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

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Abstract
Currently, there is a rapidly growing interest in modern clean energy generation in Ethiopia as a means to ensure economic and environmental sustainability. However, there is still a gap in empirical research addressing how investment in modern clean energy determines the development of a green economy in Ethiopia. This study examined the implication of renewable energy on green economy development in Ethiopia, specifically focusing on the relationship between modern clean energy consumption, economic growth, and environmental quality from 1990 to 2022. The study utilized annual time series data from the World Development Indicators (WDI), the Global Carbon Atlas (GCA), and the International Energy Agency (IEA). The auto regressive distributed lags (ARDL) econometric estimation technique was used to analyze the data. The findings revealed that the use of non-renewable energy, biomass, and modern clean energy were significant factors in explaining the variation in carbon dioxide emissions in Ethiopia. However, only contemporary clean energy demonstrated statistical significance in explaining long-term economic growth. The results suggest that the use of green energy sources, such as hydro, wind, and solar energy, can eventually lower carbon emissions while increasing output. It is recommended that Ethiopian authorities prioritize the promotion of renewable energy sources to prevent the economy from becoming more carbon-intensive in the future. This requires strong collaboration among policymakers, the government, and international cooperation organizations to boost investment in modern clean energy and ensure environmentally and economically sustainable development.

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

1 Introduction

Ethiopia, one of the least developed nations in the world, has recently experienced a significant increase in economic output and is among the fastest-growing economies globally. According to available data, Ethiopia had a remarkable growth performance, posting an average annual growth rate of 9.3% from 2013 to 2018, which was impressive (NBE, 2020). This expansion was largely driven by rising industrialization and urbanization, which were in turn fueled by increased energy use (Teka *et al.*, 2020).

Ethiopia aims to achieve middle-income status by 2025, building on its recent record of strong economic growth. Achieving this goal will primarily depend on increasing the productivity of the agricultural sector, expanding the industrial base, and promoting growth in international trade, as outlined in the Growth and Transformation Plan (GTP) (FDRE, 2011). In other words, the desire for industrialization, especially heavy industrialization, results in more energy-intensive economic activities as the country works towards reaching middle-income status.

It is widely recognized that energy infrastructure is a crucial factor influencing a nation's economic expansion and advancement, often referred to as the lifeblood of the modern economy (Kulionis, 2013). Energy is a major production input and plays a vital role in a country's economic and social development, as it increases the productivity of other factors and improves living standards.

However, according to Kulionis (2013), the rising demand for energy to fuel economic activities also contributes to worsening environmental conditions. Excessive energy usage releases substantial amounts of carbon dioxide, which has been identified as the primary contributor to global warming and climate change.

Demand for energy has recently increased in Ethiopia in line with the country's growing industrialization and rapid demographic expansion. In other words, the country's economic and population growth have driven a significant surge in energy consumption.

According to statistics from the International Energy Agency report (2020), Ethiopia's total final energy consumption rose from 16,771 KTOE in 1990 to 40,717 KTOE in 2018, reflecting a 142.78% increase. This indicates that Ethiopia's energy demand has been rising in close correlation with the country's economic and population growth.

Despite the growing energy needs, Ethiopia's energy consumption structure is inefficient, polluting, and predominantly dominated by biomass energy sources, which account for around 88% of total consumption (MoWE, 2012). Given this energy consumption pattern, the projected increase in energy demand is likely to exacerbate the country's environmental degradation.

Recognizing these challenges, and following the advice of environmentalists and economists to shift growth targets from conventional economic expansion to more environmentally conscious and sustainable development, as stated by Alam *et al.* (2016), Ethiopia has implemented the "Climate Resilient Green Economy (CRGE)" strategy. The aim is to protect the nation from the adverse impacts of global warming and transition towards a green economy.

In this strategy, Ethiopia declares its intention to achieve middle-income status by 2025 while simultaneously preserving environmental quality (FDRE, 2011). This reflects the country's commitment to pursue economic advancement in a more sustainable manner.

Given Ethiopia's location in a tropical region and the abundance of opportunities for modern environmentally friendly energy sources, the government intends to develop clean energy, specifically hydropower, wind, geothermal, and solar power, as well as non-renewable and combustible renewables and waste. The goal is to realize Ethiopia's ambition of establishing an environmentally conscious 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.

To develop effective policies, a deeper understanding of the causal relationships between renewable energy, economic growth, and the state of the environment is necessary. 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.

For an extended period, numerous economic research studies have examined the relationship between environmental conditions and some of its root causes in both wealthy and poor nations. Since the pioneering work of Grossman and Krueger (1991), several investigations have explored the interplay between environmental degradation and economic activity (including Wolde (2015) and Hamilton & Turton (2002)).

Additionally, various studies (Zakarya *et al.*, 2015; Wolde *et al.*, 2016; Kebede, 2017) have focused on the association between environmental quality, economic activity, and overall energy consumption. Some recent empirical works have also examined the disaggregated effect of conventional and modern energy use on environmental quality, as measured by carbon dioxide emissions (e.g., Jebli and Youssef, 2015).

However, to the best of the researchers' knowledge, no study has specifically examined the impact of renewable energy, particularly modern clean energy, on green economic development. 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 moving the country's energy consumption structure toward modern clean energy actually assist it to accomplish the goal of the Climate Resilient Green Economy (CRGE) strategy by 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 analyzed the effect of renewable energy, particularly modern clean energy consumption, on green economy development in Ethiopia using annual time series data spanning 32 years, from 1990 to 2022. This time frame was selected to ensure the availability of appropriate data for the investigation.

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

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.

In light of this, the model proposed in this study, which has the following form, appears to be consistent with the broader literature on the determinants of carbon dioxide emissions:

$$CO_2 = f(EC_t) \quad (1)$$

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.

However, this generic model is not fully aligned with the goal of the current study. Since the objective of this investigation is to examine the influence of the current use of clean energy on environmental quality, as measured by carbon dioxide emissions, the energy use variable in the aforementioned model needs to be further decomposed.

Specifically, the energy use variable (EC_t) in Equation (1) should be subdivided into three components: modern clean energy use (MCE_t), non-renewable energy use (NRE_t), and biomass energy use (BE_t). 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.

As a result, the following reduced-form model is proposed to assess the potential environmental impact of the variables of interest:

$$CO_2 = f(MCE_t, NRE_t, BE_t, GDPP_t, POP_t, UPG_t) \quad (2)$$

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.

According to Equation (2), the use of modern clean energy, non-renewable energy, biomass energy, real GDP per capita, population, and urbanization can all be environmental determinants in Ethiopia.

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:

$$Y = f(K, HK, LF, A) \quad (3)$$

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.

The rationale for including these additional energy variables is to mitigate the risk of omitted variable bias and to investigate their comparative impact on the country's economic growth. As a result, the final growth model is specified as follows:

$$GDPPC_t = f(K_t, HK_t, MCE_t, NRE_t, BE_t) \quad (4)$$

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.

Finally, for estimation purposes, all the variables in the equations were transformed into their logarithmic forms. This transformation offers several benefits. First, it reduces the volatility in the data series or the impact of potential outliers and large coefficients. Second, it enables the capture of growth effects or the determination of approximate growth rates. The coefficients are then interpreted as elasticities.

Elasticities 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

The primary goal of this analysis is to determine if the variables under study have a long-term relationship. To accomplish this, the researchers have utilized unit root tests, such as the Augmented Dickey-Fuller and Phillips-Perron tests, to evaluate the order of integration of each variable. This helps them determine how many times a variable needs to be differenced to achieve stationarity. Once the variables are confirmed to be stationary, the researchers can proceed with regression analysis to make accurate forecasts and conduct policy research.

After the stationarity tests were conducted, the Bound test was employed to establish whether the variables have a long-run co-integrating relationship. Additionally, the researchers performed various model diagnostic tests to ensure the accuracy and stability of the final model. These tests include the functional form test, normality test, serial correlation test, and heteroscedasticity test. The CUSUM and CUSUMSQ tests were also used to assess the model's robustness and stability over time.

4 Results and Discussions

4.1 Environmental Quality Equation of Ethiopia

To address the issue of spurious regression in time-series data co-integration assessment, it is crucial to properly evaluate the stationarity of the underlying data series. When least squares regression is applied to non-stationary, unrelated datasets, spurious regression is a common occurrence. In such cases, even though the series are unrelated, a significant statistical relationship can be erroneously established. 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

Once the model variables are found to be integrated of order less than two, the ARDL (Autoregressive Distributed Lag) specification can be established, regardless of whether the variables are I(0) or I(1) integrated. However, employing the ARDL specification in the presence of I(2) or higher integrated variables would be inappropriate.

Therefore, this study utilized the standard Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests to determine the integration order of the indicators. The optimal lag lengths for the tests were automatically identified using the Schwarz Bayesian Information Criterion (SBIC). The acceptance or rejection of the null hypothesis of the unit root tests, which implies the non-stationarity of the series, was based on the comparison of the test statistics to the critical values and the associated p-values.

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 results of the unit root tests indicate that the environmental quality model comprises indicators with integration order of less than two. This satisfies the necessary precondition for using the bounds testing approach to cointegration, as developed by Pesaran, Shin, and Smith (2001). Accordingly, the ARDL (Autoregressive Distributed Lag) model is qualified to be employed for assessing the long-term associations among the variables under consideration.

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

To ensure the validity and reliability of the estimation, model diagnostic tests such as 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 employed prior to interpreting the long and short-run elasticities of the environmental quality model. The null hypothesis the tests implies the estimates are reliable and valid.

The model diagnostic assessments are provided in Table 3.

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)

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.

The assessment can be made by comparing the plots of the test statistics to the critical bounds at the 5% level of significance. If the plots remain within the critical bounds, the null hypothesis of coefficient stability can be accepted.

As shown in Appendix A, the plots of the CUSUM and CUSUMSQ statistics were within the critical bounds at the 5% significance level for the period under consideration. This supports the stability of the coefficients estimated in the environmental quality model.

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.

Table 4 presents the results of the environmental quality model estimation, which includes the estimated coefficients, standard errors, t-values, and probability values.

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)

According to the findings of the environmental quality model, the long-run elasticity of carbon dioxide emissions with respect to modern renewable energy is -0.234596. This indicates that if all other variables remain constant, a 1% increase in the usage of modern clean energy will result in a 0.234596%

decrease in carbon dioxide emissions in the country under study. 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 finding is consistent with past empirical studies. For example, Adinew M. (2020) found a statistically significant negative association between renewable energy use and anthropogenic carbon dioxide emissions in Ethiopia, supporting the results of the environmental quality model. 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. Furthermore, Uğurlu (2022) found a decreasing effect of renewable energy consumption on CO_2 emissions for the Visegrad Group Countries, including Poland, the Czech Republic, Hungary, and Slovakia.

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.

Nevertheless, the potential benefits of limiting carbon dioxide emissions and boosting environmental quality make this investment worthwhile. Therefore, policymakers and stakeholders must work together to identify strategies for promoting the use of modern clean energy and reducing reliance on fossil fuels. This may involve implementing policies and incentives to encourage investment in modern clean energy, as well as educating the public about the benefits of reducing carbon dioxide emissions.

The long-term findings also imply that increasing the use of biomass and non-renewable energy sources will exacerbate greenhouse gas emissions and contribute to higher carbon dioxide levels. The long-run elasticity of carbon dioxide emissions is 4.395273 for biomass energy and 0.185574 for non-renewable energy. This means a 1% change in the usage of these energy sources will result in a 4.395273% and 0.185574% change in carbon dioxide emissions respectively.

The significant impact of biomass energy use on anthropogenic carbon dioxide emissions in Ethiopia is noteworthy, as biomass energy contributes to approximately 90% of the country's entire energy mix, according to UNECA (2014). This heavy reliance on wood, wood-derived fuels, and biomass waste consumption, which are classified as primary and environmentally unfriendly energy sources, is a major driver of the increasing carbon dioxide emissions in the country.

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 short-run results of the defined ARDL (1, 0, 0, 0, 2, 2, 0) model, the long-run case is supported by the coefficients of current clean energy, biomass energy, and non-renewable energy use. However, the short-run elasticity of carbon dioxide emissions with respect to modern clean energy utilization is higher than the long-run 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 indicates that in the short run, there is a direct association among output growth, population, and carbon emissions. Notably, the elasticity of carbon dioxide emissions with respect to population outweighs the effect of output growth, implying that the size of the population adds more to environmental degradation than economic growth. This finding is consistent with the results of a previous study conducted by Shafiei (2013).

Since the short-run output growth elasticity of carbon dioxide emissions is positive, there is no evidence of decoupling of economic growth from carbon dioxide emissions in the near term. However, the long-term insignificant effect of economic expansion on environmental quality could be an indication of long-term decoupling.

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

The stationarity behavior of the indicators in the economic growth model is presented in Table 5 below. The test results explored that all the indicators are stationary at their first difference, except biomass energy use. This finding qualified the use of the ARDL model for long-term co-integration analysis among the economic growth model variables.

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.

Further research by Apergis and Danuletiu (2014) for a panel of 80 countries, as well as Shahbaz *et al.* (2020) for a panel of 38 renewable-energy-consuming countries from 1990 to 2018, also found results indicating the importance 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.

In the short run, however, the effect of all other variables on output growth is found to be insignificant. The short-run elasticity of output growth for modern clean energy and non-renewable energy use is 0.194435 and 0.113614, respectively, and is statistically significant in explaining Ethiopia's output growth. 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.

According to the study's findings, modern clean energy sources such as hydroelectricity, wind, and solar have a positive and highly significant environmental impact in Ethiopia. This implies that these energy sources are critical to improving environmental quality by reducing the anthropogenic concentration of carbon dioxide emissions. The study suggests that policymakers and stakeholders in Ethiopia should prioritize the adoption of modern clean energy sources to promote sustainable economic growth and reduce carbon dioxide emissions.

From the study's economic growth model, modern clean energy use has a statistically significant positive impact on Ethiopia's economic growth in both the short and long run. This is because it raises output and contributes to sustainable economic development. In contrast, non-renewable and biomass energy use do not play a significant role in explaining the country's economic growth. These findings suggest that policymakers and stakeholders in Ethiopia should prioritize the adoption of modern clean energy sources to promote sustainable economic growth and development.

5.2 Recommendations

Given the study's findings, modern clean energy is a significant contributor to both economic growth and environmental quality in Ethiopia. The study suggests that alternative modern clean energy sources can be a solution to the climate change challenge without posing a threat to Ethiopia's economic growth. These findings highlight the importance of modern clean energy in Ethiopia's green economy development. By prioritizing the adoption of modern clean energy sources, policymakers and stakeholders in Ethiopia can promote sustainable economic growth and development while also addressing environmental concerns.

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 need for strong collaboration among the country's policymakers, government, and international cooperation organizations in boosting modern clean energy investment aiming to ensure that future development is environmentally and economically sustainable. By overcoming these challenges, Ethiopia can promote sustainable economic growth and development while also addressing environmental concerns.

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Conflicts of Interest

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

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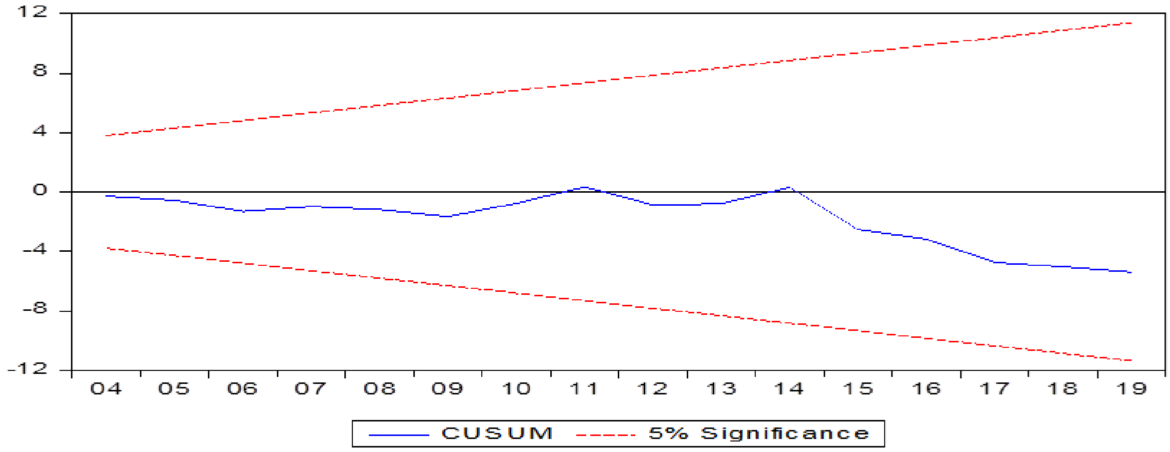
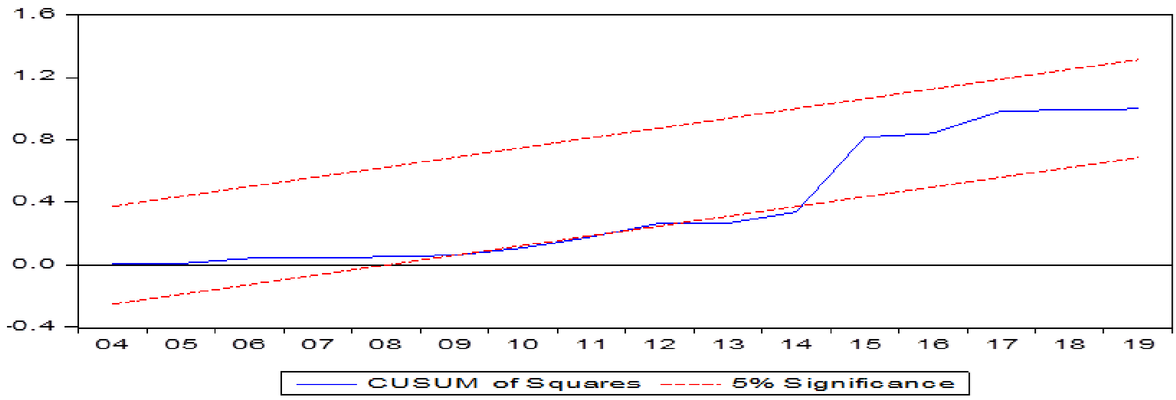
Appendices

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