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Revisiting the Environmental Kuznets Curve in Nepal: Role of Energy Transition in Economic Growth

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ABSTRACT

Sustainable energy consumption, economic growth and carbon emission (CO_2) is an ongoing global agenda for optimizing energy use including Nepal. This paper examines the effect of renewable energy consumption, economic growth, urban population growth, and trade openness on CO_2 in Nepal, revisiting environmental Kuznets Curve (EKC). The time series analysis was done using ARDL framework to examine whether Nepal follows the EKC pattern, which indicates that environmental degradation first increases with economic growth and later declines after reaching a certain level. The estimated long-run coefficients show that a percent increase in GDP growth rate is associated with 0.012 percent fall in CO2 emission. However, a 1 percent increase in squared GDP growth is associated with 0.001 unit rise in CO2 emission in Nepal. Moreover, a 1 percent rise in renewable energy use and urban population growth is associated with 0.21 percent and 0.043 percent fall in CO2 emission respectively. Finally, the result shows that a 1 percent raise in trade openness is associated with 0.12 percent raise in CO2 emission. Moreover, the error correction term (ECT) is negative and statistically significant at the 1 percent level, with a coefficient of -0.5612, which confirms the existence of a stable long-run equilibrium relationship among the variables. Therefore, the coefficient indicates that approximately 56.1 percent of the previous period's deviation from the long-run equilibrium is corrected in the current period. Hence, the significance and appropriate sign of the ECT validate the long-run causality included in the model as dependent and explanatory variables, supporting co-integration among them. This paper contributes to the ongoing debate regarding optimization energy consumption by providing Nepal-specific evidence on the complex interplay between energy consumption, economic growth and carbon emission.

Key Words: Energy consumption, GDP growth, CO_2 emission, Environmental Kuznets curve

JEL Classification: Q56, Q43, C32

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Introduction

The sustainable use of overall environmental resources is a central concern around the world in the context of examining linkage amongst the variable energy consumption, economic growth and CO_2 emission. In this regard, energy transition with a view to strike balance between economic growth and environment sustainability is a pivotal phenomenon in the contemporary world. With this line of thinking, energy transition pattern is rigorously analyzed with the help of popular analogy term as Environmental Kuznets Curve (EKC). Moreover, the EKC hypothesis postulates an inverted U-shaped relationship between pattern of environmental degradation and pace of economic growth and development (Grossman & Kruger, 1991). The hypothesis underscores that economic growth initially worsens environment in the process of transitioning economy from low to high income, followed by the beginning of improvements after turning points (Dinda, 2004). In this regard, Nepal has witnessed increase in energy demand, CO_2 emission, corresponds with GDP growth averaging around 4 percent over the past decade (World Bank, 2023; International Energy Agency, 2024). Hence, Nepal, being an emerging South Asian economy, provides a compelling case for revisiting the EKC. In this context, reducing energy intensity is vital for lowering carbon footprints without exacerbating economic growth (Ang, 2007). Therefore, this paper aims to investigate the dynamic linkage amongst the variable energy consumption, economic growth, urban population growth, trade openness, and CO_2 emission within the study period. Essentially, the paper has critical focus on the linkage amongst the variables of interest renewable energy consumption, economic growth and environmental sustainability. The study also aims examine causal direction of above selected variables. Given the global context of maintaining balance between economic growth with ecological preservation, the theme is relevant to revisit the EKC hypothesis in Nepal's context and expected to aid policymakers in designing strategies that balance economic growth with ecological preservation in Nepalese context too (Shafik & Bandyopadhyay, 1992). Hence, examining whether the EKC hypothesis confirms in Nepal is expected to offer insights into its policy frameworks for sustainable development.

Theoretical Perspectives

The theories underscore that there is non-linear relationship amongst the variables of interest variable energy consumption, economic growth and CO_2 emission. It postulates that in the initial stages of development, rising income levels lead to increased environmental degradation due to greater energy use and increased industrial activity. However, as income continues to grow,

economies began adopt cleaner technologies, implement stricter environmental regulations, and shift towards less polluting and clean energy use, resulting in reduced emissions (Stern, 2004). As a result, an inverted U-shaped curve, where pollution first increases and then declines as income reaches a certain threshold with in an economy. Evidently, Nepal is undergoing structural transformation, but its economy is still heavily reliant on imported fossil fuels and traditional biomass contributing CO2 emission with high intensity. In this context, this paper analyzes GDP growth interaction with energy intensity and this analysis is critical for better understanding of sustainable development trajectory (Grossman & Krueger, 1995).

Empirical Review

The linkage between energy consumption, GDP growth and environmental degradation has long been debated within the realm of environmental economics. Central to this discourse is the Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted-U-shaped relationship between income and pollution. According to this hypothesis, environmental degradation initially increases with economic growth but eventually declines after a certain income threshold is reached, due to structural shifts, improved technology, and stronger environmental regulations. The summary is presented subsequently.

Table 1

Literature Review Matrix

Author(s) Years	Methodology	Major Findings
Jalil & Mahmud (2009)	ARDL Model	The carbon emissions in the long relationship are mainly caused by income and the consumption of energy, and trade has statistically insignificant but positive influence on the level of carbon emissions.
Akbostancı et al. (2009)	Time Series and Panel Data Analysis	The study finds a monotonically increasing relationship between CO_2 emission and national income. The result does not support EKC hypothesis.
Apergis & Payne (2010)	Panel Vector Error	The findings of this paper indicate that energy consumption has significant effect on CO_2 emission

	Correction Model	in the long-run and real output is showing inverted U-shaped curve corresponding to the EKC hypothesis.
Ghosh (2010)	ARDL F-bound testing and Johansen–Juselius techniques	This study findings suggest neither long-run equilibrium nor long-run causality between emission and economic growth. However, it reveals a short-run causality from economic growth to energy supply, followed by the energy supply to CO_2 emission.
Fodha & Zaghdoud (2010)	Time series data and cointegration analysis	This study result suggests Tunisia can pursue emission reduction and pollution control policies without harming economic growth, supporting sustainable development in the long run.
Pao & Tsai (2011)	Panel Granger causality test	The findings of this study confirm EKC validity, showing that carbon emissions are elastic to energy consumption, strong causality links output with both emissions and energy use with emissions.
Shahbaz et al.(2012)	ARDL bound test	The study uncovers causality from economic growth to CO_2 emission, and also underscores that increased energy consumption affects CO2 emission in both short-run and long-run. It also supports the EKC hypothesis.
Saboori et al.(2012)	ARDL and Granger Causality test	This study finds an inverted-u shaped relationship between carbon emissions and GDP in both short and long-run, thus supporting the EKC hypothesis.
Shahbaz et al.(2013)	ARDL bound test approach to cointegration	This study confirms the EKC hypothesis and indicating that South Africa can sustain growth while protecting the environment through efficient energy use and supportive financial policies.
Tiwari et al.(2013)	ARDL bound test	This study concludes the confirmation of EKC hypothesis in both short-run and long-run, followed

		by the revelation of causality feedback between economic growth and CO_2 emissions, as well as between coal use and emissions.
Boutabba (2014)	Time series Analysis	This paper reveals a long-run positive impact of financial development on carbon emissions, indicating environmental degradation. These insights are crucial for policymakers to design energy and financial policies that reduce emissions without hindering economic growth.
Apergis & Ozturk (2015)	GMM methodology in a multivariate panel data framework	This study results suggest that income and institutional quality significantly influence environmental outcomes in Asia, providing empirical backing for environmentally focused policy development.
Shahbaz et al.(2018)	ARDL with the bootstrapping bounds testing approach	This study results reveal economic growth and emissions follow an inverted-U pattern, validating the EKC.
Sarkodie & Strezov (2019)	Meta-Analysis	This meta-analysis finds an average EKC income turning point of $8,910, with low- income and middle-income countries below this level and high-income countries above. Moreover, results highlight heterogeneity in turning points due to differing study periods and methods.
Leal & Marques (2022)	Systematic Review	This study identifies gaps in EKC analysis, including its failure to consider imported goods' environmental impacts, relocation of polluting industries, and inefficiencies in the inverted U-shaped growth path.

		It argues that EKC's focus on production neglects critical aspects of consumption and global emissions. The study suggests that technological progress, climate finance, and energy transition can enhance EKC evaluations.
AlKhars et al. (2022)	Systematic Review	This study revealed mixed support for EKC across the GCC. Logistic regression showed that including control variables with GDP and using panel data significantly influenced EKC validation, while factors like publication year, data breaks, study length, and methodology had no significant impact.
Voumik et al.(2023)	The Augmented Mean Group (AMG) method	This study finding show EKC doesn't hold; instead, a U-shaped link exists between GDP and pollution. Fossil fuels increase emissions, while renewable and nuclear energy reduce them in the long term. Moreover, the study urges SAARC nations to adopt clean energy for sustainable economic and environmental progress.
Jaeger et al. (2023)	Systematic Review	This study findings confirm robust inverted U-shaped relationships between air pollution, income, and population density, offering new insights into the EKC hypothesis and the challenges of decoupling economic growth from environmental degradation.
Poudel et al.(2024)	Time Series Analysis	This investigation reveals correlation between CO2 emission, socio-economic factors and renewable energy consumption based on the data spanning from 1991 to 2020 of Nepal, revealing a positive correlation with economic growth, confirming the EKC hypothesis.

Several empirical studies provide evidence of confirming the EKC, particularly in middle- income and high-income economies. Grossman and Krueger (1995) first identified this relationship while examining air pollutants in a cross-country panel. Similarly, Selden and Song (1994) confirmed the EKC for various air pollutants in the United States. In the context of emerging economies, Jalil and Mahmud (2009) found a long-run EKC relationship for carbon dioxide emissions in China, while Nasir and Rehman (2011) provided similar evidence for Pakistan. Fodha and Zaghdoud (2010) observed the EKC for local pollutants in Tunisia, suggesting that environmental quality can improve at higher income levels under certain conditions. However, the EKC is not universally valid. Based on the context of Nepal's heavy reliance on biomass, and imported fossil fuels, growing pressure of urbanization, it is pertinent to test whether Nepal exhibits any EKC behavior or emission continue to rise with growth in the absence of strict environmental regulation. Therefore, this paper contributes to the EKC literature by empirically testing the relationship between economic growth and environmental degradation in Nepal using time-series data from 1980–2024, incorporating additional control variables such as energy use, urbanization, trade openness, and renewable energy share to improve the robustness of the EKC model.

Data and Methodology

Research Design

This analysis uses time series data spanning from 1980-2024. Therefore, it adopts longitudinal research design with the application of econometric method specifically the Autoregressive Distributive Lag (ARDL) model. It is so because it confirms the condition of mixed order stationarity of time series nature of data at level and after first difference. Moreover, the Bei-perron structural break test was conducted and interaction terms are used to fix the issue. Likewise, the ARDL frameworks follows the process of bound testing approach, followed by estimation of short-run and long run long-run, diagnostic test and stability test

Research Philosophy

The current paper adopts a post-positivist paradigm of research, assuming a critical-realist ontology that postulates reality exists independently of human perception. In this context, the epistemological stance is objectivism, indication that knowledge is gained through empirical evidence such as the data on energy consumption, GDP growth, CO2 emission and so on. In axiological perspectives, the study maintains neutrality, minimizing bias and subjectivity from

sites of the researchers. Finally, it follows deductive approach as a deductive process in methodological perspectives.

Nature and Sources of Data

This analysis used annual time series data on selected variables carbon dioxide (CO_2) emission, GDP growth rate, square of GDP growth, renewable energy consumption Kilo Watt hours (KWH) per capita, urban population growth, and trade openness from 1980 to 2024. Moreover, variables, their nature and sources are presented in Table 2.

Table 2

Variables, Nature of Data and Sources

Variable Code	Nature	Definition	Data Sources
CO_2	Dependent Variable	Carbon dioxide emission per capita in ton	World Bank
GDP	Independent Variable	GDP growth rate in constant term	World Bank
GDP^2	Independent Variable	Squared GDP growth rate in constant term	World Bank
REC	Control Variable	Renewable energy consumption per capita Kilo Watt hours	Nepal Rastra Bank
UPG	Control Variable	Urban population growth percent	World Bank
TO	Control Variable	Total import and export value in USD	Nepal Rastra Bank

Note. Table 2 presents the details of variables and their measurement and definition including sources of data.

Tools and Techniques of Data Analysis

The data analysis procedure follows the standard econometric approach as stationarity test, structural break-test, descriptive statistics, ARDL modelling framework and all the test relating to diagnostic test and stability test. The computer software package Eviews 10 applied.

Specification of Empirical Model

The empirical model is presented as:

$$CO2_t = f(\text{GDP growth}, (\text{GDP growth})^2, \text{RECt}, \text{UPGt}, \text{TOt}) \quad \ldots(1)$$

In equation (1) above, $CO2_t$, GDP growth, GDP growth^2 , RECt, UPGt, and TOt denotes carbon dioxide (CO_2) emission per capita ton, GDP growth rate, square of GDP growth, renewable energy consumption Kilo Watt hours (Kwh) per capita, urban population growth, and trade openness in Nepal for the time 't' respectively. The model is specified in linear and log form as the variables CO2, GDP growth rate, square of GDP growth rate are included linear form and remaining others are transformed into log form. The equation (1) can be presented in econometric form as follows:

$$CO2_t = \alpha + \beta_1(\text{GDP growth}) + \beta_2(\text{GDP growth})^2 + \ln\beta_3(\text{REC})t + \ln\beta_4(\text{UPG})t + \ln\beta_5(\text{UPG})t + e_t \quad \ldots(2)$$

In equation (2) above, α, β and ln stand for intercept, slopes of parameters, and natural logarithm respectively.

ARDL Model

The ARDL (p, q) model in general form is presents as follows:

$$Y_t = \alpha_0 + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{j=0}^{q} \gamma_i X_{t-j} + \varepsilon_t \quad \ldots(3)$$

In the equation (3) above, Y_t, Y_{t-i}, X_{t-j}, α_i and β_j denote dependent variable, lag of dependent variable, vector of independent variables, intercept coefficients to be estimated and slope coefficient to be estimated. Likewise, in the equation p and q represent lag orders, ε_t as the residuals.

The ARDL model was estimated based on the lag length criteria provided the Akaike Information Criterion (AIC) to choose optimal lag length. In the ARDL framework, examining long-run relationship of the variables included in the model is essential using F- bound test. Hence, to test if the variables have a long-run relationship, the F-test was performed based on the following Pesaran, Shin and Smith (2001) generalized form of applied ARDL model. The equation for F-bound test is:

$$CO_2t = \beta_0 + \beta_1 (CO_2)_{t-1} + \beta_2 (\text{GDP growth})_{t-1} + \beta_3 (\text{Squared GDP growth})_{t-1} + \beta_4 \ln(\text{REC})_{t-1} + \beta_5 \ln(\text{UPG})_{t-1} + \beta_5 \ln(\text{TO})_{t-1} + \sum \gamma_i \Delta ln(CO_2)_{t-i} + \sum \delta_j \Delta ln(\text{GDP growth})_{t-j} + \sum \lambda_k \Delta ln(\text{Squared GDP growth})_{t-k} + \sum \theta_l \Delta ln(\text{REC})_{t-l} + \sum \mu_m \Delta ln(\text{UPG})_{t-m} + \sum \Psi_n \Delta ln(\text{TO})_{t-n} + \varepsilon_t \quad \ldots(4)$$

In equation (4), β_0 , β_1, β_2 … β_5 are coefficients to be estimated and subscript $_{t-1}$ implies lagged value, **Δ** represents the first difference of the variables. Similarly, γi, δj, λk, θ_l, μ_m and Ψ_n are the short-run dynamics (coefficients of the first differenced variables). Others are described as follows:

CO_2t = The natural log of the carbon emission for the time t.

$(\text{GDP growth})_{t-1}$ = The natural log of GDP growth rate at time t-1.

$(\text{Squared GDP growth})_{t-1}$= The natural log of squared of GDP growth rates at time t-1.

$\ln(\text{REC})_{t-1}$= The natural log of renewable energy consumption at time t-1.

$\ln(\text{UPG})_{t-1}$= The natural log of urban population growth arte at time t-1.

$\ln(\text{TO})_{t-1}$ = The natural log of total trade at time t-1.

ε_t = Error term.

The ARDL model for estimating long-run coefficient can be specified as follows:

$$\ln CO2_t = \alpha + \beta_1(\text{GDP growth}) + \beta_2(\text{GDP growth})^2 + \ln\beta_3(\text{REC})t + \ln\beta_4(\text{UPG})t + \ln\beta_5(\text{UPG})t + e_t \quad \ldots(5)$$

Moreover, the ECM in the ARDL approach to co-integration, the lagged error correction term is generated out of the long-run coefficients to replace a linear combination of the lagged variables, and the model is re-estimated at the optimum lags selected by using model selection criterion. The ECM for estimating short-run coefficient and error correction term is presented as follows:

$$CO_2t = \propto + \delta_j \Delta(\text{GDP growth})_{t-j} + \lambda_k \Delta(\text{Squared GDP growth})_{t-k} + \theta_l \Delta\ln(\text{REC})_{t-l} + \mu_m \Delta\ln(\text{UPG})_{t-m} + \Psi_n \Delta ln(\text{TO})_{t-n} + \gamma \text{ECT}_{t-1} + \varepsilon_t \quad \ldots(6)$$

In equation (6), $\propto$, δ_j, λ_k, θ_l, μ_m, Ψ_n and γ are coefficients to be estimated. Other noted variables are described hereunder:

CO_2t = Lagged change in the natural log of the carbon emission for the time t.

GDP growth $_{t-1}$ = Lagged change in the natural log of GDP growth rate at time t-1.

$GDP^2{}_{t-1}$= Lagged change in the natural log of squared of GDP growth rates at time t-1.

$\ln(\text{REC})_{t-1}$= Lagged change in the natural log of renewable energy consumption at time t-1.

$\ln(\text{UPG})_{t-1}$= Lagged change in the natural log of urban population growth arte at time t-1.

$\ln(\text{TO})_{t-1}$ = Lagged change in the natural log of total trade at time t-1.

ε_t = Error term.

Diagnostic Test

In the ARDL modelling framework, diagnostic test is needed to ensure the best linear unbiased estimator (BLUE) property inherent in the coefficients. In this, regard, the researcher also went through such diagnostic test. The undergone tests are Ramsey Regression Equation Specification Error Test (RESET) test, J-B test for the normality of the residuals LM Test for Serial Correlation, Test for Heteroscedasticity, and the stability test are conducted and reported.

Empirical Result and Discussion

The current sector of the empirical results and discussions are presented subsequently starting from table 1 to table 12 including figure 1.

Descriptive Statistics Interpretation

The summary result of descriptive statistics is presented in Table 3. CO_2 emissions have a positive skew (1.37), indicating more low-value observations with a few high extremes. GDP and GDP squared show moderate to high dispersion (SD = 2.40 and 22.52), with GDP squared being highly skewed (1.49) and leptokurtic (kurtosis = 4.93), indicating heavy-tailed distribution. The distribution of $lnGDP^2$ is significantly non-normal. Renewable energy consumption(lnREC) appears symmetric and roughly. Likewise, urban population growth(lnUPG) is slightly negatively skewed and platykurtic, showing a relatively flat distribution; its p-value (0.091) shows mild deviation from normality. Moreover, trade openness(lnTO) also shows slight negative skewness (Table 3).

Table 3

Summary of Descriptive Statistics

Parameters	CO_2	GDP	GDP^2	lnREC	lnUPG	lnTO
Mean	0.184	4.572	26.538	4.119	1.440	11.918
Median	0.113	4.508	20.327	4.146	1.414	12.060
Maximum	0.604	10.031	100.625	5.895	1.958	14.567
Minimum	0.034	-2.370	0.014	2.431	0.793	8.706
Std. Dev.	0.174	2.401	22.516	0.899	0.392	1.772
Skewness	1.370	-0.275	1.485	0.013	-0.177	-0.287
Kurtosis	3.475	3.890	4.925	2.235	1.426	1.970
Sum	8.106	201.172	1167.667	181.238	63.346	524.387

Sum Sq.Dev	1.296	247.887	21800.470	34.726	6.618	135.078
Observations	44	44	44	44	44	44

Note. Table 3 presents descriptive statistics of the variables included in the analysis.

Unit Root Test result

The results from both ADF and PP unit root tests reveal that variables ln GDP and ln GDP squared are stationary at level, indicating I(0) series. In addition, variables CO_2, lnREC, lnUPG, and lnTO are non-stationary at level but become stationary at first difference, implying they are I(1) processes. Moreover, the stationarity of lnTO is slightly mixed across tests but leans toward I(1). These findings clearly suggest the presence of mixed orders of integration among variables, justifying the use of an ARDL or bounds testing approach for further analysis. Thus, ensuring stationarity avoids spurious regression and validates the statistical reliability of time series models (Table 4).

Table 4

Summary of ADF Unit Root Tests and PP Unit Root Test

Variable	Test	Level/1st Diff	Test Statistic	1% CV	5% CV	10% CV	Stationary
CO_2	PP	Level	1.943	-3.661	-2.960	-2.619	
		1st Diff	-6.307	-3.661	-2.960	-2.619	I(1)
	ADF	Level	1.856	-3.661	-2.960	-2.619	
		1st Diff	-1.749	-3.661	-2.960	-2.619	
GDP	PP	Level	-10.792	-3.661	-2.960	-2.619	I(0)
		1st Diff	-27.263	-3.661	-2.960	-2.619	I(1)
	ADF	Level	-7.682	-3.661	-2.960	-2.619	I(0)
		1st Diff	-6.331	-3.661	-2.960	-2.619	I(1)
GDP^2	PP	Level	-8.464	-3.661	-2.960	-2.619	I(0)
		1st Diff	-32.614	-3.661	-2.960	-2.619	I(1)
	ADF	Level	-8.157	-3.661	-2.960	-2.619	I(0)
		1st Diff	-10.566	-3.661	-2.960	-2.619	I(1)
lnREC	PP	Level	0.057	-3.661	-2.960	-2.619	
		1st Diff	-11.737	-3.661	-2.960	-2.619	I(1)
	ADF	Level	-0.207	-3.661	-2.960	-2.619	
		1st Diff	-12.745	-3.661	-2.960	-2.619	I(1)
lnUPG	PP	Level	-1.243	-3.661	-2.960	-2.619	
		1st Diff	-4.922	-3.661	-2.960	-2.619	I(1)
	ADF	Level	-1.154	-3.661	-2.960	-2.619	
		1st Diff	-4.900	-3.661	-2.960	-2.619	I(1)

lnTO	PP	Level	-1.952	-3.661	-2.960	-2.619	
		1st Diff	-5.559	-3.661	-2.960	-2.619	I(1)
	ADF	Level	-1.952	-3.661	-2.960	-2.619	
		1st Diff	-2.494	-3.661	-2.960	-2.619	

Note. Table 4 above presents PP, and ADF stands for Phillips-Perron and Augmented Dickey-Fuller respectively where I(0) = stationary at level; I(1) = stationary at first difference.

Structural Break Test

Table 5 given below presents Bai-Perron breakpoint test result. The Bai-Perron breakpoint test result identifies statistically significant structural breaks in the variables included in the model at the 5 percent level of statistical significance. In this regard, the null hypothesis (H_0) is no structural break (the relationship is stable over time) against the alternative hypothesis (H_1) is there is at least one structural break (Bai & Perron, 2003). The structural break test result shows break dates 2016 for first 4 explanatory variables and break date for trade openness is 2012 (Table 5).

Table 5

Bai-Perron *Breakpoint Test Result*

Variable	Sequential F-Statistic	Scaled F-Statistic	Critical Value (5%)	Break Date	Decision
GDP	134.72	269.45	11.47	2016	Reject H_0
GDP^2	154.84	309.67	11.47	2016	Reject H_0
REC	131.19	262.38	11.47	2016	Reject H_0
UPG	195.21	390.43	11.47	2016	Reject H_0
TO	331.84	663.68	11.47	2012	Reject H_0

Note. Table 5 demonstrates Bai-Perron break point test result for ensuring detection of break of data used in proposed regression model computed by author.

To sum up, the test provides strong evidence of structural break in the data series, which should be accounted for in further time series modelling and analysis. In this regard, creating dummy variables and generating interacting terms with the respective variables corresponding to the break date points is standard option. The researcher has pointed creating an additional dummy variable and including it as explanatory variable as policy dummy free of cost medicine and maternity as a remedy of structural break.

Lag Length Selection

The selection of optimal lag length is essential in time series analysis and address the issue of underfitting and over fitting of the model. The result of lag length selection is presented in Table 6.

Table 6

Optimal Lag Length Selection

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-249.3059	NA	0.007675	12.15742	12.40566	12.24841
1	13.69788	438.3396*	1.58E-07*	1.34772*	3.085390*	1.984645*

Note. Table 6 shows the summary result of lag length selection.

ARDL F-Bound Test Result

The estimated result of F-bound test is summarized in Table 8, where F-statistic is 15.297 and is above the upper bound at all level of significance (10%, 5% and 1% as 15.297>3.61, 3.04, 2.77>2.44). Therefore, the null hypothesis that is no long-run relationship amongst the variables included in the model is reject. It mean there exist long-run relationship amongst the variables included in the model (Table 8).

Table 8

Estimated Result of F-bound Test

Null Hypothesis(H_0): There exist no long-run relationship.		
Test Statistics	Values	K(Explanatory Variables)
F-Statistics	15.297	10
	Critical Value Bonds	
Level of significance	I(0) Bonds	I(1) Bonds
10 %	1.76	2.77
5 %	1.98	3.04
1 %	2.41	3.61

Note. Table 8 shows estimated result of F-bound test based on the data spanning from 1980-2024.

The Estimated Coefficients for Initial ARDL Model

Table 9 below presents the initial ARDL model estimation. The model estimation examines the key determinants of CO_2 emissions per capita in Nepal, focusing on the roles of economic growth,

urban population growth, renewable energy consumption, and trade openness, while accounting for structural breaks using dummy variables for the years 2012 and 2016. The estimated model demonstrates excellent explanatory power with an R-squared of 0.996, implying more than 99 percent variation in dependent variable is explained by the explanatory variables include in the model. Moreover, the D-W Statistic 2.02 indicates that residuals are free from the issue of autocorrelation. Likewise, the coefficient of lag CO_2 bears negative and statistically significant (-0.561, $p<0.01$), satisfies the speed of correction in the long-run that is deviated in the short-run. GDP growth bears a negative effect (−0.0123, $p<0.01$), while squared term of GDP is positive but statistically insignificant. It suggests a weak but emerging signal of inverted U-shaped EKC. Renewable energy consumption bears negative and statistically significant coefficient (-0.118, $p<0.03$), indication rise in renewable energy consumption reduces CO_2 emission. Total trade has a significant negative effect (-0.210, $p<0.01$), may be indicating that trade openness reduces CO_2 emission, possibly due to cleaner import or technological gains. Similarly urban population growth is significantly negative (-0.043, $p<0.05$), possibly indicating growth of unplanned urbanization. Finally, total investment, statistically significant and positive (0.12, $p<0.01$), suggesting capital accumulation increase CO_2 emissions, likely through industrial and infrastructural development.

Table 9

Initial Estimated Result of ARDL Model

Dependent Variable:CO_2 Emission per capita ton		
Variable	Coefficient(Std.Error)	t-Statistic
C	-0.209***(0.046)	-4.584
CO_2(-1)	-0.561***(0.101)	-5.559
GDP	-0.007*(0.004)	-1.868
GDP^2	0.001(0.000)	1.423
lnREC(-1)	-0.118***(0.030)	-3.965
lnUPG	-0.024**(0.010)	-2.478
lnTO	0.067***(0.013)	5.165
lnGDP*Dum2016	0.036***(0.005)	6.633
$lnGDP^2$*Dum2016	-0.005***(0.001)	-5.952
lnREC*Dum2016 (-1)	0.052***(0.013)	3.927
lnUPG*Dum2016 (-1)	-0.072*(0.047)	-1.522
lnTO*Dum2012	0.003***(0.001)	3.722
R^2	0.996	
Adjusted R^2	0.995	
F-Statistics	644.061	
F-Statistics	0.000	
D-W Statistic	2.025	

Note. Table 9 presents coefficients for initial estimated ARDL model.

Significance Levels: ***p < 0.01; **$p < 0.05$; *$p < 0.10$.

Therefore, it can be inferred that the Environmental Kuznets Curve (EKC) hypothesis is supported, with trade openness contributing to rising emissions before and after structural breaks in Nepal.

Estimated Long Run Coefficients

The estimated long run coefficients are presented in the following table. The result shows that a percent increase in GDP growth rate is associated with 0.012 unit fall in CO2 emission. However, a 1 percent increase in squared GDP growth is associated with 0.001 unit rise in CO2 emission in Nepal. Moreover, a 1 percent rise in renewable energy use and urban population growth is associated with 0.21 percent and 0.043 percent fall in CO2 emission respectively. Finally, the result shows that a 1 percent raise in trade openness is associated with 0.12 percent raise in CO2 emission (Table 10).

Table 10

Estimated Long-run Coefficient of ARDL Model

Dependent Variable: CO2 emission per capita ton		
Variable	Coefficient (Std. Error)	t-Statistic
C	-0.372*** (0.081)	-4.567
GDP	-0.012* (0.006)	-1.948
GDP^2	0.001 (0.001)	1.456
lnREC	-0.210 ***(0.064)	-3.288
lnUPG	-0.043** (0.019)	-2.348
lnTO	0.120 ***(0.028)	4.352
GDP*Dum2016	0.064*** (0.013)	4.775
GDP^2*Dum2016	-0.009 ***(0.002)	-5.175
lnREC*Dum2016	0.093 ***(0.023)	4.065
lnUPG*Dum2016	-0.128 (0.087)	-1.462
lnTO*Dum2012	0.005 ***(0.001)	4.917

Note. Table 10 above presents long run coefficients of estimated ARDL model.

Significance Levels: ***p < 0.01; **$p < 0.05$; *$p < 0.10$.

Error Correction Model

The error correction term(ECT) is negative and statistically significant at the 1 percent level, with a coefficient of -0.5612. Essentially, the negative sign of coefficient of ECT with statistical

significance confirms the existence of a stable long-run equilibrium relationship among the variables. Therefore, the coefficient indicates that approximately 56.1 percent of the previous period's deviation is corrected in the current period. It implies that short-term disequilibrium in the system converges back to equilibrium relatively quickly. Hence, the significance and appropriate sign of the ECT validate the long-run causality included in the model as dependent and explanatory variables, supporting co-integration among them (Table 11).

Table 11

Error Correction Model

Dependent Variable: CO2 emission per capita ton			
Variable	**Coefficient (Std. Error)**	**t-Statistic**	**p-Value**
ECt(-1)	-0.561***(0.035)	-15.9901	0.00

Note. Table 11 above presents ECM model estimation result meant for ECT coefficient under ARDL model framework. Significance Level: ***p < 0.01.

Diagnostic Test Result

The diagnostic test results below clearly indicate that the ARDL model satisfies key classical assumptions of robustness. The Table 12 below shows Breusch-Godfrey LM test result and clearly depicts no evidence of serial correlation (p = 0.9409). Likewise, the BP-Godfrey test indicates no heteroscedasticity (p = 0.1759), suggesting homoscedastic and independent residuals. Moreover, the Ramsey RESET test (p = 0.7502) confirms correct model specification with no omitted variable bias. Finally, the Jarque-Bera test (p = 0.9025) suggests that the residuals are normally distributed. To sum up, all p-values exceed 0.05, so we fail to reject the null hypotheses in each test. Overall, the model passes standard diagnostic checks and is statistically sound for inference (Table 12).

Table 12

Summary of Diagnostic Test Results

Diagnostic Test	Test Type	Statistic	p-value	Decision
Serial Correlation (BG LM)	F-statistic (LM Test)	0.0611	0.9409	$p > 0.05 \rightarrow$ Fail to reject H_0
	Obs*R^2 (Chi-square)	0.2011	0.9043	$p > 0.05 \rightarrow$ Fail to reject H_0

Heteroscedasticity (BP-G)	F-statistic	1.4982	0.1759	$p > 0.05 \rightarrow$ Fail to reject H_0
	Obs*R^2 (Chi-square)	18.4159	0.1885	$p > 0.05 \rightarrow$ Fail to reject H_0
RESET	F-statistic Ramsey RESET	0.1035	0.7502	$p > 0.05 \rightarrow$ Fail to reject H_0
Normality (assumed)	J-B Statistics	0.1654	0.9025	$p > 0.05 \rightarrow$ Fail to reject H_0

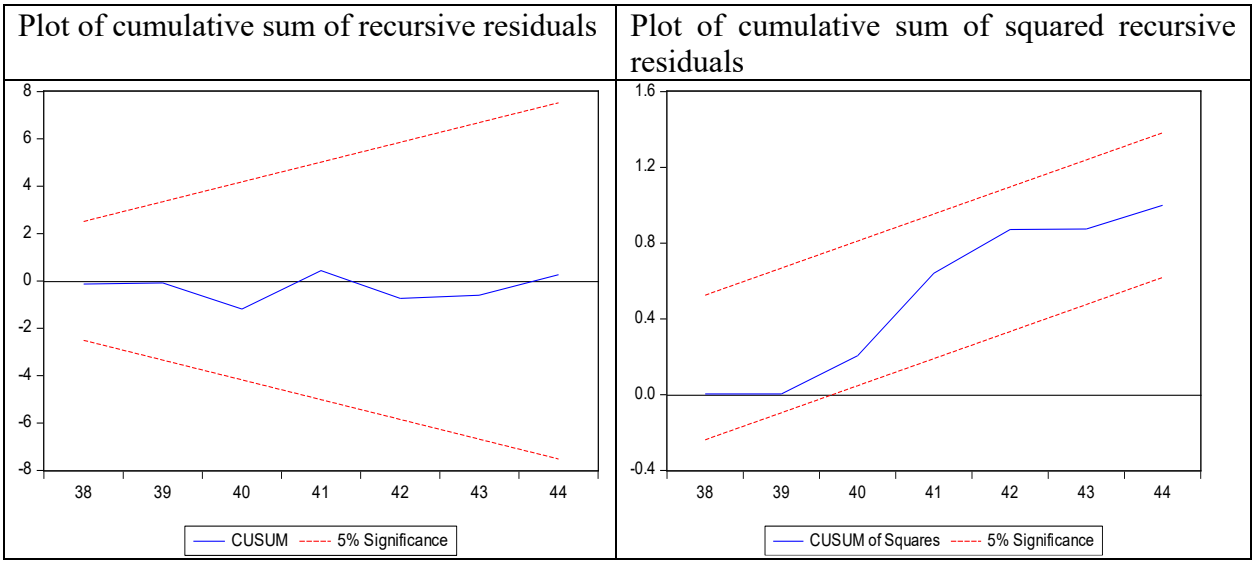
Note. Table 12 above presents summary of diagnostic test meant for model estimation robustness.

Stability Test Result

The stability test result in terms of CUSUM and CUSUM sum of squared recursive residuals are presented in Figure1. The test result shows that the model is stable as residuals line is always within 5 percent significance level (Figure 1).

Figure 1

CUSUM Sum and CUSUM Sum of Squared Recursive Residuals



Note. The above figures given in two parts presents plot of cumulative sum of recursive residual and cumulative sum of squared recursive residuals.

Discussion

The main aim of this paper was to investigate the dynamic impact of GDP growth, renewable energy consumption, urban population growth and total trade on CO2 emission in Nepal within

the EKC framework, shedding light on the nexus between economic growth and environmental sustainability. The finding shows that one percent increase in GDP per capita is associated with 1.23 percent fall in CO2 emission, though marginally significant. This may be indicating early-stage decoupling of emissions from economic growth. Likewise, the result also shows that a positive coefficient for squared GDP growth suggests emissions increase at higher income levels, but the result is statistically insignificant, indicating no strong support for the EKC in the baseline. This result aligns with Grossman & Krueger (1995), Shahbaz et al. (2015), and Apergis & Payne (2010). Regarding renewable energy consumption, a 1 percent increase in renewable energy consumption per capita leads to a 0.21 percent reduction in CO_2 emissions, statistically significant. This result confirms that renewables reduce environmental degradation. Moreover, a 1 percent rise in urban population growth leads to a 0.043 percent decrease in CO_2 emissions. This result is aligning with Zaidi et al. (2019). This result implies that urbanization reduces emissions, potentially due to denser infrastructure, efficient transport, and clean energy in the urban settlement. Finally, a 1 percent increase in trade openness increases CO_2 emissions by 0.12 percent, with statistical significance at 1 percent. This supports the Pollution Haven Hypothesis, where trade liberalization may lead to environmental degradation. The coefficient for interaction term between GDP growth ate and structural dummy 2016 is positive (0.063, $p < 0.01$), implying that GDP growth after 2016 correlates with higher emissions possibly due to increased energy use followed by policy shifts. Likewise, the coefficient for interaction term squared GDP growth and structural dummy 2016 shows a negative and highly significant result, indicating EKC holds after 2016. This may imply that as economic growth rises CO_2 emissions fall, likely due to structural reform or policy reforms.

These findings are partially or entirely align with the literature such as Poudel et al. (2024), Jaeger et al. (2023), AlKhars et al. (2022), Apergis & Ozturk (2015), Shahbaz et al. (2018, 2013), Tiwari et al. (2013), Saboori et al. (2012), and Fodha & Zaghdoud (2010), Yu (2015). They provide evidence that energy consumption and GDP growth initially increase carbon emissions, but beyond a threshold, cleaner technologies and structural changes help reduce them.

However, the EKC is not universally valid. Several scholars argue that the inverted-U shape may not apply to global pollutants like carbon dioxide or in low-income countries. In this regard, the contrasting literatures include Voumik et al. (2023), Leal & Marques (2022), and Akbostancı et

al. (2009). They argue that the EKC does not hold consistently, especially in developing economies where weak regulatory frameworks and dependency on fossil fuels can lead to a persistent rise in emissions despite economic growth. Similarly, Stern (2004) criticized the EKC's robustness, attributing the observed patterns in some studies to model misspecification and short time frames. Sharma (2011), using a panel of 69 countries, found that carbon dioxide emissions in low-income countries tend to increase monotonically with income, challenging the EKC premise.

Conclusions and Policy Insights

The findings support the EKC hypothesis in Nepalese context. Initially, GDP growth rate has a negative linear impact on emissions, and the squared GDP growth rate is insignificant in the base model. However, after 2016, GDP growth becomes positively associated with the emissions, while squared GDP growth becomes significantly negative. This inverted U-shaped pattern confirms that emissions in Nepal rise with income up to a point and then begin to decline, consistent with the EKC theory. Likewise, trade openness is found to be consistently contributing to increase the emission, indicating greater global integration brings environmental trade-offs. In conclusion, the findings provide strong empirical supports for the observation of EKC hypothesis in Nepal after 2016, where economic growth rate eventually contributes to lower emissions.

Declaration of no Conflict of Interest

The authors solemnly declare that there is no conflict of interest regarding preparation, analysis, and publication of this part of academic work.

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