The Geographical Journal of Nepal
Vol. 18: 75-93, 2025
DOI: https://doi.org/10.3126/gjn.v18i1.77062
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Nexus between Economic Growth and CO_2 Emissions: An Analysis of Environmental Kuznets Curve in Nepal

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Received: 09 November, 2024; Accepted: 10 December, 2024; Published: March, 2025

Abstract

The relationship between economic growth and environmental sustainability has been a central focus in environmental socio-economics. This study investigates the Environmental Kuznets Curve (EKC) hypothesis in the context of Nepal, analyzing the relationship between carbon dioxide (CO_2) emissions and economic and demographic factors. Employing time-series data from 1990 to 2020, the study utilizes an Autoregressive Distributed Lag (ARDL) model to investigate both the short-term and long-term dynamics among CO_2 emissions, Gross Domestic Product (GDP), population density, and trade openness. The empirical results support the EKC hypothesis, indicating a positive correlation between economic growth and environmental emissions in the short run, with this relationship intensifying over time. To ensure data stationarity and uncover causal links, unit root tests and Granger causality tests were conducted. The Granger causality tests further indicate that CO_2 emissions serve as significant predictors of GDP, population density, and trade openness. These findings highlight the critical need for sustainable economic policies that balance growth with environmental conservation in Nepal.

Keywords: *economic growth, CO_2 emissions, population density, ARDL model Environmental Kuznets Curve*

Introduction

The world is increasingly focused on balancing environmental sustainability and economic growth due to the noticeable effects of climate change and global warming, leading to international efforts like the Paris Agreement to reduce CO_2 emissions (Scott and Gössling, 2021). The IPCC (2023) confirms that human activities, particularly greenhouse gas emissions, are the primary drivers of global warming. To address this, development models need to align with climate mitigation strategies. The EKC is widely used in economic-environmental policy analysis (Zou *et al.,* 2022), suggesting that as a country's income rises, CO_2 emissions increase initially but eventually decrease once a certain income threshold is reached. This concept, proposed by Grossman & Krueger (1995), highlights the complex relationship between economic growth and environmental quality.

As countries industrialize and develop, environmental emissions typically worsen due to increased pollution and resource consumption (Mahmood *et al.,* 2023). However, as economic growth progresses and a certain level of GDP per capita is achieved, this trend often reverses, with societies focusing more on environmental sustainability, adopting cleaner technologies, and shifting towards less resource-intensive sectors, resulting in a reduction of environmental harm (Lau *et al.,* 2023). The EKC theory suggests this pattern, where early economic growth leads to environmental damage, but after reaching a certain threshold, improvements in environmental quality occur (Barak *et al.,* 2024). Although the EKC has been supported in some contexts, especially for local pollutants, its relevance is questioned for global issues like carbon emissions (Hassan *et al.,* 2024). Increasing human consumption and a growing ecological deficit, as evidenced by the advancing date of Earth's ecological overshoot, signal the increasing strain on the planet's resources (Regmi *et al.,* 2024). Recent developments further complicate the relationship between economic growth and environmental sustainability. In some advanced nations like the United States, ecological deficits continue to grow despite economic progress (Poudel *et al.,* 2024). For instance, the U.S. announced its exit from the Paris Agreement in 2020, aiming to revive traditional, pollution-heavy industries (Gyamfi *et al.,* 2024). Similarly, countries such as Austria, the Netherlands, and Germany have reverted to coal for energy in response to the 2022 energy crisis, exacerbated by the Russia-Ukraine conflict, reflecting a broader challenge in aligning economic growth with environmental protection (Biyase *et al.,* 2024).

The traditional EKC model primarily considers factors like trade openness, institutional quality, and energy consumption (Leal & Marques, 2022). However, recent studies have expanded this framework to include additional influences on carbon emissions. These include geopolitical, political, economic, and financial risks (Anser *et al.,* 2021), technological advancements like digital technology and artificial intelligence (Ding *et al.,* 2023), the shift to renewable energy (Naeem *et al.,* 2023), and social factors such as population aging and food security (Fan *et al.,* 2021). As Stern (2017)emphasized, a broader perspective beyond economic growth is crucial for understanding the EKC. This study can contribute to reassess the EKC model's relevance for global CO_2 emissions, considering new economic, technological, and social factors. Therefore, this study aimed to analyze the EKC hypothesis in the context of Nepal, analyzing the relationship between carbon dioxide (CO_2) emissions and economic growth.

Materials and Methods

Using time series data from 1990 to 2020, this study examines whether the EKC theory holds true in Nepal. Descriptive and analytical methodologies were used in a quantitative data. Secondary data was used to evaluate the effect of the independent factors on the dependent variable. The statistical software program EViews, version 12, was used to examine this data.

Econometric Model

Baseline Model

$$CO_2 = \beta_0 + \beta_1 t + \beta_2 GDP + \beta_3 SQGDP + \beta_4 POPDEN + \beta_5 TRADE + e_t \quad (1)$$

Where:

CO_2= CO_2 emissions (metric tons per capita)

GDP= GDP per capita (PPP, USD)

SQGDP = Square of GDP per capita (PPP, USD)

POPDEN= Population density (people per square kilometer)

TRADE = Trade (% of GDP)

e_t= Error term

β_i= Coefficients

GDP represents the direct impact of economic growth, while SQGDP allows the model to account for changing effects of growth at different stages of development. Together, these variables help capture a more nuanced, non-linear relationship between economic growth and environmental impact, which is essential for models like the EKC (Lau *et al.,* 2023).Despite this, most studies overlook multicollinearity, with some arguing it's not a significant issue in EKC estimation (Narayan & Narayan, 2010).

Data Sources and Variables

Annual data for each variable was collected from the World Development Indicators (WDI) database (WB, 2024).The variables, their symbols, units, and data sources are summarized in Table 1.

Table 1

Variables, Abbreviations, Units Used in Research

Variable names	Symbols	Units	Sources
CO_2 emissions	CO_2	Metric tons per capita	WB, 2024
GDP per capita	GDP	PPP, USD	WB, 2024
Population density	POPDEN	People per sq. km. of land	WB, 2024
International Trade (% of GDP)	TRADE	% of GDP	WB, 2024
Square of GDP per capita	SQGDP	PPP, USD	WB, 2024

Sources:World Bank [WB],2024

Environmental Kuznets Curve

To test the EKC, we employed a linear model with the squared GDP term. It assesses the EKC in Nepal.CO_2 emissions are modeled as a function of their determinants (Aung *et al.,*2017)as follows:

$$CO_{2t} = f\,(GDP_t, GDP_t^2, POPDEN_t, TRADEt) \qquad (2)$$

Unit Root Testing: To prevent erroneous or misleading regression findings in time series analysis, unit root tests must be performed (Poudel *et al.,* 2024). The order of integration for each time series was ascertained using the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) and Phillips-Perron (PP) tests. The time series has to be integrated at either I(0) or I(1) in order for the Autoregressive Distributed Lag Model (ARDL) model to be relevant (Khatri *et al.,* 2024).

ARDL Approach: Being able to handle non-stationary series at the same level and perform cointegration tests without determining the degree of integration makes the ARDL approach which was developed by Pesaran *et al.* (2001).

ARDL Bound Test: A statistical technique that takes into account variables with diverse integration orders is the ARDL Bound Test, which is used to assess if a long-term link exists between variables in an Autoregressive Distributed Lag model. By calculating an F-statistics and comparing it to critical values, researchers can assess whether a co-integration relationship exists among the variables.

Granger Causality Test: Based on the idea that historical data on one variable may be used to predict future values of another, the Granger Causality Test is a statistical technique used to assess if one-time series can predict another. This test helps establish the direction of causality by examining the significance of lagged values in regression models.

Results

Descriptive Statistics

A summary of essential statistics for five variables, including CO_2 emissions, GDP, SQGDP, POPDEN, and TRADE, is presented in Table 2.

Table 2

Descriptive Analysis of Concerned Variables

Statistics	CO_2	GDP	SQGDP	POPDEN	TRADE
Mean	0.18	1964.96	4851644	177.13	46.84
Median	0.12	1629.35	2654772	183.36	46.04
Maximum	0.53	4198.84	17630263	204.73	64.04
Minimum	0.05	825.67	681723	137.18	32.19
Std. Dev.	0.14	1011.72	4973976	18.87	7.29
Skewness	1.41	0.90	1.44	-0.64	0.33
Kurtosis	3.67	2.70	3.98	2.29	2.98
Observations	31	31	31	31	31
Correlation (t-Statistic)					
CO_2	1.00				
GDP	0.96	1.00			
	(17.40)				
SQGDP	0.97	0.98	1.00		
	(22.72)	(27.75)			
POPDEN	0.74	0.85	0.76	1.00	
	(5.86)	(8.82)	(6.26)		
TRADE	0.14	-0.22	-0.19	-0.12	1.00
	(0.74)	(-1.21)	(-1.06)	(-0.64)	

Table 2 presents the descriptive analysis of the concerned variables, showing notable variations in CO_2 emissions. The average CO_2 emissions per capita are 0.18 metric tons, ranging from 0.05 to 0.53, with a high standard deviation of 0.14, indicating annual variation over a 31-year period in Nepal. GDP per capita averages 1964.96 USD, also showing considerable variation (Std. Dev. 1011.72). The squared GDP (SQGDP) displays a strong right skew (Skewness of 1.44), reflecting its exponential nature. Population density averages 177 people per square kilometer, with a smaller standard deviation (18.87) and a left-skewed distribution. Trade as a percentage of GDP averages 46.85%, with moderate variation and a nearly normal distribution (Skewness of 0.33).

The correlation analysis shows a strong positive correlation between CO_2 emissions and both GDP (0.96) and SQGDP (0.97). This implies that rising income levels are linked to a stronger correlation between economic expansion and rising CO_2 emissions. Population density also positively correlates with CO_2emissions (0.74). However, trade openness has a weak and statistically insignificant negative correlation with CO_2 emissions (-0.14).

Time Series Plots

Figure 1 presents time series plots that illustrate the trends and fluctuations of key variables over the observed period, highlighting their temporal dynamics. These visualizations offer insights into patterns and potential correlations among the variables.

Figure 1

Time Series Plots of the Variables Analyzed in the Study

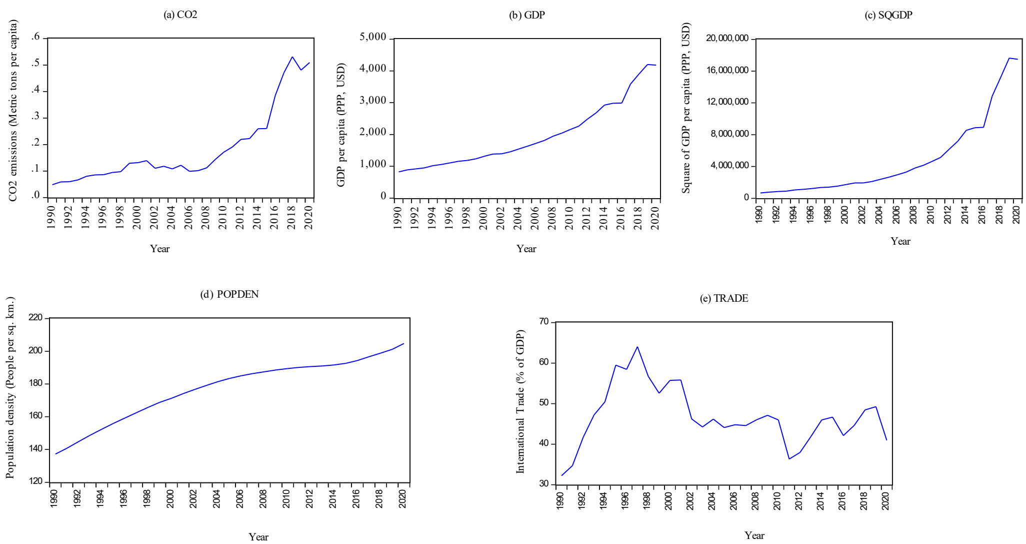


Figure 1 displays time series plots for the five variables analyzed in the study, providing a visual representation of their trends over the 31-year period in Nepal. Each plot offers insight into the temporal behavior of the variables, allowing for a better understanding of how they evolve over time. Figure 1(a) shows the trend in CO_2 emissions, which appears to fluctuate annually, reflecting changes in economic activities, industrialization, and policy measures related to emissions. Figure 1(b) illustrates the pattern of trade, which shows variation likely driven by external economic factors, such as global market conditions and trade agreements. Figure 1(c) presents data on population growth, indicating a steady increase over the years, which may correlate with rising emissions due to urbanization and economic concentration. Figure 1(d) displays energy consumption, which also shows growth, possibly linked to higher demand for energy in line with economic development. Finally, Figure 1(e) represents industrial production, highlighting periods of expansion and contraction that align with shifts in economic cycles. Together, these plots enable a comprehensive view of how the variables interact over time, providing a basis for understanding the relationships between trade, population, energy, industrialization, and CO_2 emissions in Nepal.

The Unit Root Testing

The unit root test is used to assess the stationarity of the data. The PP test and KPSS test serve as unit root tests that determine if the variables meet the stationarity condition.

Table 3

Results of Individual Unit Root Test

Unit Root test table (PP)Null Hypothesis (H_0): The series is non-stationary						
At Level		CO_2	GDP	SQGDP	POPDEN	TRADE
With Const.	t-Statistic	1.46	6.27	6.99	-3.51**	-2.47
With Const.& Trend	t-Statistic	-0.53	1.61	3.22	-2.33	-2.89
At First Difference		d(CO_2)	d(GDP)	d(SQGDP)	d(POPDEN)	d(TRADE)
With Const.	t-Statistic	-4.17***	-3.69***	-3.23**	-	-4.11***
With Const.& Trend	t-Statistic	-5.85***	-5.66***	-4.46***	-	-4.34***
Unit Root Test table (KPSS)Null Hypothesis (H_0): The series is stationary						
At Level		CO_2	GDP	SQGDP	POPDEN	TRADE
With Const.	t-Statistic	0.59**	0.69**	0.63**	0.71**	0.17
With Const.& Trend	t-Statistic	0.17**	0.19**	0.19**	0.18**	0.10
At First Difference		d(CO_2)	d(GDP)	d(SQGDP)	d(POPDEN)	d(TRADE)
With Const.	t-Statistic	0.51**	0.63**	0.57**	0.43*	0.28
With Const.& Trend	t-Statistic	0.14*	0.33***	0.17**	0.15**	0.12*

****Significant at the 1%;**Significant at the 5%; * Significant at the 10% and t-Statistics are rounded after two decimal place. Const.= Constant*

The majority of the variables (CO_2, GDP, SQGDP, POPDEN, and TRADE) are non-stationary at their levels but become stationary after initial differencing, according to Table 3's findings of the unit root tests from the PP and KPSS tables. POPDEN is stationary in the PP test at level with a constant, but other variables need to be differencing in order to be stationary. This is corroborated by the KPSS test, which shows that although CO_2, GDP, SQGDP, and POPDEN become stable only after first differencing, TRADE is stationary at level with a constant. The majority of variables, according to these findings, are integrated of mixed orders, I(0) and I(1). A typical finding of the PP and KPSS tests is that for all-time series at their initial differences, the null hypothesis of unit roots may be rejected. Both the PP and KPSS tests show that the unit root null hypothesis may be rejected for all-time series at their initial differences, which is consistent with previous findings (Frimpong & Oteng-Abayie, 2007). Because they test the null hypothesis of stationarity and adjust for an AR (1) coefficient, respectively, the PP and KPSS tests are very useful (Ibrahim *et al.,* 2011). Therefore, for trustworthy econometric analysis, these variables should be employed in their differenced form to prevent problems with spurious regression.

Table 4

VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-798.30	NA	7.90e+17	55.40	55.64	55.47
1	-533.48	420.07	5.34e+10	38.86	40.27*	39.30
2	-502.78	38.11*	4.27e+10*	38.47*	41.06	39.28*

Lag 2 has the lowest FPE, AIC, and HQ values, suggesting superior model fit, according to the VAR Lag Order Selection Criteria table, making it the best option for the model. However, the SC criterion favors Lag 1 for a simpler model. Overall, Lag 2 is preferred based on most criteria.

ARDL Model

Within a time series context, the ARDL model is used to evaluate both short- and long-term connections among variables (Poudel *et al.,* 2024).

With an R-squared of 0.99, the ARDL model findings show a high match and account for about 98.9% of the variation in CO_2 emissions. The lagged CO_2 variable (CO_2 (-1)) is significant, suggesting persistence in CO_2 emissions over time. GDP positively impacts CO_2, while the squared GDP (SQGDP) has a negative coefficient, indicating a nonlinear relationship—likely an EKC effect. Population density (POPDEN) is significant, showing a mixed impact with a positive effect initially but a negative impact at lag 2. Trade variables (TRADE) are mostly insignificant, except for TRADE (-2), which is marginally significant. The model's diagnostics suggest good overall performance, with a significant F-statistic and a Durbin-Watson statistic close to 2, indicating no severe autocorrelation issues.

Table 5

ARDL Model Result

Selected Model: ARDL(1, 0, 0, 2, 2)

Variables	Coefficient	Std. Error	t-Statistic	Prob.*
CO_2(-1)	0.56	0.21	2.61	0.02
GDP	0.000679	0.00	6.65	0.00
SQGDP	-1.05E-07	1.81E-08	-5.78	0.00
POPDEN	0.04	0.01	2.83	0.01
POPDEN(-1)	0.01	0.03	0.26	0.79
POPDEN(-2)	-0.05	0.02	-2.44	0.02
TRADE	-0.0001	0.00	-0.12	0.91
TRADE(-1)	-0.001	0.00	-0.66	0.52
TRADE(-2)	0.002	0.00	1.72	0.10
C	-0.47	0.18	-2.63	0.02
R-squared	0.99	Mean dependent var		0.19
Adjusted R-squared	0.98	S.D. dependent var		0.14
S.E. of regression	0.02	Akaike info criterion		-4.92
Sum squared resid	0.01	Schwarz criterion		-4.45
Log likelihood	81.41	Hannan-Quinn criter.		-4.78
F-statistic	193.31	Durbin-Watson stat		2.66
Prob. (F-statistic)	0.00			

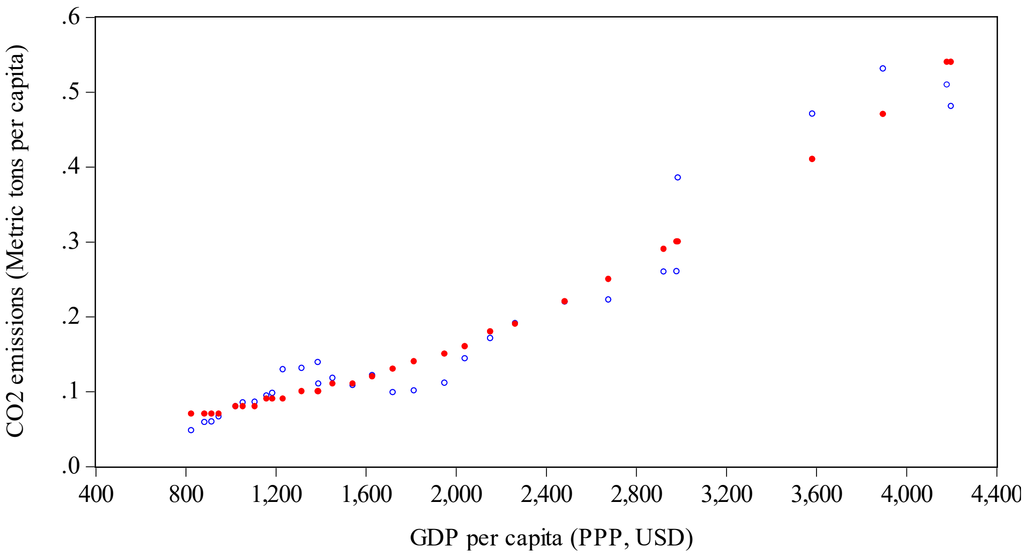
EKC in Nepal

Figure 2 presents the EKC for Nepal, highlighting the connection between economic development and environmental emissions. This curve generally indicates that while environmental quality deteriorates at the early stages of economic growth, it begins to improve once a specific income per capita threshold is attained.

The turning point of the Environmental Kuznets Curve (EKC) in Nepal, based on the given coefficients for GDP (0.000679) and squared GDP (SQGDP = -1.05×10^{-7}), occurs at a GDP per capita of approximately 3238.1 PPP, USD. This turning point suggests that, below this level of GDP per capita, economic growth is associated with an increase in CO_2 emissions. However, once GDP per capita surpasses this threshold, further economic growth is expected to lead to a reduction in CO_2 emissions, in line with the inverted U-shaped relationship proposed by the EKC theory. Thus, the turning point indicates that after reaching a certain level of economic development, Nepal may begin to experience environmental improvements as economic growth continues.

Figure 2

Environmental Kuznets Curve in Nepal



ARDL Long Run Form and Bounds Test

The co-integrating equation, which is created when co-integration is found and suggests a common stochastic trend, represents the long-term link between the variables under analysis in the context of the ARDL model (Poudel *et al.,* 2024). According to the co-integration test hypothesis, H_0 states that a co-integrating equation is absent, whereas H_1 states that one exists. To learn more about these long-term correlations between the variables, the ARDL Long Run Form and Bounds Test are also used.

Table 6

ARDL Long Run Form and Bounds Test

Null Hypothesis: No level relationship	Value of Statistics
Computed F- Statistics	10.24
5% Critical Value(Actual Sample Size)	
Value in Lower Bound	3.06
Value in Upper Bound	4.22

The absence of a long-run equilibrium relationship that is, no cointegration between the variables is the null hypothesis. At a 5% level of significance, the computed F-statistic, 10.24, is compared to the critical values. The critical values for the lower and upper bounds are 3.06 and 4.22, respectively.

It has rejected the null hypothesis because the estimated F-statistic (10.24) is substantially more than the upper limit critical value (4.22). This indicates the presence of a level relationship or co-integration among the variables, suggesting that they share a long-term equilibrium relationship.

Table 7

Long Run Coefficients in the EKC Framework

Variables	Coefficient	t-statistic
GDP	0.001	6.65
SQGDP	-1.05E-7	-5.78
POPDEN	0.04	2.83
TRADE	-0.0001	-0.12
C	-0.47	-2.63
R^2	0.99	

The high t-statistic indicates that the GDP coefficient is positive and statistically significant. Holding all other factors fixed, CO_2 emissions per capita rise by around 0.001metric ton per capita for every PPP, USD increase in GDP per capita. The EKC theory is supported in the context of economic growth by the positive coefficient, which indicates that CO_2 emissions tend to rise as GDP per capita grows. The coefficient for SQGDP is negative and significant. This indicates a quadratic relationship between GDP and the environmental outcome. The negative coefficient indicates that once a certain threshold of GDP is attained, subsequent increases in GDP result in a decline in environmental emissions, thereby aligning with the inverted U-shaped pattern proposed by the EKC hypothesis. The coefficient for population density is positive and significant. This implies that higher population density is associated with increased environmental emissions. This could be due to the greater resource consumption and waste production associated with higher population densities. The coefficient for trade openness is very close to zero and statistically insignificant. This suggests that, in this model, trade openness does not have a significant impact on environmental emissions. Therefore, further investigation with more comprehensive sectoral trade data or an exploration of potential lag effects might provide a clearer picture of trade's impact on environmental outcomes in Nepal.

Table 8

Short Run Coefficients in the EKC Framework

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(POPDEN)	0.04	0.01	4.79	0.00
D(POPDEN(-1))	0.05	0.01	3.82	0.00
D(TRADE)	-0.00	0.00	-0.18	0.86
D(TRADE(-1))	-0.00	0.00	-2.41	0.03
CointEq(-1)*	-0.44	0.05	-8.81	0.00

Within the context of the EKC, the short-term study yielded significant insights into the relationships between explanatory factors and CO_2 emissions, thanks to the calculated coefficients. The current change in population density (D(POPDEN)) has a positive and statistically significant coefficient (0.04) with a high t-statistic (4.79), indicating that short-term increases in population density significantly raise CO_2 emissions. This effect is further supported by the positive coefficient for the lagged change in population density (D(POPDEN (-1))) at 0.05, showing that past increases in population density continue to exert a notable influence on current CO_2 emissions. In contrast, the coefficient for the current change in trade openness (D(TRADE)) is negligible and statistically insignificant (p-value 0.86), suggesting that short-term fluctuations in trade do not significantly impact emissions. However, the lagged change in trade openness (D(TRADE(-1))) has a negative and significant coefficient (-0.00), indicating that past trade openness decreases CO_2 emissions over time, possibly due to efficiency gains or shifts in production practices. The error correction term's (CointEq (-1)) highly significant negative coefficient, at -0.44, highlights a robust correction mechanism that quickly corrects short-term deviations from the long-term equilibrium in CO_2 emissions. This strengthens the model's ability to gradually return to equilibrium.

Granger Causality Test

The Granger Causality Test is a popular technique for analyzing the causal linkages between the variables in the model. According to Poudel *et al.* (2023), a significant result means that past values of the proposed predictor variable may be used to forecast the dependent variable.

Table 9

Granger Causality Test

Null Hypothesis:	Obs	F-Statistic	Prob.
GDP →CO_2	29	3.29	0.05
CO_2→GDP		22.10	4.E-06
SQGDP →CO_2	29	2.90	0.07
CO_2→SQGDP		35.80	6.E-08
POPDEN CO_2	29	0.86	0.44
CO_2→POPDEN		13.38	0.00
TRADE →CO_2	29	0.47	0.63
CO_2→TRADE		2.98	0.07
SQGDP →GDP	29	1.31	0.29
GDP →SQGDP		1.49	0.25
POPDEN GDP	29	0.15	0.86
GDP →POPDEN		17.54	2.E-05
TRADE →GDP	29	1.29	0.29
GDP →TRADE		3.15	0.06
POPDEN SQGDP	29	0.38	0.69
SQGDP →POPDEN		20.82	6.E-06
TRADE →SQGDP	29	0.97	0.39
SQGDP →TRADE		2.48	0.11
TRADE →POPDEN	29	1.12	0.34
POPDEN TRADE		3.74	0.04

The Granger causality test results show the predictive relationships between variables like GDP, CO_2 emissions, population density (POPDEN), and trade. A low p-value (typically < 0.05) indicates rejection of the null hypothesis, meaning one variable can predict another. For instance, CO_2 significantly Granger-causes GDP ($p = 4.E-06$), indicating CO_2 emissions can predict GDP. However, GDP does not significantly predict CO_2 ($p = 0.05$). Similarly, population density does not Granger-cause CO_2 ($p = 0.44$), but CO_2 does Granger-cause population density ($p = 0.00$). These findings suggest that CO_2 emissions play a predictive role in other variables, highlighting potential feedback loops in economic and environmental interactions.

Table 10

Diagnostics and Stability Tests

Diagnostics	Statistics	p-value
Normality(J-B)	4.83	0.09
Serial Correlation $\chi^2(1)$	0.19	0.07
B-G Test(Scaled explained SS)	7.98	0.54
Ramsey RESET(F_{STAT})	1.89	0.19

The diagnostic and stability tests for the regression model suggest that the model meets several key assumptions. The Jarque-Bera test for normality yields a p-value of 0.09, indicating that there is no strong evidence against the normality of the residuals, which is acceptable given that the result is above the 0.05 threshold. The serial correlation test shows a p-value of 0.07, suggesting that while there is some evidence of autocorrelation, it is not strong, and the model's residuals are generally free from serial correlation. The Breusch-Godfrey test, with a p-value of 0.54, further supports this, showing no significant higher-order autocorrelation issues. Finally, the Ramsey RESET test, with a p-value of 0.19, indicates that the model is likely correctly specified, with no substantial evidence of specification errors. Overall, these results suggest that the model is well-specified, with residuals behaving in accordance with the key assumptions of normality and lack of autocorrelation.

Discussion

According to the ground breaking research of Grossman and Krueger (1995), which found an inverted U-shaped correlation between economic development and environmental emissions, the results of this study primarily support the EKC hypothesis within the Nepalese context. The inflection point in Nepal occurs at a lower GDP per capita compared to more industrialized nations, reflecting its developing economy. In contrast to industrialized countries where higher population density often correlates with increased CO_2 emissions due to industrial activities (Shi, 2003), Nepal exhibits a more significant impact of population density, likely due to the widespread use of biomass and inefficient energy sources in rural regions.

The study also reveals that trade openness has a weak and statistically insignificant relationship with CO_2 emissions in Nepal, differing from findings in regions like the MENA countries where trade exacerbates environmental emissions(Gorus& Aslan, 2019). This discrepancy may be attributed to Nepal's lower level of industrialization and focus on less pollution-intensive trade sectors. The observed short-run increase in CO_2 emissions with GDP growth, followed by a long-run reduction, mirrors findings from emerging economies like China (Wang *et al.,* 2017), though Nepal's transition period is notably longer. Additionally, the slower adoption of green technologies in Nepal, compared to G7 countries (Li &Haneklaus, 2022), contributes to this lag. The minor role of energy consumption in driving CO_2 emissions, as seen in Nepal, contrasts with its significance in countries like Turkey (Tutulmaz, 2015), likely due to Nepal's reliance on less carbon-intensive hydroelectric power. While the unique causation between CO_2 and population density emphasizes regional demographic pressures, the bidirectional causality between CO_2 emissions and GDP in Nepal is comparable with observations in Turkey (Jebli& Youssef, 2015). Although the EKC hypothesis is confirmed in Nepal, its applicability varies by region, as seen in MENA countries where the EKC is not always observed (Fakih &Marrouch, 2019). The less pronounced impact of trade on CO_2 emissions in Nepal, compared to newly industrialized countries (Ghazali & Ali, 2019), emphasizes the current economic structure of Nepal. These findings emphasize the need for Nepal to implement sustainable development policies, particularly addressing population density and trade practices, aligning with recommendations for other developing nations (Ohlan, 2015).

Conclusion and Implications

The results confirm the EKC hypothesis for Nepal, showing that CO_2 emissions initially rise with GDP per capita but decline as the economy develops. The findings also highlight the significant role of population density in driving CO_2 emissions, while trade openness has a less direct impact. These results emphasize the need for sustainable economic policies that balance growth with environmental conservation, particularly in developing countries like Nepal.

Policymakers should prioritize strategies that foster economic growth while mitigating environmental impacts through cleaner technologies and energy efficiency. With population density significantly influencing emissions, effective urban planning and population management are essential. Although trade openness has a weaker link to CO_2 emissions, monitoring its environmental effects is crucial as Nepal increases global trade. Integrating environmental concerns into Nepal’s Sustainable Development Goals (SDGs) will help balance growth and sustainability. This research contributes to the EKC literature by offering a context-specific analysis of Nepal, a less industrialized nation with unique challenges. The study’s use of the ARDL model captures both short- and long-term dynamics, while Granger causality tests provide insights into the interconnections between GDP, emissions, population density, and trade. The findings not only support the EKC hypothesis for Nepal but also emphasize the importance of demographic factors, offering significant policy implications for Nepal and similar developing economies.

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