EJED 2024 6(1):1–17
Ethiopian Journal of Environment and Development
http://journal.du.edu.et/index.php/ejed
EJED

The effect of renewable energy on Green Economy Development: evidence from the Ethiopian economy running from the year 1990 to 2022

Demisse Jarsa * **and Garedew Aweke**

Department of Economics, College of Business & Economics, Dilla University, Ethiopia.
**Corresponding author; Email: demissejarsa032@gmail.com*

Received: 01 December 2023 *Accepted: 07 August 2024* *Published: 10 August 2024*

Article DOI: **10.20372/ejed.v06i1.01**

Abstract

Ethiopia is currently seeing a sharp rise in interest in modern clean energy generation as a means of achieving environmental and economic sustainability. However, there is still a lack of empirical study examining how investments in contemporary clean energy impact Ethiopia's progress toward a green economy. The impact of renewable energy on Ethiopia's green economy development was examined in this study, with a focus on the relationship between modern clean energy consumption, economic growth, and environmental quality between 1990 and 2022. The study used yearly time series data from the International Energy Agency (IEA), the Global Carbon Atlas (GCA), and the World Development Indicators (WDI). The auto regressive distributed lags (ARDL) econometric estimation method was applied to analyze the data. The results indicated that the utilization of non-renewable energy, biomass, and modern clean energy were significant contributors to the variations in carbon dioxide emissions in Ethiopia. However, only contemporary clean energy exhibited statistical significance in relation to long-term economic growth. The findings imply that the adoption of green energy sources, such as hydro, wind, and solar energy, has the potential to reduce carbon emissions while enhancing output. It is advised that Ethiopian authorities prioritize the advancement of renewable energy sources to avert the economy from becoming increasingly carbon-intensive in the future. This necessitates robust collaboration among policymakers, the government, and international cooperation organizations to enhance investment in modern clean energy and ensure sustainable development both environmentally and economically.

Keywords/Phrases: Economic growth, Environmental quality, Green development, Modern clean energy

1 Introduction

Ethiopia, recognized as one of the least developed countries globally, has recently witnessed a notable surge in its economic output, positioning itself among the fastest-growing economies worldwide. According to the data available, Ethiopia demonstrated an impressive growth trajectory, achieving an average annual growth rate of 9.3% from 2013 to 2018 (NBE, 2020). This growth was primarily propelled by increased industrialization and urbanization, which were significantly supported by a rise in energy consumption (Teka *et al*, 2020).

Ethiopia aspires to attain middle-income status by the year 2025, leveraging its recent achievements in robust economic growth. The realization of this objective will largely hinge on enhancing productivity within the agricultural sector, broadening the industrial base, and fostering growth in international trade, as delineated in the Growth and Transformation Plan (GTP) (FDRE, 2011). In essence, the ambition for industrialization, particularly heavy industrialization, leads to more energy-intensive economic activities as the nation strives to achieve middle-income status.

It is widely acknowledged that energy infrastructure serves as a vital element affecting a nation's economic growth and development, often described as the lifeblood of the contemporary economy (Kulionis, 2013). Because it increases the productivity of other resources and raises living standards, energy is a crucial input in production and is necessary for a nation's economic and social advancement.

Nevertheless, as noted by Kulionis (2013), the increasing demand for energy to support economic activities also exacerbates environmental issues. The excessive consumption of energy results in the release of significant quantities of carbon dioxide, which has been recognized as the leading cause of global warming and climate change.

Recently, the demand for energy in Ethiopia has surged in response to the nation's accelerating industrialization and rapid population growth. In other words, the economic and demographic expansion of the country has led to a notable increase in energy consumption.

According to the International Energy Agency's report (2020), statistics indicate that Ethiopia's total final energy consumption increased from 16,771 KTOE in 1990 to 40,717 KTOE in 2018, representing a rise of 142.78%. This trend suggests that the demand for energy in Ethiopia has been growing in close alignment with the country's economic and population expansion.

Despite the increasing energy requirements, the structure of Ethiopia's energy consumption remains inefficient, environmentally harmful, and primarily reliant on biomass energy sources, which constitute approximately 88% of total consumption (MoWE, 2012). Given this consumption pattern, the anticipated rise in energy demand is expected to worsen the country's environmental degradation.

In light of these challenges, and in response to recommendations from environmentalists and economists to redirect growth objectives from traditional economic development to more environmentally sustainable practices, as noted by Alam *et al.* (2016), Ethiopia has adopted the "Climate Resilient Green Economy (CRGE)" strategy. As the country moves toward a green economy, this project seeks to protect it from the negative effects of global warming. Through this strategy, Ethiopia expresses its goal to attain middle-income status by 2025 while concurrently safeguarding environmental quality (FDRE, 2011). This demonstrates the country's dedication to pursuing economic progress in a more sustainable fashion.

Ethiopia's government plans to develop clean energy, particularly hydropower, wind, geothermal, and solar power, as well as non-renewable and combustible renewables and waste, because of the country's tropical location and the abundance of opportunities for contemporary environmentally friendly energy sources. The objective is to fulfill Ethiopia's desire to create an ecologically sensitive economy.

According to available data, Ethiopia's performance in modern clean energy development has been outstanding. From 1980 to 2018, the country's hydroelectricity net generation climbed from 5,184.04 Terajoules to 123,790.46 Terajoules, demonstrating an exceptionally high average growth rate of 58.66%.

Wind energy investment in Ethiopia has also increased significantly. Wind electricity net generation has grown from 307.53 Terajoules in 2011 to 5,119.59 Terajoules in 2019, reflecting a 173.86% average growth rate during this period. Solar energy generation has also increased from 1.04 Terajoules in 2008 to 192.1 Terajoules in 2019 (IEA, 2020).

The key concern here is: to what extent can renewable energy developments, particularly modern clean energy, contribute to the development of Ethiopia's green economy? Since the goal of green economic growth is to achieve middle-income status by increasing output while maintaining environmental quality, it is important to analyze the impact of current clean energy initiatives from both an economic and environmental perspective.

A deeper comprehension of the causal links between renewable energy, economic growth, and environmental conditions is required in order to create effective policies. This will help determine how renewable energy developments can best support Ethiopia's ambition of transitioning to a green economy and achieving its middle-income target by 2025 while safeguarding environmental quality.

The connection between environmental conditions and some of their underlying causes in both prosperous and poor countries has been the subject of various economic research studies for a long time. Numerous studies have examined the relationship between environmental deterioration and economic activity since the groundbreaking work of Grossman and Krueger (1991), including Wolde (2015) and Hamilton & Turton (2002).

Furthermore, a number of research have examined the relationship between economic activity, environmental quality, and total energy consumption (Zakarya *et al*., 2015; Wolde *et al*., 2016; Kebede, 2017). The impact of traditional and modern energy use on environmental quality as determined by carbon dioxide emissions has also been the subject of some recent empirical studies (e.g., Jebli and Youssef, 2015).

To the best of the researchers' knowledge, however, no study has explicitly looked at how renewable energy—especially contemporary clean energy—affects the growth of green economies. This investigation aims to contribute to the existing body of knowledge and the ongoing debate on environmental issues by employing the Autoregressive Distributed Lag (ARDL) model, a recently developed co-integration method, to analyze this relationship.

2 Research question

The following research question guides this study:

- Does moving the country's energy consumption structure toward modern clean energy actually help the country accomplish the goal of the Climate Resilient Green Economy (CRGE) plan by preserving environmental quality?

- Does shifting the nation's energy consumption structure to modern clean energy genuinely help it achieve the Climate Resilient Green Economy (CRGE) strategy's objective of increasing output?

- Which source of energy has the most effect on Ethiopia's environmental quality and economic growth?

3 The study Approach

3.1 Data sources and types

The study used annual time series data covering 32 years, from 1990 to 2022, to examine the impact of renewable energy, especially contemporary clean energy consumption, on Ethiopia's green economic development. This period of time was chosen to guarantee the availability of pertinent data for the study.

The Environmental, Forest, and Climate Change Commission of Ethiopia (EFCCC), World Development Indicators (World Bank), Global Carbon Atlas (GCA), and the International Energy Agency (IEA) were the sources of the data.

3.2 Model specification

Model One: In their empirical analyses, some empirical studies in economic literature often used carbon dioxide emission as a primary indicator of environmental quality (Kebede, 2017; Oh and Bhuyan, 2018). They utilized it as an essential environmental quality indicator based on the three criteria listed below. To begin with, it is the primary type of gas that results from activities associated with energy. Second, it is a predominant greenhouse gas found throughout the planet's atmosphere and is responsible for approximately 75 percent of worldwide pollution. Third, it is being minimized in order to benefit the environment. Following the preceding studies and taking into account the conditions described above, the current study additionally proxies environmental quality by carbon dioxide emission.

Several previous studies, such as Kebede (2017), Poku (2016), Wolde *et al*. (2016), Halicioglu (2009), and Oh and Bhuyan (2018), have included economic growth and energy use indicators in their modeling approaches to investigate the implications of these factors on carbon dioxide emissions. These factors were found to be relevant and to affect carbon dioxide emissions in a statistically significant way.

Following the precedent set by prior research, the current study employs an environmental quality model proxied by carbon dioxide emissions, with energy consumption considered as a determining factor, in order to assess the environmental impact of modern clean energy use.

Given this, the study's model, which takes the following form, seems to be in line with the larger body of research on the factors influencing carbon dioxide emissions:

$$CO_2 = f(EC_t) \tag{1}$$

Where CO_2 = carbon dioxide emission at year t and is a proxy for environmental quality, EC_t = total energy consumption at a year t.

Nevertheless, the current study's objective is not entirely in line with this generic model. The energy consumption variable in the aforementioned model needs to be further broken down because the goal of this study is to investigate how the current use of clean energy affects environmental quality as assessed by carbon dioxide emissions.

Specifically, the energy use variable (ECt) in Equation (1) should be subdivided into three components: modern clean energy use (MCEt), non-renewable energy use (NREt), and biomass energy use (BEt). This disaggregation will provide a clearer policy context and better align with the study's goal.

Additionally, other relevant factors, such as economic and demographic variables (e.g., population growth, urbanization, economic growth), can be included to more comprehensively describe the environmental quality model in the context of Ethiopia.

Therefore, the following reduced-form model is suggested to evaluate the variables of interest's possible environmental impact:

$$CO_2 = f(MCE_t, NRE_t, BE_t, GDPP_t, POP_t, UPG_t) \tag{2}$$

Where MCE_t stands for modern clean energy consumption at period t, NRE_t stands for non-renewable energy consumption at period t, BE_t stands for biomass energy consumption at period t, $GDPP_t$ stands for output per capita at period t, POP_t stands population at period t, and UPG_t stands for urbanization at period t.

Equation (2) indicates that Ethiopia's real GDP per capita, population, urbanization, use of contemporary clean energy, non-renewable energy, and biomass energy can all be environmental drivers.

Model Two: The current investigation utilized the augmented Solow model and the endogenous growth framework to assess the growth implications of renewable energy, particularly modern clean energy. The GDP growth equation was specified based on the theoretical underpinnings of the Solow (1956) and endogenous growth models, which can be summarized as follows:

$$Y = f(K, HK, LF, A) \tag{3}$$

Where Y stands for economic growth, K stands for Capital stock, HK stands for human capital, LF stands for labor force, and A stands for technology.

To determine whether the shift in the energy consumption structure toward modern clean renewable energy contributes to the country's economic growth, the current study employed an augmented Solow model and an endogenous growth model. In these models, modern clean energy consumption (MCE) is included as an input alongside capital stock (K) and human capital (HK). Other energy variables, such as non-renewable energy use (NRE) and biomass energy consumption (BE), are also taken into account.

In order to reduce the possibility of omitted variable bias and examine their relative effects on the nation's economic growth, these extra energy variables were included. Consequently, the following is the final growth model specification:

$$GDPPC_t = f(K_t, HK_t, MCE_t, NRE_t, BE_t) \tag{4}$$

Where K_t stands for capital formation at period t, HK_t stands for human capita at period t and all the remaining variables in the models are as defined above.

Lastly, all of the variables in the equations were converted into their logarithmic representations for estimation purposes. There are various advantages to this change. First, it lessens the influence of possible outliers and big coefficients, as well as the volatility in the data series. Secondly, it makes it possible to determine approximate growth rates or to capture growth effects. Elasticities are then deduced from the coefficients.

Elasticity's are particularly informative, as they represent the responsiveness of the dependent variable to changes in the independent variables. Therefore, the empirical models of economic growth and the associated carbon dioxide emissions (in Equations (2) and (4)) can be clearly represented as follows:

$$lnCO_{2t} = \theta_0 + \theta_1 lnMCE_t + \theta_2 lnNRE_t + \theta_3 lnBE_t + \theta_4 lnGDPPC_t + \theta_5 lnPOP_t + \theta_6 lnUPG_t + e_t \quad (5)$$

$$lnGDPPC_t = \alpha_0 + \alpha_1 lnK_t + \alpha_2 lnHK_t + \alpha_3 lnMCE_t + \alpha_4 lnNRE_t + \alpha_5 lnBE_t + e_t \quad (6)$$

Where *ln*= is natural logarithm, e_t = is disturbance term, θ_s and α_s in equation (5) and (6), respectively are elasticities. All variables in the models are as defined above.

3.3 Method of Estimation

As carried out earlier by Kamran *et al.* (2020) and Jebli and Youssef (2015b), the current study relied on the bound testing procedure recommended by Pesaran *et al.* (2001) to assess both the short-term and long-term implications of each of the independent variables on both environmental quality and economic growth. Compared to other common time series data models, the ARDL model, which is based on the bound co-integration technique, is preferred as it can be applied regardless of whether the regressors are I(1) or I(0). The following equations describe the ARDL Bound testing approach:

$$\Delta lnCO_{2t} = \theta_0 + \theta_1 lnMCE_{t-1} + \theta_2 lnNRE_{t-1} + \theta_3 lnBE_{t-1} + \theta_4 lnGDPPC_{t-1} + \theta_5 lnPOP_{t-1} + \theta_6 lnUPG_{t-1} + \sum_{j=1}^{n} \beta_{1j} \Delta lnCO_{t-j} + \sum_{j=1}^{n} \beta_{2j} \Delta lnMCE_{t-j} + \sum_{j=1}^{n} \beta_{3j} \Delta lnNRE_{t-j} + \sum_{j=1}^{n} \beta_{4j} \Delta lnBE_{t-j} + \sum_{j=1}^{n} \beta_{5j} \Delta lnGDPPC_{t-j} + \sum_{j=1}^{n} \beta_{6j} \Delta lnPOP_{t-j} + \sum_{j=1}^{n} \beta_{7j} \Delta lnUPG_{t-j} + U_t \quad (7)$$

$$\Delta lnGDPPC_t = \alpha_0 + \alpha_1 lnK_{t-1} + \alpha_2 lnHK_{t-1} + \alpha_3 lnMCE_{t-1} + \alpha_4 lnNRE_{t-1} + \alpha_5 lnBE_{t-1} + \sum_{j=1}^{n} \beta_{1j} \Delta lnGDP_{t-j} + \sum_{j=1}^{n} \beta_{2j} \Delta lnK_{t-j} + \sum_{j=1}^{n} \beta_{2j} \Delta lnMCE_{t-j} + \sum_{j=1}^{n} \beta_{3j} \Delta lnHK_{t-j} + \sum_{j=1}^{n} \beta_{4j} \Delta lnNRE_{t-j} + \sum_{j=1}^{n} \beta_{5j} \Delta lnBE_{t-j} + U_t \quad (8)$$

β_s captures the short-term elasticities of growth and environmental quality with respect to their respective determinant variables. The ongoing link between the model variables is represented by the coefficients θ_s and α_s in equations (7) and (8), respectively. n is the length of the model variables' lag, and Δ implies the difference operation.

3.4 Estimation procedure

Finding out whether the variables under investigation have a long-term relationship is the main objective of this analysis. In order to do this, the researchers have assessed the order of integration of each variable using unit root tests, such as the Phillips-Perron and Augmented Dickey-Fuller tests. This enables them to calculate the number of times a variable must be differentiated in order to reach stationarity. The researchers can proceed with regression analysis to provide accurate forecasts and conduct policy research after the variables have been confirmed to be stationary.

Following the completion of the stationarity tests, the Bound test was utilized to determine if the variables exhibit a long-term co-integrating relationship. Furthermore, the researchers conducted several model diagnostic tests to verify the precision and stability of the final model. These tests encompass the functional form test, normality test, serial correlation test, and heteroscedasticity test. Additionally, the CUSUM and CUSUMSQ tests were employed to evaluate the model's robustness and stability over time.

4 Results and Discussions

4.1 Environmental Quality Equation of Ethiopia

To tackle the problem of spurious regression in the assessment of co-integration within time-series data, it is essential to accurately assess the stationarity of the foundational data series. The application of least squares regression to non-stationary, independent datasets often lead to spurious regression. In these instances, despite the lack of a true relationship between the series, a misleadingly significant statistical connection may be incorrectly identified. This can lead to conclusions about the behavior of the indicators at a specific point in time, without accurately capturing the trends over the years under consideration.

Evaluating the stationarity of the variables is a fundamental task in time series analysis. It is recommended to thoroughly investigate whether the data are stationary or non-stationary. Pre-estimation tests, such as unit root and co-integration tests, should be performed and discussed before estimating and interpreting the study's specified environmental quality equation. Both post-estimation tests and the corresponding findings should then be presented.

4.1.1 Unit root test

Regardless of whether the variables are I (0) or I (1) integrated, the ARDL (Autoregressive Distributed Lag) specification can be formed after it is determined that the model variables are integrated of order less than two. However, it would not be suitable to use the ARDL specification when there are I (2) or higher integrated variables.

In order to ascertain the indicators' integration order, this study employed the conventional Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. The Schwarz Bayesian Information Criterion (SBIC) was used to automatically determine the ideal lag times for the experiments. The comparison of the test statistics to the critical values and the corresponding p-values determined whether the null hypothesis of the unit root tests, which suggests the non-stationarity of the series, was accepted or rejected.

Table 1. Unit Root Tests of the Environmental Quality Equation Variables

Variables	Augmented Dickey-Fuller (ADF) and Phillps Perron (PP) Test		
	ADF T-statistics	PP T-statistics	Decision
lnCO_2	0.4329	1.2184	I(1)
D(lnCO_2)	-5.7547***	-6.3754***	
lnCME	1.4644	1.5766	I(1)
D(lnCME)	-3.6920***	-3.8130***	
lnBE	-4.1908***	-8.3005***	I(0)
lnNRE	0.7038	0.8192	I(1)
D(lnNRE)	-4.7582***	-4.7582***	
lnGDPPC	2.009	1.7511	I(1)
D(lnGDPPC)	-4.1557***	-4.2076***	
lnPOP	-5.1324***	-4.3126***	I(0)
UPG	-1.5339	-1.7098	I(1)
D(UPG)	-3.9769***	-3.9698***	

Note: triple stars in the table indicates significance of the test statistics, indicating rejection of the null hypothesis at a 1% level of significance. (Source: own computation using EViews 9.0)

The environmental quality model includes indicators with an integration order of fewer than two, according to the unit root test findings. This meets the prerequisite for applying Pesaran, Shin, and Smith's (2001) bounds testing technique to cointegration. As a result, the ARDL (Autoregressive Distributed Lag) model can be used to evaluate the long-term relationships between the variables in question.

4.1.2 Bound Co-integration Testing of Environmental Quality Equation

The establishment of the integration order is the foundation for assessing the long-run associations between the model indicators. The unit root tests reveal that the series under investigation in the environmental model are a mix of I(0) and I(1) integrated variables.

Given the mixed integration order of the variables, the long-run association between the model indicators has been examined using the bounds testing approach to co-integration.

Table 2 presents the results of the bounds testing procedure conducted on the environmental model. The F-statistic obtained from the test is highly significant, with a value of 9.518193. This F-statistic exceeds the upper bound or I (1) critical values at the 5% level of significance, suggesting the rejection of the null hypothesis of no long-run association among the model indicators, such as carbon dioxide emissions, modern clean energy, biomass energy, non-renewable energy, real GDP per capita, population, and urbanization. This indicates that changes in one variable will have a lasting impact on the others, and vice versa.

Table 2. Bounds Testing for the Environmental Quality Equation

ARDL bounds testing result		
Null-hypothesis: No long-run association among the model variables		
Test-statistics	Value	K
F-statistics	9.518193	6
Critical value bounds		
Significance	I0 Bound	I1 Bound
1 percent	3.15	4.43
2.5 percent	2.75	3.99
5 percent	2.45	3.61
10 percent	2.12	3.23

(Source: own computation using EViews 9.0)

4.1.3 Bound Co-integration Testing of Environmental Quality Equation

Before interpreting the long and short-run elasticities of the environmental quality model, model diagnostic tests like the Breusch Godfrey LM test for serial correlation, the Breusch-Pagan-Godfrey test for heteroscedasticity, the Ramsey Reset test for functional misspecification in the model, and the Jarque-Bera test for normality of the error term were used to ensure the validity and reliability of the estimation. The tests' null hypothesis suggests that the estimations are accurate and legitimate.

Table 3. Model Diagnostics Testing for Environmental Quality Equation

Tests	Method	√F-statistics √Jarque-Bera for normality	P-value
Seral correlation	Breusch Godfrey LM	0.9388	0.4144
Heteroscedasticity	Breusch-Pagan Godfrey	0.8621	0.5897
Functional form	Ramsey Reset	1.0858	0.3139
Normality	Jarque-Bera	3.3839	0.1841

(Sources: own computation using EViews 9.0)

The model diagnostic assessments are provided in Table 3 below. Since the probability values of the tests all exceed the 5% significance level, the null hypotheses of the diagnostic tests cannot be rejected. This indicates that the model is trustworthy for generating predictions and drawing inferences, and there are no econometric issues with the established coefficients.

4.1.4 Model Stability Testing of Environmental Quality Equation

The stability of the long-run coefficients in the environmental quality model has been assessed by employing the CUSUM (Cumulative Sum) and CUSUMSQ (Cumulative Sum of Squares) tests.

Plots of the test statistics at the 5% level of significance can be compared to the critical boundaries to make the assessment. The null hypothesis of coefficient stability may be accepted if the graphs stay inside the crucial boundaries.

The plots of the CUSUM and CUSUMSQ statistics were inside the critical boundaries at the 5% significance level during the time under review, as Appendix A demonstrates. This demonstrates that the calculated coefficients in the environmental quality model are stable.

4.1.5 Long-run and Short-run Estimates of Environmental Quality Equation

Next to the assessment of the integration order of the series, long-run association, model diagnostics, and model stability, the dynamic long-run and short-run coefficients of the ARDL (1, 0, 0, 0, 2, 2, 0) model were evaluated and interpreted.

The estimated coefficients, standard errors, t-values, and probability values from the environmental quality model estimation are shown in Table 4.

Table 4. Long-run and Short-run Estimates of the Environmental Quality Equation

Method: ARDL **Model selected: ARDL (1, 0, 0, 0, 2, 2, 0)**				
Long-run coefficients				
Variables	Coefficients	Standard error	t-statistics	P-values
lnMCE	-0.234596	0.114716	-2.045020	0.0577*
lnBE	4.395273	1.508174	2.914300	0.0101**
lnNRE	0.185574	0.081717	2.270945	0.0373**
lnGDPPC	0.346595	0.227844	1.521196	0.1477
lnPOP	-1.709507	1.287249	-1.328031	0.2028
UPG	-0.018869	0.025934	-0.727606	0.4774
C	-53.570706	14.338129	-3.736241	0.0018***
Short-run coefficients				
D(lnMCE)	-0.295155	0.141650	-2.083690	0.0536*
D(lnBE)	5.529874	1.696130	3.260289	0.0049***
D(lnNRE)	0.233478	0.109226	2.137567	0.0483**
D(lnGDPPC)	0.253128	0.357718	0.707619	0.4894
D(lnGDPPC(-1))	0.546840	0.210915	2.592700	0.0196**
D(lnPOP)	4.116509	1.875618	2.194748	0.0433**
D(lnPOP(-1))	7.470220	2.132907	3.502365	0.0029***
D(UPG)	-0.023740	0.033058	-0.718146	0.4830
ECM-1	-1.258141	0.135778	-9.266194	0.0000***

Note: ***, **, and * indicate statistical significance of the coefficients at 1%, 5,%, and 10% levels of significance, respectively. (Sources: own estimation using Eviews 9.0)

The environmental quality model's results indicate that the long-term elasticity of carbon dioxide emissions in relation to contemporary renewable energy is -0.234596. This shows that a 1% increase in the use of contemporary clean energy will result in a 0.234596% reduction in carbon dioxide emissions in the nation under investigation, assuming all other factors stay the same. This inverse relationship between the two variables is important for policymakers and researchers to understand, as it can inform decisions about energy and environmental policies. The result is in line with previous empirical research. For instance, Adinew M. (2020) supported the findings of the environmental quality model by discovering a statistically significant negative correlation between the use of renewable energy and anthropogenic carbon dioxide emissions in Ethiopia.

Additionally, the finding aligns with other previously conducted empirical works, such as Asongu *et al.* (2019) for 40 African countries, Heryadi and Hartono (2017) for a panel of G-20 countries, Zandi and Haseeb (2019) for Sub-Saharan African countries, and Shafiei (2013) and Khan *et al.* (2021) for developing countries. Additionally, Uğurlu (2022) discovered that the Visegrad Group countries—Poland, the Czech Republic, Hungary, and Slovakia—saw a declining impact of renewable energy use on CO2 emissions.

These empirical studies provide good evidence that investing in modern clean energy can have a significant positive contribution to the environment by limiting the concentration of carbon dioxide emissions.

Given the inverse relationship between modern renewable energy usage and carbon dioxide emissions, expanding the output of modern clean energy can have a positive impact on Ethiopia's environmental quality by limiting the concentration of carbon dioxide in the atmosphere. However, this expansion requires significant investment, which may be challenging for the country.

Nonetheless, the potential advantages of curtailing carbon dioxide emissions and enhancing environmental quality render this investment valuable. Consequently, it is essential for policymakers and stakeholders to collaborate in identifying strategies that promote the adoption of modern clean energy while decreasing dependence on fossil fuels. This may entail the implementation of policies and incentives aimed at fostering investment in contemporary clean energy, in addition to raising public awareness regarding the benefits of minimizing carbon dioxide emissions.

The long-term findings also imply that using more biomass and non-renewable energy sources will increase greenhouse gas emissions and raise carbon dioxide levels. It is determined that the long-run elasticity of carbon dioxide emissions is 0.185574 for non-renewable energy and 4.395273 for biomass energy. This means that a 1% change in these energy sources' consumption will result in variations in carbon dioxide emissions of 4.395273% and 0.185574%, respectively.

Given that biomass energy makes up almost 90% of Ethiopia's total energy composition, the significant impact of biomass energy use on human-induced carbon dioxide emissions is astounding (UNECA, 2014). One of the main causes of the nation's rising carbon dioxide emissions is its significant reliance on wood, wood-derived fuels, and biomass waste consumption—all of which are categorized as primary and environmentally harmful energy sources.

The findings corroborate the results of a study carried out by Brini (2021) for a panel of African nations, which observed a positive and statistically significant relationship between non-renewable energy use and carbon dioxide emissions. This suggests that non-renewable energy use is a significant contributing factor to the increased anthropogenic carbon dioxide emissions in the country under study.

According to the environmental quality model, over the long term, the concentration of anthropogenic emissions in a country is found to be independent of both demographic factors like population and urbanization, as well as macroeconomic factors like real gross domestic product per capita.

Referring back to the defined ARDL (1, 0, 0, 0, 2, 2, 0) model's short-run outcomes, the coefficients of present clean energy, biomass energy, and non-renewable energy use support the long-run case. But when it comes to the use of contemporary renewable energy, the short-term flexibility of carbon dioxide emissions is greater than the long-term elasticity. This suggests that the country should put more effort into deploying modern clean energy to boost the long-term elasticity and further reduce carbon dioxide emissions.

The short-run environmental effect of lagged economic growth and population in Ethiopia was found to be significant and positive across the study period. Carbon dioxide emissions have a short-run elasticity of 0.546840 and 4.116509 with respect to lagged output growth and population, respectively. This means a 1% change in lagged output and population induces a 0.546840% and 4.116509% change in carbon dioxide emissions, respectively, when all other factors remain constant.

This suggests that output growth, population, and carbon emissions are directly correlated in the short term. Interestingly, the effect of output growth is outweighed by the elasticity of carbon dioxide emissions with respect to population, suggesting that population size contributes more to environmental deterioration than economic growth. This result is in line with Shafiei's (2013) earlier research findings.

There is little indication that economic growth and carbon dioxide emissions will soon decouple because the short-run output growth elasticity of carbon dioxide emissions is positive. However, a long-term decoupling may be shown by the long-term negligible impact of economic growth on environmental quality.

Interestingly, the study also found that the urbanization variable does not affect carbon dioxide emissions in the short or long run, which raises questions for future research to explore this dynamic further.

Economic Growth Equation of Ethiopia

To answer the second research question, the study also assessed an economic growth model, in addition to the environmental quality model investigation. Prior to estimating and discussing the specified economic growth equation, the researchers conducted pre-estimation tests such as unit root and co-integration analyses, just as they had done for the environmental quality model analysis.

4.1.6 Unit Root Testing

Table 5 below displays the indicators' stationarity behavior in the economic growth model. All indicators, with the exception of biomass energy use, are stationary at their first difference, according to the test results. This result made the ARDL model suitable for long-term co-integration analysis between the variables in the economic growth model.

Table 5. Unit Root Testing of the Economic Growth Equation variables

Variables	Augmented Dickey Fuller (ADF) and Phillps Perron (PP) Test		
	ADF T-statistics	PP T-statistics	Decision
lnCME	1.4644	1.5766	I(1)
D(lnCME)	-3.6920***	-3.8130***	
lnBE	-4.1908***	-8.3005***	I(0)
lnNRE	0.7038	0.8192	I(1)
D(lnNRE)	-4.7582***	-4.7582***	
lnGDPPC	2.009	1.7511	I(1)
D(lnGDPPC)	-4.1557***	-4.2076***	
lnK	-0.7791	-1.1817	I(1)
D(lnK)	-4.2336***	-7.5448***	
lnHK)	-0.4070	-0.1449	I(1)
D(lnHK)	-4.6299***	-4.6299***	

Note: *** indicate the significance of the test statistics at 1% level of significance.
(Sources: Own Estimation using Eviews 9.0)

4.1.7 Bound Co-integration Testing of Economic Growth Equation

After the stationarity aspects of the variables under inquiry have been established, the long-run association or co-integration between the model's indicators is investigated, much like the environmental quality model investigation. The growth model's long-run association outcome is shown in Table 6.

The table reveals that the F-statistic (5.619849) is highly statistically significant, indicating the presence of a long-run relationship among the variables in the economic growth model. This means the alternative hypothesis of long-run co-integration among the indicators is not rejected.

Table 6. Bounds Testing of the Economic Growth Equation

ARDL bounds testing result		
Null-hypothesis: No long run association among the model variables		
Test-statistics	Value	K
F-statistics	5.619849	5
Critical value bounds		
Significance	I0 Bound	I1 Bound
1 percent	3.41	4.68
2.5 percent	2.96	4.18
5 percent	2.62	3.79
10 percent	2.26	3.35

(Sources: own computation using EViews 9.0)

4.1.8 Model Diagnostic Testing of Economic Growth Equation

Before analyzing the long- and short-term elasticities of the economic growth equation, the model is first subjected to diagnostic tests.

Table 7 reveals the output of the diagnostic tests, and the test statistics cannot reject the null hypotheses presented for each test. This indicates that the diagnostic tests for serial correlation, heteroscedasticity, the Jarque-Bera test for normality, and functional form all show that the computed coefficients are independent of econometric issues, thus validating the overall findings of the study.

Table 7. Model Diagnostics Testing of Economic Growth Equation

Tests	Method	√F-statistics √Jarque-Bera for normality	P-value
Seral correlation	Breusch Godfrey LM	1.2046	0.3217
Heteroscedasticity	Breusch-Pagan Godfrey	0.3983	0.8926
Functional form	Ramsey Reset	2.7510	0.1128
Normality	Jarque-Bera	3.9055	0.1418

(Sources: own computation using EViews 9.0)

4.1.9 Model Stability Testing of Economic Growth Equation

As indicated in Appendix B, the stability test of the long-run coefficient of the economic growth model revealed the stability of the long-run coefficients, implying that they cannot affected by any significant changes over time.

4.1.10 Long-run and Short-run Estimates of Economic Growth Equation

Table 8 below depicts the long- and short-term elasticities of economic growth with respect to its explanatory variables.

Table 8. Long and Short-run Elasticities of the Economic Growth Equation

Dependent variable: Real gross domestic product per capita Model selected: ARDL (1, 0, 0, 1, 0, 0) Long-run coefficients				
Variables	Coefficients	Standard error	t-statistics	P-values
lnMCE	0.503853	0.115261	4.371429	0.0003***
lnBE	0.241128	0.425655	0.566486	0.5771
lnNRE	-0.104305	0.129726	-0.804045	0.4304
lnK	-0.142698	0.150111	-0.950616	0.3526
lnHK	0.063585	0.076620	0.829883	0.4159
C	-1.075321	4.789449	-0.224519	0.8245
Short-run coefficients				
D(lnMCE)	0.194435	0.075256	2.583669	0.0173**
D(lnBE)	0.093050	0.152194	0.611393	0.5475
D(lnNRE)	0.113614	0.060215	1.886797	0.0731*
D(lnK)	-0.055067	0.065944	-0.835051	0.4131
D(lnHK)	0.024537	0.032319	0.759230	0.4562
ECM-1	-0.385897	0.122787	-3.142806	0.0049***

Note: ***, **, and * statistical significance of the coefficients at 1%, 5%, and 10% levels of significance, respectively. (Sources: own computation using EViews 9.0)

The modern clean energy elasticity of economic growth is positive and statistically significant, amounting to 0.503853. This indicates a direct association between output growth and modern clean energy use. Specifically, if all other factors remain constant, a 1 percent increase in modern clean energy use would translate into a 0.503853 percent increase in output in Ethiopia. This result corroborates the findings of previous studies, such as Neuhaus (2016), Shafiei (2013), Pearson (2021), Soava *et al.* (2018), Bhattacharya *et al.* (2016), and Bozkurt & Destek (2015), which found that increasing modern clean energy use helps to raise a country's output growth over time.

Additional studies by Shahbaz *et al.* (2020) for a panel of 38 nations that consumed renewable energy between 1990 and 2018 and Apergis and Danuletiu (2014) for a panel of 80 countries also revealed results that demonstrated the significance of renewable energy for economic growth. Investing in renewables is essential to make economic growth sustainable, and economic growth is also very important for renewable energy investment, as these two variables are complementary. A nation can switch from conventional to modern clean energy when there is economic growth to meet the needed funds for renewables investment.

All other factors, however, are found to have negligible short-term effects on output growth. Ethiopia's output growth may be statistically explained by the short-run elasticity of output growth for modern clean energy and non-renewable energy use, which are 0.194435 and 0.113614, respectively. When all parameters are held equal, a 1 percent rise in modern clean energy and non-renewable energy use results in a 0.194435 percent and 0.113614 percent increase in Ethiopia's growth, respectively.

5 Conclusion and Recommendation

5.1 Conclusion

The study's findings suggest that non-renewable energy, as measured by gasoline, and biomass energy consumption have a negative environmental impact in Ethiopia in the medium and long term. These two energy sources are the primary cause of increased carbon dioxide emissions in the country. The study suggests that the large share of unclean or environmentally unfriendly energy in the total energy consumption mix and limited penetration of clean energy in Ethiopia may explain the detrimental impact of these energy sources on environmental quality.

These findings highlight the need for policymakers and stakeholders in Ethiopia to prioritize the adoption of clean energy sources to reduce carbon dioxide emissions and promote sustainable economic growth.

The study's conclusions indicate that modern clean energy sources like solar, wind, and hydroelectric electricity have a major and favorable impact on Ethiopia's environment. This indicates that these energy sources are essential for enhancing environmental quality by decreasing the anthropogenic levels of carbon dioxide emissions. The study recommends that policymakers and stakeholders in Ethiopia should focus on the implementation of modern clean energy sources to foster sustainable economic growth and mitigate carbon dioxide emissions.

From the economic growth model presented in the study, the utilization of modern clean energy has a statistically significant positive effect on Ethiopia's economic growth in both the short term and the long term. This is attributed to its ability to increase output and support sustainable economic development. Conversely, the use of non-renewable and biomass energy does not significantly contribute to the explanation of the country's economic growth. These findings further imply that policymakers and stakeholders in Ethiopia should prioritize the adoption of modern clean energy sources to encourage sustainable economic growth and development.

5.2 Recommendations

According to the findings of the study, contemporary clean energy plays a crucial role in fostering both economic development and environmental quality in Ethiopia. The research indicates that alternative modern clean energy sources could serve as a viable solution to the challenges posed by climate change, without jeopardizing Ethiopia's economic progress. These results underscore the significance of modern clean energy in the advancement of Ethiopia's green economy. By emphasizing the integration of modern clean energy sources, policymakers and stakeholders in Ethiopia can facilitate sustainable economic growth and development while simultaneously tackling environmental issues.

As a result, governments should implement effective support policies to encourage investment in modern clean energy capacity to achieve sustainable growth of clean energy use. The government should prioritize the development of environmentally friendly energy sources by increasing investment capital in modern clean energy for long-term green economy development. In Ethiopia, there is a need to invest more in greener energy choices such as wind, solar, and hydro. Ethiopia faces potential challenges in spreading renewable energy technologies and developing modern renewable energy sources. These challenges include high initial investment and development costs, user awareness issues, institutional and capacity issues, and international and regional challenges in developing hydro and other resources. To address these difficulties and improve the energy consumption structure, the national and local governments must coordinate and implement effective mechanisms. This will require devising strategies to increase user awareness, building institutional and capacity frameworks, and addressing international and regional challenges. There is a necessity for robust collaboration among the nation's policymakers, government entities, and international cooperation organizations to enhance investments in modern clean energy, with the goal of ensuring that future development is both environmentally and economically sustainable. By addressing these challenges, Ethiopia can foster sustainable economic growth and development while simultaneously tackling environmental issues.

Acknowledgments

We thank the Office for Research, Publication, Ethics and Dissemination Directorate, Dilla University, for funding this research.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Adinew, M. (2020). The Relationship Between Renewable Energy Consumption, Economic Growth and Carbon Dioxide Emissions in Ethiopia: Empirical Evidence from ARDL Bound Testing

Model.

Alam, Md, M., Md, Wahid, M. Abu, H., Md, N. & Ilhan, O. (2016). Relationships among carbon emissions, economic growth, energy consumption, and population growth: Testing Environmental Kuznets Curve hypothesis for Brazil, China, India, and Indonesia. *Ecological Indicators*, 70: 466-479.

Apergis, N. & Danuletiu, D.C. (2014). Renewable energy and economic growth: Evidence from the sign of panel long-run causality. *International Journal of Energy Economics and Policy*, 4(4): 578-587.

Ghassan, El, M. & Hassen, T. (2016). Testing the relationships between energy consumption, CO_2 emissions and economic growth in 24 African countries: a panel- ARDL approach, https://www.doi.org/10.1007/s11356-015-5883-7.

Bozkurt, C. & Destek, M.A. (2015). Renewable energy and sustainable development nexus in selected OECD countries. *International Journal of Energy Economics and Policy*, 5(2): 507-514.

Bhattacharya, M., Paramati, S.R., Ozturk, I., & Bhattacharya, S. (2016). The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. *Applied Energy*, 162: 733-741.

Brini, R. (2021). Renewable and non-renewable electricity consumption, economic growth and climate change: Evidence from a panel of selected African countries. *Energy*, 223, 120064.

FDRE (2011). Federal Democratic Republic of Ethiopia: Climate Resilient Green Economy: Green Economy Strategy. Addis Ababa, Ethiopia.

Grossman, G, M. & Krueger A, B. (1991). Environmental impacts of A North American Free Trade Agreement. NBER Working Paper series. No. 3914.

Haicioglu, F. (2009). An econometric study of carbon emissions, energy consumption, income and foreign trade in Turkey. *Energy policy*, 37: 1156-1164.

Hamilton. C. & Turton, H. (2002). Determinants of emissions growth in OECD countries. *Energy policy*, 30: 63-71 .

Heryadi, M. D. & Hartono, D. (2017). Energy efficiency, utilization of renewable energies, and carbon dioxide emission: case study of G20 countries. *International Energy Journal*, 16(4). IEA (2020). International energy agency, Global energy and CO_2 emissions status report.

Jebli MB, Youssef SB (2015). The environmental Kuznets curve, economic growth, renewable and non-renewable energy, and trade in Tunisia. *Renew Sust Energ Rev*. 47:173–185.

Kamran, M.M., Muhammad, I.K., & Mummed, R. (2020). The relationship between energy consumption, economic growth and carbon dioxide emission in Pakistan. *Financial innovation*.

Kebede, S. (2017). Modeling energy consumption, CO_2 emissions and economic growth nexus in Ethiopia: evidence from ARDL approach to co-integration and causality analysis. MRPA paper, No. 83000.

Kulionis, V. (2013). The relationship between renewable energy consumption, CO_2 emissions and economic growth in Denmark. School of Economics and Management, Lund University.

Narayan, P.K. (2005). The saving and investment nexus for China: evidence from co-integration tests. *Applied Economics*, 37(17): 1979-1990.

Neuhaus, L. (2016). Examining the renewable energy consumption-economic growth nexus in sub-Saharan African countries.

Mahmood, H. & Chaudhary, A.R. (2012). FDI, population density and carbon dioxide emissions: A case study of Pakistan. *Iranica Journal of energy and environment*, 3(4): 356-360.

Ministry of Water and Energy (2012). Federal Democratic Republic of Ethiopia, Scaling - Up Renewable Energy Program. Ethiopia Investment Plan.

Oh, Y.K & Bhuyan, I.M. (2018). Trade openness and carbon dioxide emissions: Evidence from Bangladesh. *Asian Journal of atmospheric environment*, 12(1): 30-36.

(2021). The Effect of Renewable Energy Consumption on Economic Growth in Croatia. *Zagreb International Review of Economics & Business*, 24(1),:113-126.

Pesaran, M. H & Shin, Y. (1999). "An Autoregressive Distributed Lag Modeling Approach to Cointegration" in Econometrics and Economic Theory in the 20th Century. The Ragnar Frisch Centennial Symposium, Cambridge University Press, Chapter. 4, 371-413.

Pesaran, M.H., Shin, Y., & Smith, R.J. (2001). Bounds testing approaches to the analysis of level relationships. *J Appl Econ*, 16(3): 289–326.

Poku, A. F (2016). Carbon dioxide emissions, urbanization, and population: Empirical evidence in Sub-Saharan Africa. Energy economics letters, 3(1): 1-16

Romer, D. (1996). "The Solow growth model", Advanced Macroeconomics, McGraw-Hill, pp. 5 140.

Shafiei, S. (2013). Economic growth, energy consumption, and environment: assessing evidence from OECD countries (Doctoral dissertation, Curtin University).

Shahbaz, M., Raghutla, C., Chittedi, K. R., Jiao, Z., & Vo, X. V. (2020). The effect of renewable energy consumption on economic growth: Evidence from the renewable energy country attractive index. *Energy*, 207, 118162.

Soava, G., Mehedintu, A., Sterpu, M., & Raduteanu, M. (2018). Impact of renewable energy consumption on economic growth: Evidence from European Union countries. *Technological and Economic Development of Economy*, 24(3): 914-932.

Solow, R. (1956), A contribution to the theory of economic growth, *The Quarterly Journal of Economics*, 70(1): 65-94.

Teka, G. N, Ta, T.H, Izhar, H.S and Hung-Suck, P (2020). Determinants of energy-based CO_2 emission in Ethiopia: A decomposition analysis from 1990 to 2017. *Sustainability*, 12, 4175: https://www.doi.org/10.3390/su12104175.

Uğurlu, E. (2022). Impacts of Renewable Energy on CO Emission: Evidence from the Visegrad Group Countries. *Politics in Central Europe*, 18(2): 295-315.

Wolde, E. T. (2015). Economic growth and environmental degradation in Ethiopia: An environmental Kuznets curve analysis approach. *Journal of Economics and International Finance*, 7(4): 72-79.

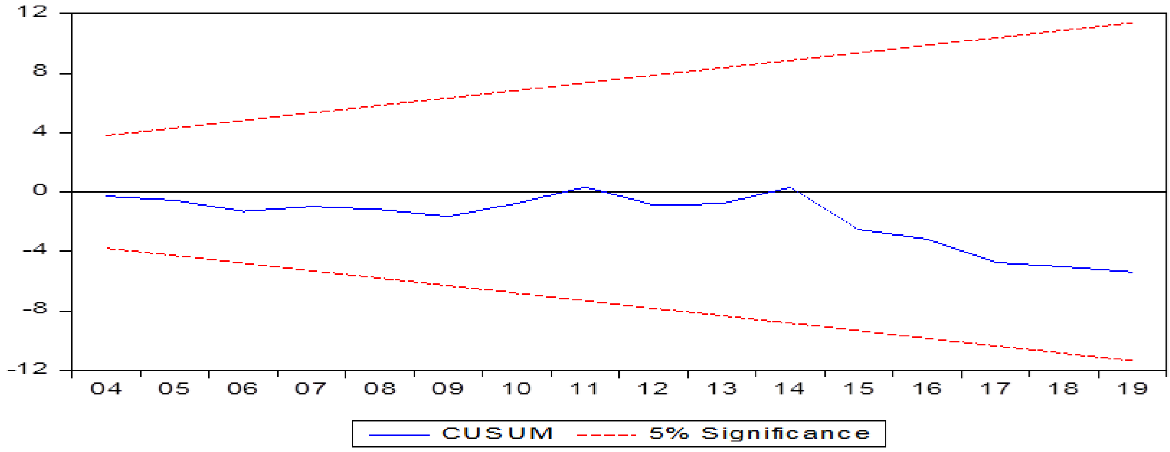
Wolde, E. T. Wendaferahu, M. & Muhadin, M, H. (2016). Energy consumption, carbon dioxide emissions, and economic growth in Ethiopia. *Global Journal of Management and Business Research Economic and Commerce*, 16, online ISSN: 2249-4588 and print ISSN: 0975-5853.

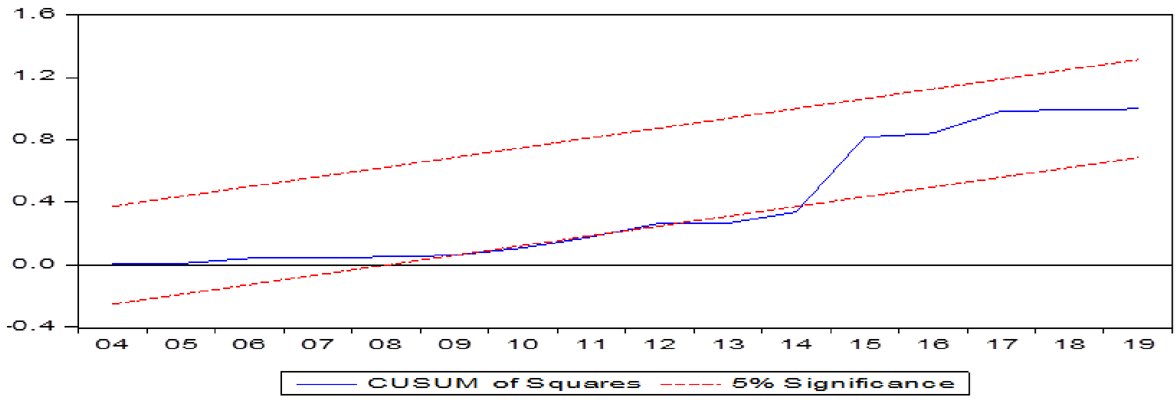
Zakarya, Y.G, Belmokaddem, M, Sahraou, M. A and Gueuil, M. S (2015). Factors affecting carbon dioxide emissions in the BRICS countries: A panel data analysis. *Procedia economics and finance*, 26: 114-125.

Zandi, G., & Haseeb, M. (2019). The importance of green energy consumption and agriculture in reducing environmental degradation: Evidence from sub-Saharan African countries. *International Journal of Financial Research*, 10(5): 215-227.

Appendices

Appendix A: Plot of cumulative sum and cumulative sum of square testing of Environmental Quality Equation





Appendix B: Plot of cumulative sum and cumulative sum of square testing of Economic Growth Equation