE, NRE and NR are not stationary at (I (0)) but at (I (1)) on both the ADF and the PP techniques. EFP, EP, and EG variables are stationary at the level on both the ADL unit root and the PP unit root. This aids in determining the integration order of the indication. Finding the factor's order of integration facilitates choosing the best analysis technique for the given model. The ARDL is the best method when the model is integrated into different orders I (0), I (1), or a combination of both for robust findings. The only problem with this technique is that it will not work in the presence of a stochastic trend of I (2).

Table 3 Unit Root results.

	ADF				PP			
	Level I (0)		1st Difference I (1)		Level I (0)		1st Difference I (1)	
	t-statistic	p-value	t-statistic	p-value	t-statistic	p-value	t-statistic	p-value
EFP	-5.83804***	0.0002			-5.88324***	0.0002		
EP	-4.11047**	0.0176			-3.55564*	0.0508		
RE	-1.88579	0.6368	-4.665596***	0.0043	-2.02253	0.5659	-4.66702***	0.0043
NRE	-2.81459	0.2030	-5.452687***	0.0006	-2.947	0.1626	-8.61399***	0.0000
NR	-2.71795	0.2367	-5.675015***	0.0003	-2.82996	0.1979	-5.81003***	0.0002
EG	-3.39743*	0.0701			-3.42264*	0.0666		

Note: ***, ** and * indicate level of significance at 1%, 5% and 10% respectively. EFP means ecological footprint, EP means energy poverty, RE means renewable energy, NRE means non-renewable energy, NR means natural resources and EG means economic growth.

Moreover, we examine the long-run relationship of the variables by using the ARDL bounds testing approach, presented in Table 4. The outcomes indicate that the computed F-statistic is greater than the upper and lower critical bounds at all levels of conventional significance (1%, 5%, and 10%), showing the presence of a statistically significant long-run relationship between the dependent variable, Ecological Footprint, and independent variables comprising Energy Poverty, Renewable Energy, Non-Renewable Energy, Natural Resources, and Economic Growth. This implies that the variables indeed move together in the long run, even though their movement might be affected in the short run.

Table 4 Bound test.

	Significance level	I (0)	I (1)
F- Statistics			
8.9176	1%	4.768	6.670
	5%	3.354	4.774
	10%	2.752	3.994
t- Statistics			
-6.2974	1%	-3.430	-4.600
	5%	-2.860	3.990
	10%	-2.570	-3.660

The model's t-statistic is also greater than the critical bounds at the 1%, 5%, and 10% levels, which further justifies a meaningful long-run relationship. In fact, these results prove the reliability of the ARDL model regarding the long-term equilibrium relationship under scrutiny.

These results are significant because policies aimed at energy poverty, renewable and non-renewable energy sources, natural resource management, and economic growth will have sustained and lasting effects on environmental outcomes in Zimbabwe. The findings highlight the need to address these variables holistically to ensure sustainable development and environmental progress.

4.2 ARDL Outcomes and Discussion

The ARDL estimation results presented in Table 5 demonstrate the significant short- and long-term effects of each independent variable on ecological footprint. The results show coherence and consistency, which supports the idea that every one of these elements plays a critical role in forming and affecting the overall ecological footprint over both the short and long term. Depending on the results of the ECT term, the production functions change from the short-run equilibrium to the long-run equilibrium at a rate of 1.154.

Table 5 ARDL model.

Variable	coefficient	t-statistic	p-value
Long-run			
RE	0.002748	0.43429	0.6678
NRE	0.014174***	3.097214	0.0048
NR	-0.007124	-1.603402	0.1214
EG	-0.00042	-0.220351	0.8274
Short-run			
RE	-0.007163	-0.860230	0.4004
RE (-1)	-0.002365	-0.263925	0.7947
NRE	0.01636***	2.903539	0.0091
NR (-1)	-0.016666**	-2.851113	0.0102
EG	0.004323**	2.165675	0.0433
EG (-1)	-0.004808**	-2.345466	0.0300
ECT*	-1.154214***	-7.346774	0.0000

Note: ***, ** and * indicate the level of significance at 1%, 5% and 10% respectively. EFP means ecological footprint, EP means energy poverty, RE means renewable energy, NRE means non-renewable energy, NR means natural resources and EG means economic growth.

Furthermore, the ARDL result implies that RE will eventually improve Zimbabwe's ecological effect. The results indicated a 0.0027 long-term increase in the ecological footprint for every unit increase in RE. This suggests that even if implementing RE may call for specific actions or infrastructure upgrades that momentarily increase the ecological footprint, doing so nevertheless helps with environmental sustainability. According to earlier research, one of the most important components or solutions for reducing ecological deterioration is renewable energy [48, 65]. According to [44], governments ought to encourage the use of renewable energy. The greatest standard of environmental purity is promoted by the use of renewable resources. However, in the short run, it is unhelpful to associate RE with ecological footprint. According to the ARDL analysis, for every unit increase in RE, Zimbabwe's ecological footprint will decrease in the short term by 0.0072. This small reduction may have resulted from building renewable energy systems directly, which cut emissions and the need for fossil fuels. The outcome is in alignment with the report of [66-69]. Surprisingly, the insignificant long-run relationship between RE and ecological footprint obtained in this study contradicts the findings obtained for Kenya and Ethiopia by [70, 71], respectively, where renewable energy investments have proved to be measurable in yielding some environmental benefits. Perhaps such insignificance in Zimbabwe could reflect some of the obstacles in renewable energy infrastructure, limited financing, and inconsistent policy implementation. This shows a dire need to increase the adoption of renewable energy sources to achieve sustainable development in Zimbabwe.

Moreover, there is a long-term positive correlation between NRE and ecological footprint. According to this, a one-unit increase in NRE would result in short- and long-term increases of 0.0142 and 0.0164, respectively. The results demonstrate how the ecosystem is seriously harmed by rising emissions and resource depletion resulting from the use of non-renewable energy (NRE) sources, including coal, oil, and gas. Furthermore, the immediate consequences highlight the immediate environmental costs connected to NRE use. These results highlight the pressing need for policies that mitigate the adverse environmental effects of NRE and diminish Zimbabwe's dependency on it in order to assist the nation's transition to more sustainable energy sources. Also, the outcome aligns with the study of [72-76]. The positive and significant long-run relationship between NRE and EFP is in line with the findings from South Africa and Nigeria [77, 78], where high dependence on fossil fuels has been a major contributor to environmental degradation. This points out the common challenge facing Sub-Saharan Africa in terms of shifting to cleaner energy sources to reduce ecological destruction. The powerful negative impact of lagged NR on EF is replicated in the short run by evidence from resource-dependent economies such as Zambia [79], whose resource exploitation has relieved environmental pressure in the short term. At the same time, the latter presents long-term sustainability challenges. The mixed short-run effects of EG on EF, being positive in the current period and negative in lagged terms, reflect findings from Tanzania's experience, as shown by [80], where economic growth stimulates environmental pressures in the short term but, after some time, moderates due to structural adjustments.

Additionally, natural resources and ecological footprints have detrimental short- and long-term effects. According to the results, a unit increase in NR would result in a short-term decline of 0.0167 and a long-term decline of 0.0071. Given this inverse relationship, it stands to reason that more ecologically friendly behaviors or improved resource management could lessen the ecological footprint by increasing the use or access to natural resources. While the longer-term advantage shows sustained favorable results, it is less significant than the more apparent short-term effect, suggesting that exploiting natural resources will have a positive influence immediately. These results show how Zimbabwe might use its natural resources wisely to attain environmental sustainability. Also, the outcome aligns with the study of [66, 81, 82].

Lastly, there is a negative correlation between EG and ecological footprint in the short and long durations. The results show that a rise in EG would result in a short- and medium-term decrease in the ecological footprint of 0.00042 and 0.0048, respectively. This illustrates the link between Zimbabwe's economic expansion and a decline in the country's environmental impact. This may be explained by the country's adoption of more environmentally friendly technologies, stricter environmental laws, and changing consumer behavior as the economy expands. The long-term decline, however slight, shows long-term positive effects of economic expansion, while the more obvious short-term decline shows instant benefits. These results demonstrate the possibility of achieving both environmental sustainability and economic growth, underscoring the significance of policies that support sustainable development and green growth in Zimbabwe. This is consistent with studies by [83] that found a link between environmental change and economic growth. Also, the findings align with the study of [68, 84-86].

4.3 Diagnostic Outcomes

The test results for serial correlation Breusch-Godfrey, heteroskedasticity Breusch-Pagan-Godfrey, and Ramsey RESET are represented in Table 6, showing that the estimated model is robust and reliable. It should be noted that, based on the Breusch-Godfrey test results, the null hypothesis of no serial correlation was confirmed. This means that each residual is not dependent on past values, which provides excellent credibility to the model's estimates. The normality test indicates that, in addition, residuals are normally distributed, which confirms a good specification of the model using the results on different critical levels: 1%, 5%, and 10%.

Table 6 Diagnostic Outcomes.

	Normality test	serial correlation	Heteroskedasticity	Ramsey Reset
EFP				
F-statistic	0.04532**	0.047777**	0.82964	0.82964
p-value	0.97760	0.9535	0.3744	0.3744

Note: * is 10% significant, ** is 5% significant, *** 1% significant. Jarque-Bera for normality test, LaGrange multiplier test of residual serial correlation, Autoregressive conditional heteroskedasticity and Ramsey's misspecification test using a square of fitted values.

Without serial correlation, which has also been verified in results when energy poverty is considered a dependent variable, these validate the accuracy of parameter estimates. However, the Breusch-Pagan-Godfrey heteroskedasticity test shows that heteroskedasticity exists at 1%, 5%, and 10% significance levels. Even though heteroskedasticity can create bias in the standard errors of the coefficients, the parameter estimates remain consistent. Therefore, robust standard errors were applied to ensure that the inferences obtained from the model were appropriate and valid.

The Ramsey RESET test also confirms that the functional form of the model is well specified, hence there are no significant omitted variable biases. Overall, the combination of these diagnostic tests underlines the validity, reliability, and robustness of the findings, therefore making them suitable for drawing policy-relevant conclusions in the context of the nexus between energy poverty and environmental change in Zimbabwe.

Moreover, the CUSUM and CUSUM of Squares tests were conducted to check the stability of the estimated ARDL bounds test model. These tests are very important in checking for structural stability in the estimated parameters over time so that the relationships captured by the model would be consistent and reliable. Figure 1 depicts the CUSUM graph, which stays within the 5% significance bounds throughout the sample period. This indicates that the model is stable and free from structural breaks or parameter instability. Similarly, the CUSUM of Squares test corroborates this result, further confirming the robustness of the model's specification. The stability of the model enhances the credibility of the short-run and long-run estimates, making them suitable for policy analysis and forecasting in the context of Zimbabwe's energy poverty and environmental change dynamics.

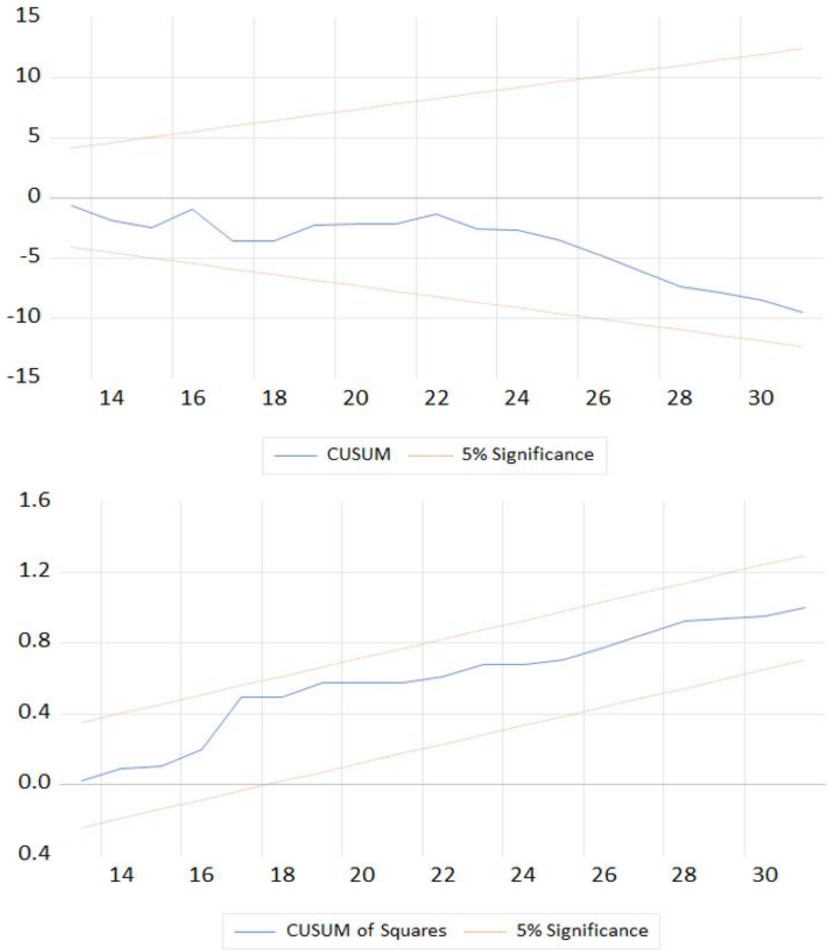

Figure 1 CUSUM and CUSUMQ test.

5. Conclusion and Policy Implications

The present article examined the relationship between energy poverty and environmental change during the period 1990-2021 in Zimbabwe. The method implied for the evaluation is the ARDL which was used because of its advantageous nature. The short-run shows a correlation between variables. The literature analyzed the intricate dynamics of the association between energy poverty and environmental change. Through the conscientiousness of the ARDL model, we analyzed or investigated the implications of RE, NRE, NR, and EG on the ecological footprint. RE is crucial in preserving or conserving ecological footprint. We also ascertain a bidirectional causality among the two variables, EFP and RE. Economic growth negatively affects the ecological footprint at the early stages and then later on contributes positively to the ecological footprint. RE and NRE exerted a heterogeneous impact on the EFP. This research gives robust results that are important for the policy implications since it employs the ARDL model. The time series ARDL bound test and ECM technique give long-run, short-run, and ECM results, which are vital. Zimbabwe should foster the consumption of RE in order to mitigate pollution whilst aiming to accomplish zero carbon emissions in the future. This will assist in achieving the United Nations Sustainable development goals of energy for all by 2030 goal. In promoting RE, the government of Zimbabwe will have to forgo/tradeoff. This research provides that RE has a crucial role in ecological footprint in the short-run; we must take note that the short-run findings are essential for law implication for the study. The research results can be generalized to emerging economies experiencing energy poverty, like Zimbabwe. RE energy not only decreases the carbon emission rate but also reduces global warming and environmental degradation [32, 87]. The implications for this study are as follows: RE should be promoted through encouraging investment in the country. Encourage investment through favorable policies. Zimbabwe's main energy sources are thermal power and hydroelectricity; more investment must be made to increase the power generation from these power plants. At the moment, Zimbabwe's current electricity stands at 1200 megawatts. The Zimbabwean government should also focus on investing in solar and wind because of the high solar radiation that the country experiences throughout the year, accompanied by strong winds [88, 89]. Renewable energy technologies are mainly managed by the Zimbabwean Energy Regulatory Authority (ZESA), such as solar photovoltaic, geothermal, hydropower facilities, wind, and biomass. However, Zimbabwe's hydropower generation is constrained by climate issues, erratic rainfall, and antiquated infrastructure. Infrastructure must be updated, climate change resilience must be increased, and the station's energy sources must be diversified in order to improve sustainability and dependability [90].

However, according to [91], Zimbabwe has several factors that impede RE development. Factors such as policy uncertainty and, climate change, extreme weather can prevent investment, which may compromise RE. There are also issues regarding effective planning and development because of the existence of inequalities in competition from energy sources coupled with the lack of information RE, which is often the primary problem for many countries [92, 93]. Disgruntled communities delay the adoption of RE, especially in rural areas. Policy implantation and lack of policy correction have led to inconsistency in decarbonization, resulting in contradictions [91]. A shortage of skilled technical staff exacerbates issues with industrial systems designs, such as those involving the design, implementation, and education of renewable energy systems [94]. Large-scale renewable energy projects are also challenging to integrate because of the grid's antiquated architecture. The high upfront costs, restricted access to financing, and volatility of energy prices further impede the deployment of renewable energy [95]. The Zimbabwean government should implement some of the policies that have helped its neighbors in the region (SADC region) to improve their energy production and financial situation towards improving renewable energy production. It can implement the investment incentives and the procurement programs. Investment incentives are fiscal, economic, and other incentives that promote private-sector investment in renewable energies. Angola implemented this policy in 2022 for businesses that are involved in the production and sale of RE. The policy included a 35% reduction in corporate income tax and a 60% reduction in investment tax. Procurement programs from independent power producers (IPP) can promote investments in RE, although vital and effective regulated policies are implemented. IPPs are the fastest-growing means of mobilizing private investment in RE in Southern Africa. The South Africa REIPP program is the main program attracting investment in the SADC region. In 2020, REIPP attracted 80% of the total IPP investment (Investing in renewable energies for Southern Africa's sustainable development report).

Enforce stringent laws that promote environmentally friendly techniques in terms of natural resource extraction in the country. Zimbabwe must move away from the convection energy sources, resulting in an enhanced quality environment. The government, the energy organizations, and the media must work together and put forward programs that bring awareness about the utilization of renewable resources. In order to facilitate future studies, it is imperative to do further research to ascertain the impact of renewable energy utilization on EG and other economic variables in both emerging and developed countries, employing the ARDL panel methodology.

The main limitations of this study are that it only analyzes the nexus between environmental change and energy in Zimbabwe only as compared to if more countries were included. Future studies can do more work on the same topic in other regions of the World because different areas have different characteristics; hence, different outcomes can be presented. Various techniques can be utilized in this study, examining the whole SADC region in order to find a concrete solution for this problem as it affects the whole area.

Author Contributions

Annette Siakamba: Writing – original draft, formal analysis, Software, Methodology. Mehdi Seraj: Conceptualization, visualization, writing – review and editing, Supervision. Huseyin Ozdeser: Supervision. All authors have read and approved the published version of the manuscript.

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Data Availability Statement

The data used is from Sub-Sahara Africa countries from 1990 to 2021.The ecological footprint data was gathered from the "Global Network Footprint database". The EFP represents the environmental change in this model. An index accumulated by considering six components supports human activities such as cropland, fishing ground, grazing land, carbon, forestland and built-up area (Global Network Footprint 2023). The data NRE, RE, EC, EP and EP is accumulated from the World Bank database.

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