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Economic growth and environmental degradation in Ethiopia. An Environmental Kuznets Curve Hypothesis analysis approach.

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Abstract

The main objective of this study was to investigate the relationship between GDP per capita and carbon dioxide emission per capita in Ethiopia from 1981 to 2020. All the variables in this paper are stationary in their difference. Johansen cointegration is chosen over the Engel-Granger approach due to the presence of two cointegration equations. The result from the vector error correction model implies the existence of a short and long-run relationship between the carbon dioxide emission per capita, gross domestic product per capita, and trade openness. In the long run, the Environmental Kuznets curve hypothesis is valid in this study.

Key terms: VECM, EKC, GDP, and CO₂.

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1. Introduction

Greenhouse gases (GHG) are substances that help regulate our planet's temperature. Without these gases, our world would be too cold. However, due to the expansion of human activity, the accumulation of GHG has increased at a fast pace in the atmosphere, causing rapid global warming. Several binding agreements were held internationally to limit GHG emissions, such as the Paris climate accord of 2015. However, while developed countries are investing a tremendous amount of money in research and development, cap and trade, applying stringent environmental policies, targeting to have net zero-emission cities, and encouraging the renewable energy sector, the priority of the developing countries is still how to improve their economy not the environment.

There are several reasons for the growth of greenhouse gas emissions. Still, the major ones are burning fossil fuels, forestry harvest, agricultural activities, land-use change, and expansion of industrial activities (Engdaw, 2020). The main GHGs are carbon dioxide, nitrous oxide, and methane. Compared to the developed countries, the Nile basin countries' contribution to climate change is minimal. However, they are the most vulnerable to the adverse impacts of this phenomenon (IPCC, 2007).

Ethiopia is a landlocked country bordering Kenya, Eritrea, Somalia, Sudan, and South Sudan, with an estimated population of 115 million in 2020 (World Bank, 2020). Agriculture has been the backbone of the economy for many years. However, with the rise of the service sector, foreign direct investment and industrialization are taking over the lion's share contribution of agriculture to the gross domestic product. Over the past fifteen years, Ethiopia's economy has been the fastest growing in the region at an average of 9.5% per year. However, it is one of the poorest countries, with a per capita gross national income of USD 890. Ethiopia aims to reach lower-middle-income status by 2025 (World Bank, 2020), encouraging import substitution and trade openness. Like most developing countries, Ethiopia's primary carbon dioxide emission sources are land use and agricultural activities. Ethiopia suffered from air pollution, deforestation, forest degradation, soil erosion, biodiversity loss, and land degradation (Besfat, 2017).

This paper deals with the relationship between GDP per capita and CO₂ emission per capita. The hypothesis which analyzes this relationship is the so-called Environmental Kuznets Curve (EKC henceforth). This hypothesis shows an inverted U-shaped relationship between per capita income and CO₂ emission per capita. When the per capita income of the citizens is low, they prioritize consumption over the quality of the environment. However, increases in per capita income eventually lead to increased demand for a better living environment. Thus, the early-stage economic growth of a country is at the expense of the environment. However, after reaching a certain level of per capita income, this relationship reverses, and high levels of economic growth at the later stage lead to environmental improvement (Mahrous, 2017). Based on this hypothesis, several authors found an inverted U-Shaped curve relationship between per capita income and CO₂ emission (Engdaw, 2020).

An extensive amount of research has been carried out to check the validity of the EKC by applying different econometric methodologies for different periods (Stern et al., 1996). In the early days, the EKC literature focused only on the quadratic relationship between income and environment (Grossman & Krueger, 1995). However, recently the framework has been extended to include other variables that can affect carbon emission, such as urbanization rate, population, financial development, tourism, energy consumption, trade openness, institutional quality, foreign direct investment, political freedom, etc. (Wang et al., 2014). However, despite the methodological approach updating over time, the outcomes from empirical literature regarding the validity of the EKC are inconclusive.

The main objective of this study is to investigate the relationship between GDP per capita and CO₂ emission per capita in Ethiopia for the period 1981 to 2020. Similarly, the effect of trade openness on the CO₂ emission in Ethiopia will also be discussed in this paper. Due to composition, technique, and scale effects, trade openness can positively or negatively affect the environment. The scale effect shows that pollution emissions are increasing because of higher economic activities and energy consumption, which means more emphasis is placed on economic growth than pollution control at the initial stages of the development process. However, economic growth promotes increased demand for a cleaner environment and replacing old production systems due to composition and technique effects. The study applies the Johansen cointegration and granger causality test to investigate the long-run and causal relationship between CO₂ emission, GDP per capita, and trade openness.

Since the EKC hypothesis has been evolving, this study will contribute to the literature by testing the EKC hypothesis in the case of Ethiopia using the most recent available data. This paper is organized into five sections: Introduction, literature review, Methodology, Discussion of results, and conclusion.

2. Literature review

The EKC is named after Simon Kuznets, who suggested that income inequality first increases and then decreases after a certain threshold as income per capita income increases (Kuznets, 1955). In an analogous framework, the EKC hypothesis describes the inverted U-shaped relationship between GDP per capita and CO₂ emissions per capita (Panayotou, 1993).

Figure 1 illustrates the EKC hypothesis graphically. It indicates that as GDP per capita rises, so does environmental degradation. However, after a particular point, an increase in GDP per capita reduces the environmental damage. At a low income, pollution abatement is undesirable as individuals are better off using their limited income to meet their consumption needs. Once a certain income level is achieved, individuals consider the trade-off between environmental quality and consumption, and ecological damage increases at a lower rate. However, concerns for environmental quality become gradually more important as the per capita increases.

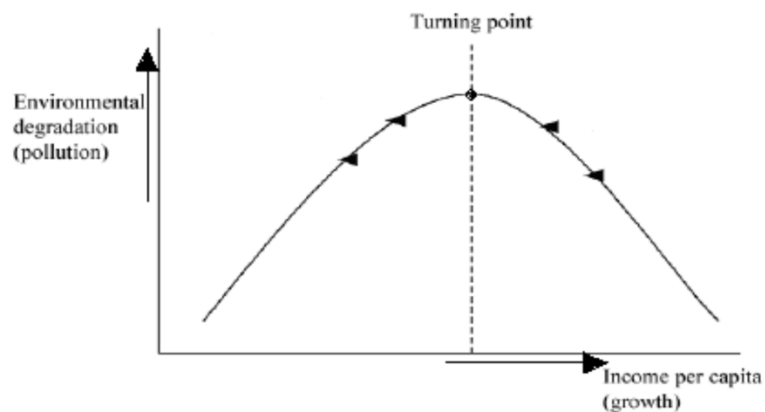


Figure 1. Inverted U shaped EKC Source: (Yurttagüler & Kutlu, 2017)

There are several critiques of the EKC hypothesis (Dinda, 2004). Firstly, it is undeniable that the level of many pollutants per unit of output in specific processes has declined in developed countries with technological innovations and increasingly stringent environmental regulations. However, the emission has shifted from sulfur and nitrogen oxides to carbon dioxide and solid

waste, so aggregate waste is still high, and waste might not have declined per capita. Secondly, critics argued that the EKC relationship existed partly or mainly because of the effects of trade on the distribution of polluting industries (Dinda, 2004). Under free trade, developing countries are endowed with a relative abundance of labor and natural resources. On the other hand, developed countries specialize in human capital and capital-intensive activities. Due to outsourcing, the environmental regulation in developed countries might further encourage polluting activities in developing countries. This situation would make it difficult for developing countries to reduce pollution with rising income. Lastly, in our finite world, today's developing countries would be unable to find other countries to import resource-intensive products as they become wealthy. When the poorer countries apply similar levels of environmental regulation, they will face more difficult tasks of abating these activities rather than outsourcing them to other countries (Stern et al., 1996).

The nexus between economic growth and carbon emission has been extensively discussed in the previous empirical literature. Grossman & Krueger (1991) and Grossman & Helpman (1993) were the first to investigate such issues. They reported that economic growth leads to environmental degradation, followed by subsequent environmental improvement. However, the literature regarding the EKC hypothesis is evolving, considering numerous variables that can affect the environment.

In Ethiopia, the relationship between CO₂ per capita and GDP per capita was previously studied by Endeg (2015). Using time-series data from 1970 to 2011 in a vector error correction model (VECM), the author provided evidence consistent with an inverted U-shaped EKC. This study included only trade openness as an additional explanatory variable affecting the environment. Similarly, Kebede (2017) applied an autoregressive distributive lag (ARDL) approach to test the cointegration and causality between CO₂ emission and GDP per capita in Ethiopia. Energy consumption, financial development, trade openness, urbanization, and the population were included as explanatory variables in the model from 1970 to 2014. The Toda-Yamamoto approach was used to determine the direction of causality between variables. This test involves estimating a VAR model in levels and minimizes the risk of incorrectly identifying the order of integration of the respective time series. The result shows that cointegration exists among the variables. While the GDP per capita exhibits an EKC relationship with the CO₂ emissions per capita, energy consumption, population, and trade openness contribute to increased CO₂ emissions per capita.

Hundie (2020) investigated the relationship between GDP per capita and environmental quality using time series data from 1981 to 2012. He included the population growth rate and GDP per capita as explanatory variables in the model affecting the level of carbon dioxide emissions. The vector error correction model used by the author shows that economic growth helps improve environmental quality in the long run while population growth exacerbates environmental degradation. The author concluded that the primary cause of biodiversity loss in Ethiopia is deforestation to expand agricultural production for a rapidly growing population.

Mahrous (2017) investigated the main economic determinants contributing to Ethiopia's GHG emissions. Annual data from 1981 to 2013 was used by applying the bound test approach and ARDL model to estimate the short and long-run impacts of economic growth, trade openness, and industry on air pollution in Ethiopia. The result indicates that when trade liberalization and industry interact, they adversely impact the environment. However, there was no evidence to support the validity of EKC in this study. The EKC hypothesis was also discussed in the context of East African countries. Using a pooled mean group approach from 1990 to 2013, Panayotou et al. (1993) has studied the EKC for 12 east African countries. Their result shows that the relationship between per capita income and environmental degradation is an inverted U-shaped curve.

The EKC hypothesis has also been tested in Malaysia. Saboori et al (2012) have established a long-run and causal relationship between GDP per capita and CO₂ emission in Malaysia from 1980 to 2009. The empirical result from this study suggests a long-run relationship between GDP per capita and CO₂ per capita. Furthermore, the Granger causality test based on the vector error correction model showed an absence of causality between GDP per capita and CO₂ emissions in the short run while showing uni-directional causality from GDP per capita to CO₂ emissions in the long run.

Similarly, Osiobe (2021) established a long-run and causal relationship between economic growth, CO₂ emissions, international trade, energy consumption, and population density in Malaysia by using time series data from 1970 to 2014. Using the ARDL model, a long-run relationship between CO₂ emissions and explanatory variables was discovered. The Granger causality test results indicate the absence of causality between the dependent and independent variables in the short run while uni-directional causes from economic growth to CO₂ emissions in the long run.

The test of the EKC hypothesis was not limited to only one country. Using the dynamic ordinary least squares method, Mitić et al. (2017) tested the relationship between real GDP and CO₂ emissions for seventeen transitional economies based on annual data from 1997 to 2014. Their analysis indicates a statistically significant long-run cointegrating relationship between the variables. Based on the results, the authors recommended that the transitional economies should follow global policy incentives such as emissions-trading schemes, environmental taxes, and carbon capture and storage to reduce CO₂ emissions while attaining economic growth.

The validity of the EKC hypothesis is inconclusive in the literature, which means the relationship between economic growth and CO₂ emission can be monotonic or parallel. Kunnas and Myllyntaus (2007) tested the hypothesis for emissions in Finland from 1800 to 2003 using the newly constructed emissions series. Although the carbon dioxide emissions from Finnish energy production increased at the beginning of the study period, a decline in these emissions after a certain threshold could not be found. In this study, only the emission of sulfur dioxide supports the hypothesis of the EKC.

Akbostanci (2009) investigated the relationship between environmental quality and income per capita for Turkey in two different approaches. The time series model was analyzed for 1968-2003 using annual data, and the panel data model covers 1992-2001, including observations from 58 provinces. According to the time series analysis, a monotonically increasing relationship between CO₂ and income per capita was found in the long run. However, an N-shaped relationship was found for the panel data analysis. Therefore, neither of the two approaches supports the EKC hypothesis.

Simiyu (2017) examined the applicability of the EKC hypothesis in Kenya and the effects of trade openness on the environment from 1960 to 2012. In this study, environmental quality was proxied by ecological footprint and motivated by an increment of environmental degradation. The autoregressive distributive lag model was used to see the impact of real gross domestic product, urbanization, trade openness, and energy consumption on the environment. The result shows that real GDP per capita harms environmental quality in the long run. However, trade openness was observed to have a negative effect in the short run but a positive effect in the long run. The EKC hypothesis was invalid in this study. As technical development is one of

the main reasons to support the EKC hypothesis, opening for trade is encouraged in this study to facilitate the transfer of clean technologies to improve environmental quality in Kenya.

Ozatac et al (2017) investigated the EKC hypothesis for the case of Turkey from 1960 to 2013 by considering energy consumption, trade openness, urbanization, and financial development variables. Although previous literature examines various aspects of the EKC hypothesis for the case of Turkey, the authors focused on the basic EKC model with several covariates to develop a better understanding of the relationship among the variables and avoid omitted variables bias. The results from the bound test and the error correction model under the autoregressive distributed lag mechanism show long-run relationships among the variables and the validity of the EKC hypothesis caused by the scale effect. Furthermore, the short-run Granger causality test showed causal relationships between variables. The authors suggested polluters pay principles such as implementing a carbon tax for pollution trading, investing in environmentally friendly technology, and raising awareness on adopting renewable energy.

The impact of economic growth and trade openness on the environment in China for the period 2004 to 2013 was investigated by Fang et al (2020) using a fully modified method. This method modifies least squares to account for serial correlation and endogeneity that results from the existence of a cointegrating relationship. The author's considered industrial wastewater and sulfur dioxide as proxies for environmental degradation and employed three measures of openness in the regression. The result indicates that the EKC hypothesis holds for some cities in the Republic of China. Also, the wastewater pollution increases with economic development until GDP per capita reaches the turning point of CNY 31,849-49,446, depending on the specific measure of trade openness. However, the turning point for sulfur dioxide occurs around CNY9,274-10, GDP per capita. Furthermore, cities featuring greater trade openness tend to have lower industrial wastewater emissions but higher sulfur dioxide emissions.

To investigate the effect of trade openness on the environmental quality and investigate the existence of the EKC hypothesis in transitional countries focusing on the commonwealth of independent states, Yu et al (2019) used panel data from 2000 to 2013. The two-equation model was used to estimate the direct effect of trade openness on CO₂ emissions and the indirect effect on GDP per capita. An instrumental variables technique was employed to take the endogeneity of per capita income and trade openness into account to estimate the indirect effect. A generalized least square analysis was conducted to evaluate the direct impact of trade openness

on CO₂ emissions. The results support the EKC hypothesis and verify the existence of the inverted U-shaped curve between per capita income and CO₂ emission.

Finally, even though the existing literature on the EKC hypothesis is vast, most of the literature discussed above implies a long-run relationship between CO₂ per capita and GDP per capita. This study will also contribute to the literature of the EKC by testing the hypothesis in the case of Ethiopia.

3. Methodology

To investigate the relationship between per capita CO₂ and GDP per capita, we follow the standard methodology of the EKC hypothesis. The quadratic effect of the GDP per capita is assumed to affect the proxy for environmental degradation. Quadratic and cubic polynomial models were used to test the EKC hypothesis, including several macroeconomic control variables such as population growth, urbanization rate, foreign direct investment, energy consumption per capita, financial development, tourism, etc. The EKC hypothesis in its general format is specified as follows:

$$E = f(Y, Y^2, Z)$$

where E is an environmental degradation indicator, Y is income, Y^2 is the square of income and Z is other control variables that may affect the environment.

3.1 Model Specification

The following long run model is estimated:

$$\ln CO_{2t} = \beta_0 + \beta_1 \ln GDPPC_t + \beta_2 \ln GDPPC_t^2 + \beta_3 \ln TO_t + U_t$$

where CO₂ per capita is used as a proxy for environmental degradation, GDPPC is gross domestic product per capita at market price (constant 2010 USD), GDPPC² is the square of gross domestic product per capita, and it is included in this model to test for a reduction in carbon emission when per capita income increases, TO is trade openness, t is the period, and U_t is the error term. All variables are used in logarithm form to capture the elasticity parameters and a more straightforward interpretation. β_1 and β_2 are the income elasticities used to assess the applicability of the EKC hypothesis. If β_1 is positive and β_2 is negative, we conclude that the EKC is applicable.

Most of the studies on the EKC hypothesis include energy consumption and other explanatory variables in their model. However, (Jaforullah & King, 2017) argued that energy consumption generates systematic volatility in the model's estimated coefficients and generates biases between GDP and CO₂ emissions. Due to multicollinearity and data unavailability, other variables that can affect CO₂ emission are not included in this study.

3.2 Data

This study uses a time series of annual data for 39 years, from 1981 to 2020. The study period was limited to the given period because of data availability. The data series for gross domestic product per capita, trade openness, and CO₂ emission per capita was collected from the website of the World Bank. However, the author computed the square of gross domestic product per capita.

Table 1. Summary of Variables and data sources.

Variable	Symbol	Measurement	Source
CO ₂ per capita	CO ₂	Metric ton	World Bank
GDP per capita	GDPPC	Constant \$ 2010	World Bank
Square of GDP per capita	GDPPC ²	Constant \$ 2010	Computed
Trade openness	TO	% Of GDP	World Bank

The per capita carbon dioxide emission is the summation of those stemming from the burning of fossil fuels and the manufacturing industries. It also includes the carbon dioxide produced during day-to-day activities. Gross domestic product is a financial measure that breaks down a country's economic output per person and is calculated by dividing GDP by its population. The spillover of trade openness is very high by enabling economic growth, job creation, and poverty reduction. It provides new market opportunities for domestic firms, more vital productivity, innovation through competition, and technology transfer from developed countries to the developing.

3.3 Estimation procedures

When carrying out a standard regression analysis in a time series model, the assumption is that the data under consideration is stationary; the mean and variance are time-invariant.

Running a regression when variables are non-stationary may result in spurious and inconsistent results, especially when the variables have a trend over time. To avoid this, the present study starts the analysis by testing for the presence of a unit root. The Augmented Dickey-Fuller test (ADF) is an improved version of the Dickey-Fuller test. ADF is preferred since it assumes that the error term in the model is uncorrelated. Choosing optimal lag for the model follows a stationary test. The optimal lag can be selected using the Akaike Information Criterion (AIC), Schwarz and Bayesian information criterion (SBIC), and Hannan-Quin information criterion (HQIC).

Once the optimal lag length is selected, we test if there is a long-run relationship between the variables. The most accustomed tests for cointegration are Johansen and Engle-Granger's approaches. The Engle-granger approach has several shortcomings. For example, it doesn't allow the estimation of more than one cointegrating equation. Therefore, the Johansen cointegration approach is preferred in this case since it addresses the shortcomings of the Engle-Granger approach. The result from the cointegration test also indicates which model to adopt for studying short-run dynamics. VAR model is recommended if there is no cointegration. However, VECM or ARDL is applicable if cointegration occurs. VECM can be used if the variables are integrated in the same order and if there is more than one cointegrating equation in the model. On the other hand, ARDL is also applicable when the variables are stationary in their level and differences. Therefore, this paper chooses VECM over ARDL since all variables are integrated in the same order, and two cointegration equations occur. VECM is specified as follows:

$$\Delta \ln CO_{2t} = \alpha + \sum_{i=1}^{k-1} \gamma_i \Delta \ln CO_{2t-i} + \sum_{j=1}^{k-1} \beta_j \Delta \ln GDP_{t-j} + \sum_{m=1}^{k-1} \mu_m \Delta \ln GDP_{sq_{t-m}} + \sum_{n=1}^{k-1} \tau_n \Delta \ln TO_{t-n} + \lambda_1 ECT_{t-1} + U_{1t}$$

$$\Delta \ln GDP_t = \theta + \sum_{i=1}^{k-1} \gamma_i \Delta \ln CO_{2t-i} + \sum_{j=1}^{k-1} \beta_j \Delta \ln GDP_{t-j} + \sum_{m=1}^{k-1} \mu_m \Delta \ln GDP_{sq_{t-m}} + \sum_{n=1}^{k-1} \tau_n \Delta \ln TO_{t-n} + \lambda_2 ECT_{t-1} + U_{2t}$$

$$\Delta \ln GDP_t^2 = \delta + \sum_{i=1}^{k-1} \gamma_i \Delta \ln CO_{2t-i} + \sum_{j=1}^{k-1} \beta_j \Delta \ln GDP_{t-j} + \sum_{m=1}^{k-1} \mu_m \Delta \ln GDP_{sq_{t-m}} + \sum_{n=1}^{k-1} \tau_n \Delta \ln TO_{t-n} + \lambda_3 ECT_{t-1} + U_{3t}$$

$$\Delta \ln TO_t = \sigma + \sum_{i=1}^{k-1} \gamma_i \Delta \ln CO_{2t-i} + \sum_{j=1}^{k-1} \beta_j \Delta \ln GDP_{t-j} + \sum_{m=1}^{k-1} \mu_m \Delta \ln GDP_{sq_{t-m}} + \sum_{n=1}^{k-1} \tau_n \Delta \ln TO_{t-n} + \lambda_4 ECT_{t-1} + U_{4t}$$

where,

$K-1$ shows the lag length reduced by one lag when VECM is estimated.

γ_i, β_j, μ_m , and τ_n are short-run dynamic coefficients of the model to the long-run equilibrium.

Δ indicates the first difference of the variables.

λ is the speed of adjustment coefficient to the long-run equilibrium

ECT explains that the previous period's deviation from the long-run equation influences short-run movement in the dependent variable.

The Granger-causality test examines the causal relationship between the dependent and independent variables. The test is conducted after a VECM estimation with the assumption of cointegration between variables. The long-run causality relies on the significance of the error correction term. However, the short-run Granger causality is detected by the chi-squared statistics of the estimated parameters of the lagged control variables. Finally, diagnostic tests such as serial correlation, normality, and impulse response function tests are performed to ensure the appropriate fit within the model and see if the model reacts when shock happens to the explanatory variables.

4. Discussion of results

4.1 Summary of descriptive statistics

In this section, the descriptive statistics of the variables under this study are presented in Table 2 and discussed accordingly. The result shows that the mean annual carbon emission per capita is 0.073 metric tons, with the lowest and highest emission values of 0.039 and 0.147 metric ton recorded in 1981 and 2020, respectively. This figure implies that carbon emissions are increasing in Ethiopia but not rapidly. The significant difference between the mean value of average emission and standard deviation indicates wide variation across the data points. The annual average GDP per capita is 335 USD from 1981 to 2020. The minimum and maximum GDP per capita are 116 USD and 994 USD observed in 2002 and 2020. The mean and standard deviation figures for GDP per capita illustrate a wide gap in data points across the sample period. Finally, the mean value of trade openness is 35% of the GDP from 1981 to 2020, with the minimum and maximum values of 23% and 49%, respectively, in 1990 and 2005.

Table 2. Summary of descriptive statistics

Variables	Obs	Mean	Median	Std.Dev	Min	Max	Skewness	Kurtosis
CO ₂	40	.073	.062	.32	.039	.147	1.217	3.194
GDPPC	40	335.401	247.24	250.742	116.452	994.19	1.421	3.793
TO	40	35.007	33.57	8.387	23.386	49.991	.805	.013

Source: Author's calculation from Stata 17

Skewness and Kurtosis are test of normality distribution. While Kurtosis measures the heaviness of the tails of a given probability distribution, Skewness indicates the scale and bearing of asymmetry. Carbon emission and gross domestic product capita are leptokurtic kurtosis since their value is greater than three, but trade openness is platykurtic kurtosis. The result for kurtosis implies that the distribution is not too peaked. All variables are skewed to the right. However, the degree of skewness is small. Since the mean and median values are almost equal, we can conclude that the data used is not seriously skewed. Therefore, using these data for regression will not affect the reliability of the finding.

4.2 Unit root test

Before running any regression test in a time series analysis, it is essential to check if the variables are stationary or not. Some macroeconomic variables are non-stationary; however, they can be transformed into stationary by taking their first or second differences. The null hypothesis state that the variable has a unit root. However, the alternative hypothesis defines the time series variables as stationary. The Augmented Dickey-Fuller (ADF) test is one of the most common statistical tools to test a unit root in time series analysis. It is an extension of the Dickey-Fuller test, which removes autocorrelation from the series.

Table 3. Augmented Dickey-Fuller Test.

Variable	ADF at level		ADF at first difference	
	Test Statistic	P-value	Test Statistic	P-value
lnCO ₂	-0.255	-2.961	-6.920**	-2.964
lnGDPPC	0.958	-2.961	-3.877**	-2.964
lnGDPPC ²	1.257	-2.961	-3.913**	-2.964
lnTO	-0.986	-1.690	-3.652**	-1.691

Source: Author's calculation from Stata 17

** indicates the significance level at 5%.

The decision criteria to accept or reject the null hypothesis is based on comparing the absolute value of the test statistic with the absolute value of the p-value. If the absolute value of the test statistic is greater than the absolute value of the p-value, we reject the null hypothesis and vice versa. All the variables in this study are stationary at their first difference or $I(1)$. Therefore, we accept the alternative hypothesis at first difference.

4.3 Lag order Selection

Determining the number of optimal lags precedes the cointegration test. Based on Akaike's information criteria (AIC), Hannan and Quinn's information criteria (HQIC), and Schwarz's and Bayesian Information criteria (SBIC), we choose the optimal lag length for the model.

Table 4. Choosing optimal lag.

<i>Lag</i>	<i>AIC</i>	<i>HQIC</i>	<i>SBIC</i>
0	1.194	1.256	1.370
1	-6.319	-6.012*	-5.440*
2	-6.389	-5.837	-4.806
3	-6.628*	-5.830	-4.341
4	-6.391	-5.347	-3.400

Source: Author's calculation from Stata 17

* Implies the lag order

We choose the lag with a minimum value as a rule of thumb to determine the optimal lag length. Therefore, the optimal lag for the model specified is three from AIC. (Gonzalo, 1994) has suggested that underspecifying the number of lags in a vector error correction model can significantly increase the finite-sample bias in the parameter estimates and lead to serial correlation.

4.4 Johansen cointegration

When a time series variables are integrated of order one, an additional test is required to check if there is a long-run relationship among the variables (Wassell & Saunders, 2000). Johansen's cointegration test is preferred over Engle and Granger because two cointegration equations appear in our model. The null hypothesis suggests an absence of a cointegration equation for the given maximum rank. In contrast, the alternative hypothesis indicates the presence of cointegration.

Table 5. Johansen cointegration

Maximum rank	Parameters	LL	Eigenvalue	Trace Statistic	5% Critical value
0	36	135.389	.	68.125	47.21
1	43	150.541	0.559	37.820	29.68
2	48	162.143	0.465	14.617*	15.41
3	51	169.091	0.313	0.719	3.76
4	52	169.451	0.019		

Source: Author's calculation from Stata 17

The decision criteria to reject or accept the null hypothesis is based on comparing the value of the trace statistic and the 5% critical value. There is a cointegration if the trace statistic value is greater than the critical value. However, there is no cointegration if the 5% critical value is greater than the trace statistic. Thus, there is two cointegrating equation in this model at rank one. Therefore, we reject the null hypothesis.

4.5 Long-run Equation

The result of the long-run equation is derived from the VECM. The sign of the coefficients is reversed when reported in the long-run equation. Johansen identification scheme has placed four restrictions on the parameters in both cointegrating vectors. $\ln\text{CO}_2$ and $\ln\text{GDPPC}$ are normalized to one. Since the main objective of this study is to investigate the relationship between CO_2 per capita and GDP per capita, only the first cointegration equation can detect this relationship. It's impossible to see this relationship in the second cointegration equation since the estimated value of $\ln\text{CO}_2$ is zero.

$$\ln\text{CO}_2 = 6.585 + 4.440\ln\text{GDPPC} - .047\ln\text{GDPPC}^2 - 2.334\ln\text{TO}$$

In the long run, while GDP per capita increases carbon emission, the square of GDP per capita and trade openness decreases it. All coefficients of the explanatory variables are statistically significant at a 10% level. A percentage change in GDP per capita will increase the carbon emission by 440%. However, a percentage change in the square of GDP per capita will decrease the carbon emission by 4.7%. These results imply the validity of the EKC hypothesis in Ethiopia. Moreover, a percentage change in trade openness will reduce carbon emissions by

approximately 240%. This result agrees with Endeg (2015), who concluded that the EKC's validity in Ethiopia and trade openness would reduce environmental degradation.

Table 6. Cointegrating vectors.

First cointegration equation			
Beta	Coef.	Std. Err	p-value
<i>lnCO₂</i>	1	.	.
<i>lnGDPPC</i>	-4.440	.013	.032
<i>lnGDPPC²</i>	.047	.028	.092
<i>lnTO</i>	2.334	.670	.001
<i>constant</i>	-6.585	.	.

Second cointegration equation			
Beta	Coef.	Std. Err	p-value
<i>lnCO₂</i>	0	(omitted)	
<i>lnGDPPC</i>	1	.	.
<i>lnGDPPC²</i>	-.076	.003	.000
<i>lnTO</i>	-.349	.091	.000
<i>constant</i>	-1.96	.	.

Source: Author's calculation from Stata 17

The second cointegration equation shows the relationship between GDP per capita and trade openness. Both variables are statistically significant at the 5% level. A percentage change in trade openness will approximately increase GDP per capita by 35%. From the above results, it's possible to conclude that encouraging trade openness in Ethiopia will improve both the environment and GDP per capita.

4.6 Vector Error Correction Model

Vector autoregressive (VAR) model is a framework used to describe the dynamic relationship among stationary variables. However, if the time series variables are not stationary at the level, then the VAR framework needs to be modified to allow consistent estimation of the relationships among the series. The VECM is a particular case of VAR for variables that are

stationary in their first difference. The VECM can also consider any cointegrating relationships among the variables. The error correction term shows that the long-run equilibrium's deviation will gradually go through partial short-run adjustments.

Table 7 shows the result of the short-run model CO₂ equation and error correction terms. Et-1 and Et-2 denote the error correction term for the two cointegrating equations. We observe that the coefficient of the second error correction term is negative and significant at a 5% level of significance and the first error correction term is also negative but not significant. The speed of adjustment in the second equation when there is a short-run shock is approximately 46% every year toward a stable long-run equilibrium.

Table 7. Estimated Short-run coefficient

$\Delta \ln \text{CO}_2$	Coef.	Std. Err	t-value	p-value
E _{t-1}	-.033	.024	-1.37	.170
E _{t-2}	-.495	.205	-2.41	.016
$\Delta \ln \text{CO}_{2t-1}$	-.069	.173	-0.40	.688
$\Delta \ln \text{CO}_{2t-2}$	.155	.145	1.07	.286
$\Delta \ln \text{GDP}_{t-1}$	2.109	1.816	1.16	.246
$\Delta \ln \text{GDP}_{t-2}$	-4.920	1.772	-2.78	.006
$\Delta \ln \text{GDP}^2_{t-1}$	-.150	.165	-0.91	.363
$\Delta \ln \text{GDP}^2_{t-2}$	.438	.162	2.70	.007
$\Delta \ln \text{TO}_{t-1}$	-.306	.155	-1.97	.048
$\Delta \ln \text{TO}_{t-2}$	-.271	.147	-1.85	.065
Constant	.005	.016	.30	.766

Source: Author's calculation from Stata 17

In the short run, the lagged GDP per capita negatively affects CO₂ per capita at a 5% significance level. The coefficient of -4.92 suggests that a 1% increase in gross domestic product per capita will reduce carbon emissions by 492% ceteris paribus. However, this figure doesn't seem reasonable. The lagged coefficient of the square of the gross domestic product implies a positive effect on the environment. A 1% increase in GDP per capita will increase the carbon emission by 43.8% ceteris paribus. Finally, trade openness reduces carbon emissions in both lagged levels. A 1% increase in trade openness will reduce carbon emissions by 30% and 27%. From the short-run model, the p-value of the variables, and the error correction term imply Short and long-run causality, respectively. In the short run, GDP per capita and the

square of GDP per capita cause CO₂ emission at the 5% significance level. Similarly, there is a long-run causality in the second equation at a 5% significance level.

4.7 Autocorrelation Test

The vector error correction model's estimation, inference, and post estimation analysis rely on the residuals not being autocorrelated. The autocorrelation test is performed for three lags. The null hypothesis states that no autocorrelation is present at the lag order. However, the alternative hypothesis indicates the presence of autocorrelation at the lag order.

Table 8: Autocorrelation test

Lag	Chi²	df	prob > chi²
1	13.361	16	0.646
2	16.350	16	0.428
3	16.583	16	0.413

H0: no autocorrelation at lag order

Source: Author's calculation from Stata 17

At the 5% level of significance, the p values for the three lags are insignificant. Therefore, we accept the null hypothesis. Hence, it means that at lag three, the VECM is free from the problem of autocorrelation.

4.8 Normality Test

A normality test is performed to check if the residuals in the VECM are normally distributed. The null hypothesis states that the residuals of the variables are normally distributed. However, the alternative hypothesis suggests that the residuals are not normally distributed.

Table 9: Jarque-Bera test

Equation	Chi ²	Df	Prob > Chi ²
$\Delta \ln CO_2$	.429	2	.806
$\Delta \ln GDPPC$	5.232	2	.073
$\Delta \ln GDPPC^2$	1.765	2	.413
$\Delta \ln TO$	2.976	2	.225
All	10.403	8	.237

Source: Source: Author's calculation from Stata 17

The result shows the test statistics for individuals and all equations jointly. Apart from $\ln GDPPC$, the p values of all other variables are insignificant, indicating the null hypothesis is accepted. Therefore, the residuals of these variables are normally distributed jointly. The VECM specified earlier carries no problem with normality.

4.9 Impulse response functions for VECMs

An impulse response function describes the evolution of the variable along a specified time horizon after a shock in a given moment. It measures the effect of a shock to an endogenous variable on itself or another endogenous variable. The impulse response function from cointegrating VECM does not always die out because the variables are integrated of order one or they are not mean-reverting.

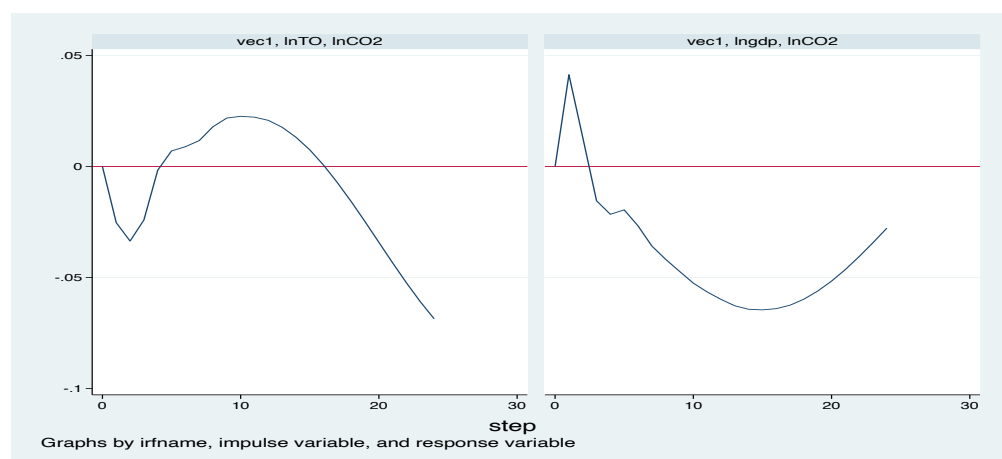


Figure 3: Impulse response functions

Source: Author's calculation from Stata 17

The observed immediate responses of CO₂ per capita to the shocks in GDP per capita and trade openness are given in the above figure. Carbon emission responds negatively to the shock in gross domestic product per capita and trade openness. A one-time shock in trade openness and GDP per capita has a transitory effect on CO₂ per capita. Furthermore, CO₂ per capita responds immediately to the shocks in the explanatory variables because the change starts in the first period. The shock in GDP per capita squared is not included because the shock in GDP will automatically also affect the square of GDP.

5. Conclusion

Over the last two decades, Ethiopia has moved towards a more open trade regime. It has simultaneously tried to curb environmental degradation by adopting a series of environmental policies. Based on the EKC hypothesis, this paper investigated the relationship between CO₂ emission per capita, GDP per capita, and trade openness from 1981 to 2020. The result from the cointegration test suggests a robust long-run relationship between the variables. In parallel with the EKC hypothesis, an inverted U-shape relationship between GDP per capita and CO₂ per capita was captured from the VECM. However, the above result doesn't provide much information about the inverted U-shaped relationship between CO₂ emission and GDP per capita since other potential factors affecting carbon emissions, such as population growth, urbanization, energy consumption, foreign direct investment, etc., are not included in the model.

The following argument can support the validity of the EKC hypothesis in this paper. The economy of Ethiopia was highly dependent on traditional agriculture, so it was inevitable to avoid environmental degradation in the early stages of economic growth. However, the development policy strategy, so-called Agricultural development led to industrialization (ADLI), implemented in 1993, has created a chance for technological transfer and modernizing of the agricultural sector. Furthermore, the eco-friendly policies, stringent environmental policies, regulations, the service sector's rise, expansion of industrialization, and rising social awareness of the environment can be the main reasons for the decline of environmental degradation in the country.

In this study, trade openness reduces Ethiopia's carbon emissions in the short and long run. Trade openness promotes the efficient allocation of resources, factor accumulation, technology diffusion, and knowledge spillovers. Increasing trade openness can support economic growth, development, and social welfare, contributing to a greater capacity to manage the environment more effectively. It also improves access to new technologies that make local production processes more efficient by diminishing the use of inputs. Similarly, trade liberalization can incentivize firms to adopt more stringent environmental standards. As the country becomes more integrated within the world market, exporters become more exposed to environmental requirements imposed by the leading importers. It stimulates cleaner production processes and technologies in the local market.

5.1 Policy recommendation

Based on the results, this study offers the following policy suggestions. The government should promote trade by lowering the taxation rate, imposing high excises and penalties on import products that can damage the environment, and imposing a carbon excise on the production and consumption of carbon-emitting technologies. It's also vital to include environmental provisions in bilateral and regional trade agreements since more advanced economies can provide capacity-building resources and institutions to strengthen environmental regulations.

Stringent environmental policies and institutional frameworks are needed at the local and regional levels because the impact of trade liberalization on a country's welfare depends on whether appropriate environmental policies are in place within the country. For example, correctly pricing exhaustible environmental resources. Finally, developing a set of policy indicators on trade and environment to help monitor progress towards more policy coherence and identify policy priorities at the intersection of trade and environment.

5.2 Limitations of the study and future research areas

Because of data unavailability and multicollinearity, this study considered only trade openness as a control variable affecting CO₂ emission to test the EKC hypothesis. To check if this result still holds, the author recommends that future studies include potential CO₂ determinants such as urbanization, foreign direct investment, financial development, institutional quality, and energy consumption. Testing the EKC hypothesis in the case of Ethiopia would be even more interesting in the future for several reasons, such as the rise of foreign direct investment, the

rapid financial development growth, and the long-run effect of the green environment policy adopted in 2020.

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