NCCS Research Journal, Volume 3, No. 1 October 2024, *ISSN NO: 2822-1605*

Received Date: June 2024 *Revised: August 2024* *Accepted: October 2024*

Modeling CO_2 Emissions in Nepal: The Role of Renewable Energy

Omkar Poudel

Assistant Professor of Economics, Birendra Multiple Campus, Tribhuvan University.

Email: omkar.poudel@bimc.tu.edu.np

Orcid: 0009-0008-7873-0237

Khom Raj Kharel, PhD. (**Corresponding Author**)

Associate Professor of Economics, Saraswati Multiple Campus, Tribhuvan University, Kathmandu

Email: kharelkhom@yahoo.com

Orcid: 0000-0002-9806-7224

Pradeep Acharya

Account Specialist at NOWCFO, MBA, Tribhuvan University, Kathmandu, Nepal.

Email: pradeep.acharya197@gmail.com

Orcid: 0000-0001-8055-8757

Deep Raj Sharma

BP Koirala Memorial Cancer Hospital, Chitwan, Nepal

Email: deep48440@gmail.com

Yadav Mani Upadhyaya, PhD.

Assistant Professor of Economics, Saraswati Multiple Campus, Tribhuvan University, Kathmandu

Email: yadav.upadhyaya@smc.tu.edu.np

Orcid: 0000-0003-3089-3615

Abstract

Climate change and environmental degradation, largely driven by carbon dioxide (CO_2) emissions, have become significant global concerns. In Nepal, the challenge of balancing economic growth with environmental sustainability is pertinent due to the country's reliance on agriculture and hydropower. This study explores the relationship between CO_2 emissions, socio-economic factors, and renewable energy consumption in Nepal, utilizing advanced econometric techniques. Using a 30-year dataset from 1991 to 2020, this study employs the Dynamic Ordinary Least Square (DOLS) model to examine long-term relationships between CO_2 emissions and key independent variables such as renewable energy consumption, GDP, and human development. Unit root tests (ADF and PP) are conducted to ensure stationarity, followed by co-integration and causality tests. The findings indicate a positive and significant relationship between CO_2 emissions and economic growth, supporting the Environmental Kuznets Curve (EKC) hypothesis. Conversely, renewable energy consumption is found to significantly reduce CO_2 emissions, underscoring its role in mitigating environmental impacts. The coefficient for renewable energy consumption (LNREC) is -5.818686. This implies that for every 1% increase in renewable energy consumption, CO2 emissions decrease by approximately 5.82%.The results highlight the importance of renewable energy in balancing Nepal's economic and environmental goals.

Keywords: CO_2 emissions, renewable energy, economic growth, DOLS, environmental Kuznets curve.

JEL: Q56, O13, C32

Modeling CO_2 Emissions in Nepal: The Role of Renewable Energy

Climate change and global environmental degradation have emerged as major challenges for both developed and developing nations, with carbon dioxide (CO_2) emissions being a primary contributor to these issues. In Nepal, the challenge of balancing economic growth with environmental sustainability is particularly pertinent, given its reliance on agriculture and hydropower as primary economic drivers (Regmi& Rehman, 2021). While the country has made progress in leveraging its vast renewable energy resources, particularly hydropower, the relationship between renewable energy consumption, socio-economic factors, and CO_2 emissions remains underexplored (Regmi et al., 2024).

This study seeks to address this gap by modeling the impact of renewable energy and socio-economic indicators on Nepal's CO_2 emissions, utilizing the Autoregressive Distributed Lag (ARDL) approach to capture both short-term and long-term relationships. Nepal's reliance on both traditional agricultural practices and renewable energy, especially hydropower, offers a unique opportunity to explore how these factors influence CO_2 emissions (Shakya et al., 2023). As the country navigates its development path, balancing economic growth with the need to reduce emissions remains a critical challenge (Regmi & Rehman, 2021).

The environmental Kuznets curve (EKC) hypothesis has often been applied to explore the relationship between economic growth and environmental degradation, positing that emissions rise during early stages of development but eventually decrease as economies become more advanced (Abdulqadir, 2022; Regmi et al., 2024). However, empirical evidence regarding this theory in the context of Nepal remains limited. In their study, Regmi et al. (2024) found that while economic growth has contributed to CO_2 emissions in Nepal, the country's renewable energy initiatives have helped mitigate some of these negative effects.

Globally, studies have shown that renewable energy consumption plays a crucial role in mitigating emissions while promoting sustainable development (Bekhet & Othman, 2018; Zhou, 2023). For instance, Adebayo et al. (2021) highlighted how agricultural practices and renewable energy contribute to CO_2 emissions in Indonesia, findings which resonate with Nepal's reliance on agriculture as a major economic driver. Similarly, Aydoğan and Vardar

(2020) emphasized the critical role of renewable energy in reducing emissions across emerging economies, suggesting that targeted energy policies could significantly reduce environmental damage.

This study builds on this growing body of literature by focusing on Nepal, a country with distinct socio-economic and energy dynamics. By utilizing a 30-year dataset from 1991 to 2020 and employing advanced econometric techniques such as Dynamic Ordinary Least Squares (DOLS), this research provides a deeper understanding of the relationship between renewable energy consumption, socio-economic factors, and CO2 emissions. The findings aim to inform Nepal's energy and environmental policies by offering insights into how renewable energy can contribute to a sustainable development pathway.

Literature Review

The relationship between economic growth and carbon dioxide (CO_2) emissions has been mostly studied, particularly within the framework of the environmental Kuznets curve (EKC). The EKC hypothesis posits that CO_2 emissions rise during the early stages of economic growth but decrease as economies mature and adopt cleaner technologies (Farhani & Rejeb, 2012; Zhou, 2023). Studies such as those by Alam et al. (2016) and Adebola Solarin et al. (2017) have validated this hypothesis in large developing economies like India and China, where economic expansion initially contributed to higher emissions. However, the shift toward cleaner energy sources, including hydroelectricity, was shown to mitigate these emissions over time.

Energy consumption, particularly from non-renewable sources, remains a significant driver of environmental degradation and CO_2 emissions. Farhani and Rejeb (2012) emphasize that in the MENA region, energy consumption is directly correlated with higher emissions due to the reliance on fossil fuels. Similarly, studies by Bekhet and Othman (2018) and Aydoğan and Vardar (2020) highlight that energy consumption from non-renewable sources in emerging economies like Malaysia and the E7 countries leads to increased emissions, complicating efforts to achieve sustainable growth.

However, renewable energy has been increasingly recognized as a viable solution to curbing these emissions. In their study of OECD countries, Cheng et al. (2018) found that integrating renewable energy and technological innovations significantly reduced CO_2 emissions. This transition toward renewable energy is critical for countries like Nepal, where hydropower and other renewable sources are poised to play a key role in the country's future energy strategy (Shakya et al., 2023). The experience of EU countries, where renewable energy consumption has contributed to substantial reductions in CO_2 emissions, offers valuable lessons for Nepal (Alavijeh & Shadmehri, 2022).

The role of renewable energy in reducing CO_2 emissions has been well-documented in both developing and developed countries. Cheng et al. (2018) found that renewable energy consumption reduces CO_2 emissions, particularly when combined with innovation and technological advancement. This view is supported by Dam and Işik (2022), who showed that renewable energy adoption, coupled with strong institutional frameworks, significantly lowers emissions in MENA countries.

Alavijeh and Shadmehri (2022) conducted a panel data analysis on EU countries and demonstrated that the expansion of renewable energy infrastructure plays a vital role in achieving emissions reduction targets. These findings are particularly relevant for Nepal, where investments in renewable energy, especially hydropower, are expected to drive long-term emissions reductions (Regmi, et al., 2024). The shift toward renewable energy in Nepal is also supported by research from Saleem and Khan (2022), who emphasize the role of green financing and technological innovation in promoting the adoption of clean energy sources and reducing carbon footprints.

The concept of green growth, which emphasizes economic growth alongside environmental sustainability, has gained prominence in both academic and policy discussions. Hao and Umar (2021) explored green growth strategies in the G7 countries, highlighting how low-carbon policies and investments in natural resources and human capital contribute to reduced emissions. Similarly, Do et al. (2021) demonstrated that green growth, supported by ecological innovation and ICT integration, can lead to both economic development and environmental preservation in emerging economies.

These green growth strategies are particularly relevant to Nepal, where the government has prioritized low-carbon development as part of its long-term energy and environmental policies. Green financing mechanisms, as highlighted by Saleem and Khan (2022), can provide the necessary support to ensure that renewable energy projects are both economically viable and environmentally beneficial. Such mechanisms can help Nepal achieve its sustainability goals while fostering economic growth.

The studies reviewed highlight the critical role that renewable energy and policy frameworks play in achieving sustainable development. As seen in EU countries (Alavijeh & Shadmehri, 2022) and OECD nations (Cheng et al., 2018), strong institutional support and green financing are essential for promoting the widespread adoption of renewable energy technologies. For Nepal, lessons from these regions, as well as the Middle East and North Africa (MENA) countries (Dam & Işik, 2022), suggest that robust policies promoting renewable energy and green growth can significantly reduce CO_2 emissions without hindering economic progress.

Regmi and Rehman (2021) emphasize that both long-term and short-term strategies are needed to balance economic growth with environmental sustainability in Nepal. Investments in renewable energy infrastructure, green financing, and ecological innovation will be critical for the country's future development path. With targeted policy interventions and continued emphasis on renewable energy, Nepal can effectively navigate the challenges of economic growth and emissions reduction.

While prior studies, such as Regmi et al. (2024) and Shakya et al. (2023), have examined the relationship between renewable energy, economic growth, and CO2 emissions in Nepal, critical gaps remain unaddressed. This study advances the field by evaluating the effectiveness of Nepal-specific policies, such as the National Renewable Energy Policy (2016), which prioritizes hydropower expansion, the Rural Energy Policy (2006), which aims to increase rural electrification, and the Energy White Paper (2018), which emphasizes renewable energy investment to meet Nepal’s target of 15% renewable energy in its total energy mix by 2030.

Additionally, it incorporates socio-economic variables like renewable installed capacity (LNRIC), agriculture, forestry, and fishing value-added (LNAV), and the Human Development Index (LNHDI), which are uniquely tied to Nepal's economic and environmental dynamics. By utilizing a comprehensive 30-year dataset (1991–2020) and employing advanced econometric techniques, such as Dynamic Ordinary Least Squares (DOLS), this study provides robust insights into both short-term and long-term relationships between variables. These contributions offer a deeper understanding of Nepal’s distinctive context, supporting the development of tailored policies for sustainable growth and emissions reduction.

Methodology

This quantitative study employed analytical and descriptive research designs (Poudel & Sapkota, 2022). Secondary data were used to evaluate the impact of independent variables on the dependent variable. The data were analyzed and interpreted using EViews version 10. The investigation relies on secondary and time series data. The study utilized 30 sets of time series data spanning from 1991 to 2020 to analyze the relationship between the dependent and independent variables.

Nature and Sources of Data

The information utilized in this analysis is derived from secondary and time series data. Data sources include World Development Indicators database, World Bank (Online) only.

Table 1.

Variable, their description and measurement

Variables	Definition	Measurement
$LNCO_2$	Natural Log of CO_2 Emissions	metric tons per capita
LNREC	Natural Log of Renewable Energy Consumption	% of Total Final Energy Consumption
LNGDP	Natural Log of Gross Domestic Product Per Capita.	constant 2015 US$
LNRIC	Natural Log of Renewable Installed Capacity	Mega Watt
LNAV	Natural Log of Agriculture, Forestry, Fishing Value Added	% of GDP
LNHDI	Natural Log of Human Development Index	Value between 0-1

Specification of the Model

The suggested model structure is presented as: CO_{2t}=f (REC_t, GDP_t, RIC_t, AV_t, HDI_t)
This model can be further elaborated based on specific assumptions and available data. For a basic linear model, the representation is as follows:

$$CO_{2t} = \beta_0 + \beta_1 REC_t + \beta_2\, GDP_t + \beta_3\, RIC_t + \beta_4 AV_t + \beta_5\, HDI_t + \varepsilon_t$$

Where:

CO_2 =Carbondioxide (CO_2) Emission (metric tons per capita)

REC = Renewable Energy Consumption (% of Total Final Energy Consumption)

GDP = Gross Domestic Product Per Capita (constant 2015 US$)

RIC= Renewable Installed Capacity (MW)

EIC = Electricity Installed Capacity (MW)

AV = Agriculture, Forestry, Fishing Value Added (% of GDP)

HDI= Human Development Index

β_0 ,β_1 ,β_2 , β_3, β_4, β_5 are coefficients to be estimated.

ε_t represents the error term.

We estimate an alternative specification of our model, with all variables expressed in their natural logarithmic form, as follows:

$$lnCO_{2t} = \beta_0 + \beta_1 lnREC_t + \beta_2\ lnGDP_t + \beta_3\ lnRIC_t + \beta_4 lnAVt + \beta_5\ lnHDI_t + \varepsilon_t$$

Econometric Method

Econometrics is a field within economics that utilizes statistical techniques to analyze economic data. This tool is utilized for testing economic theories, estimating economic relationships, and predicting future economic outcomes (Poudel,2022; Poudel, 2023). Econometrics is a versatile tool that can be utilized to address a broad spectrum of inquiries regarding the economy.

The unit root testing

The unit root test allowed us to determine the order of integration for each time series. To proceed with the DOLS, the time series needed to be integrated at either I(0) or I(1). Therefore, the ADF and P-P tests were used in this study to identify the order of integration.

DOLS

Due to the accumulation of leads and lags among the explanatory variables, this estimator consequently gives solutions to the problems of endogeneity, small sample bias, and autocorrelation (Stock & Watson, 1993). The DOLS method was used to find the different level of integrations of dependent and independent variables as well as it is also used when endogeneity in independent variables.

Data Analysis and Results

Descriptive Statistics

The descriptive statistics for Nepal's economic indicators show significant variability and deviations.

Table 2.

Descriptive Statistics

	$LNCO_2$	LNGDP	LNAV	LNHDI	LNRIC	LNREC
Mean	-1.895456	6.468779	3.478456	-0.685547	6.247251	4.467471
Median	-2.077202	6.415276	3.511563	-0.693197	6.362136	4.490709
Maximum	-0.632839	6.967425	3.800497	-0.492658	7.224025	4.545314
Minimum	-2.834831	6.077881	3.071923	-0.896488	5.451038	4.307976
Std. Dev.	0.649349	0.272470	0.202139	0.126202	0.547915	0.067608
Skewness	0.636844	0.311358	-0.530462	-0.008880	-0.117803	-1.205743
Kurtosis	2.367283	1.888500	2.334830	1.712778	1.829949	3.387911
Observations	30	30	30	30	30	30

Source: *Results from data analysis.*

The descriptive statistics for Nepal's economic indicators reveal notable patterns and variability, providing insight into the country's development and sustainability challenges. The mean value of $LNCO_2$ (-1.895) indicates low per capita carbon emissions, likely due to Nepal's reliance on renewable energy sources, as reflected by a high mean for LNREC (4.467). However, the wide range in CO_2 emissions, from -2.835 to -0.633, suggests considerable variability, which could be driven by fluctuations in industrial activity and energy consumption patterns.

The moderate standard deviation in LNGDP (0.272) highlights stable economic output per capita, yet skewness (0.311) and kurtosis (1.889) suggest a mildly right-skewed distribution with a flatter than normal peak, implying that while GDP growth has been steady, periods of rapid growth or downturns exist. LNHDI's low mean (-0.685) underscores the country's developmental challenges, reflected in its Human Development Index. The relatively higher variability in renewable installed capacity (LNRIC) shows Nepal's ongoing efforts to expand clean energy infrastructure. Overall, these indicators reflect the complex interplay between environmental sustainability, energy consumption, and economic growth, with policy implications for balancing development goals with ecological preservation.

Table 3.

Covariance Analysis: Ordinary

Correlation (Prob.)	$LNCO_2$	LNGDP	LNAV	LNHDI	LNRIC	LNREC
$LNCO_2$	1.0000					
LNGDP	0.9571	1.0000				
	0.0000					
LNAV	-0.9453	-0.9800	1.0000			
	0.0000	0.0000				
LNHDI	0.9287	0.9904	-0.9587	1.0000		
	0.0000	0.0000	0.0000			
LNRIC	0.8798	0.9549	-0.9397	0.9624	1.0000	
	0.0000	0.0000	0.0000	0.0000		
LNREC	-0.9750	-0.8952	0.9094	-0.8458	-0.8141	1.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	

Source: *Results from data analysis.*

The covariance analysis in Table 3 highlights strong correlations among Nepal's economic and environmental indicators. $LNCO_2$ and LNGDP exhibit a highly positive correlation (0.957), suggesting that as economic output grows, carbon emissions rise significantly, reflecting a potential trade-off between growth and sustainability. Conversely, LNREC has a strong negative correlation with $LNCO_2$ (-0.975), indicating that higher REC is associated with lower emissions, supporting the case for cleaner energy transitions. The inverse relationship between LNAV and both LNGDP (-0.980) and $LNCO_2$ (-0.945) underscores the declining role of agriculture in driving emissions and economic development. Overall, these correlations suggest critical links between economic growth, energy policy, and environmental outcomes in Nepal.

Trend lines of concerned variables

The trend lines of the concerned variables reveal distinct trajectories over time, reflecting Nepal's economic and environmental shifts.

Figure 1.

Time series plots

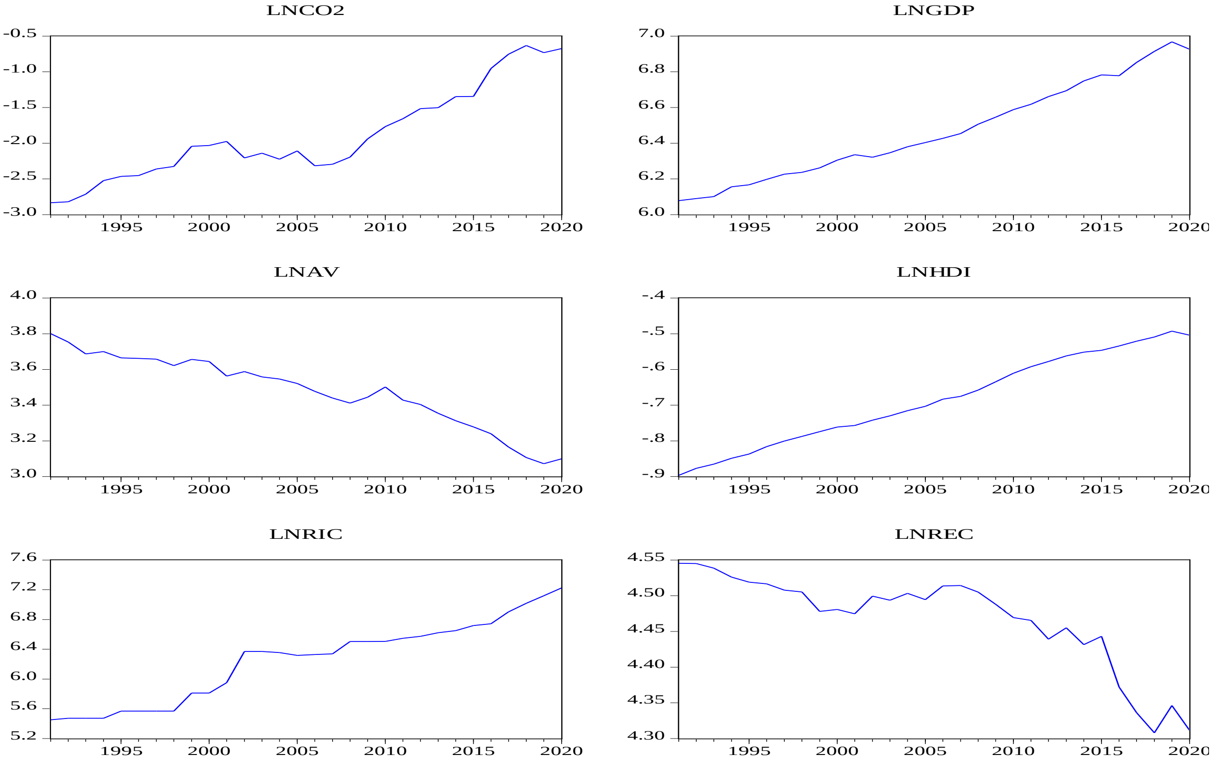


Figure 1 illustrates the time-series trends of Nepal's key economic and environmental indicators from 1991 to 2020, including CO2 emissions (LNCO2), GDP per capita (LNGDP), renewable energy consumption (LNREC), renewable installed capacity (LNRIC), agriculture's contribution to GDP (LNAV), and the Human Development Index (LNHDI). The steady increase in LNCO2 indicates rising carbon emissions, driven by economic growth and industrial activities, as reflected in the upward trend of LNGDP. However, while GDP growth signifies improved living standards and economic development, it also highlights the trade-offs between economic expansion and environmental sustainability. LNREC and LNRIC, though showing positive trends, lag behind GDP growth, suggesting that Nepal's energy demand remains heavily reliant on traditional or non-renewable sources despite progress in renewable energy infrastructure.

A closer examination of LNAV reveals a gradual decline in agriculture's share of GDP, indicating a shift toward industrialization and urbanization, which increases energy demand and emissions. At the same time, the steady rise in LNHDI reflects improvements in socio-economic conditions, such as education and healthcare, which influence energy consumption and environmental practices. These trends underscore the need for targeted policies to accelerate renewable energy adoption, decouple economic growth from carbon emissions, and ensure a sustainable transition for agriculture-dependent populations. The interplay between these indicators highlights Nepal's ongoing challenge of balancing development with environmental preservation.

Unit Root Testing

Unit root testing determines whether a time series is non-stationary and possesses a unit root, indicating that shocks to the series have a permanent effect. Common tests, like the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP), help identify whether differencing is required to achieve stationarity.

Table 4.

Unit root test results (ADF and PP).

PP

At Level		$LNCO_2$	LNGDP	LNAV	LNHDI	LNRIC	LNREC
With Const.	t-Statistic	0.1232	2.2515	0.1577	-1.5351	0.1249	1.6373
	Prob.	***0.9621***	***0.9999***	***0.9648***	***0.5020***	***0.9622***	***0.9993***
		no	no	no	no	no	no
With Const. & Trend	t-Statistic	-1.4262	-2.0148	-1.7592	-1.0622	-2.2319	-1.0659
	Prob.	***0.8313***	***0.5692***	***0.6981***	***0.9184***	***0.4554***	***0.9178***
		no	no	no	no	no	no
At First Difference		d($LNCO_2$)	d(LNGDP)	d(LNAV)	d(LNHDI)	d(LNRIC)	d(LNREC)
With Const.	t-Statistic	-4.9751	-4.4750	-5.1048	-3.2302	-4.9241	-5.9063
	Prob.	***0.0004***	***0.0015***	***0.0003***	***0.0287***	***0.0005***	***0.0000***
		***	***	***	**	***	***
With Const.& Trend	t-Statistic	-4.9171	-4.5177	-5.2507	-3.3620	-4.8758	-6.3629
	Prob.	***0.0025***	***0.0064***	***0.0011***	***0.0772***	***0.0028***	***0.0001***
		***	***	***	*	***	***

ADF

At Level		$LNCO_2$	LNGDP	LNAV	LNHDI	LNRIC	LNREC
With Constant	t-Statistic	0.9375	2.7819	0.0859	-1.5612	0.1411	2.0163
	Prob.	***0.9944***	***1.0000***	***0.9590***	***0.4891***	***0.9635***	***0.9997***
		no	no	no	no	no	no
With Const. & Trend	t-Statistic	-1.9509	-2.0938	-1.6895	-0.7364	-2.0836	0.5606

	Prob.	***0.5973***	***0.5275***	***0.7301***	***0.9603***	***0.5329***	***0.9989***
		no	no	no	no	no	no
At First Difference		d(LNCO2)	d(LNGDP)	d(LNAV)	d(LNHDI)	d(LNRIC)	d(LNREC)
With Constant	t-Statistic	-3.6337	-1.7717	-5.1159	-3.2381	-4.9253	-1.3990
	Prob.	***0.0120***	***0.3850***	***0.0003***	***0.0282***	***0.0005***	***0.5664***
		**	no	***	**	***	no
With Const.& Trend	t-Statistic	-3.9578	-5.0972	-5.1404	-3.3544	-4.8762	-4.4820
	Prob.	***0.0237***	***0.0019***	***0.0015***	***0.0783***	***0.0028***	***0.0076***
		**	***	***	*	***	***

*Significant at the 10%; **Significant at the 5%;

*** Significant at the 1%. and no Not Significant.

Source: *Results from data analysis*

The unit root test results (ADF and PP) reveal the stationarity properties of the variables, crucial for econometric modeling. At the level, both the ADF and PP tests fail to reject the null hypothesis for all variables, indicating non-stationarity. This suggests that variables like carbon emissions ($LNCO_2$), GDP per capita (LNGDP), and renewable energy consumption (LNREC) follow a stochastic trend, which can lead to spurious regressions if not addressed. However, after first differencing, most variables become stationary, as indicated by significant t-statistics and probabilities below the 5% level, except for LNGDP and LNREC in some cases.

This transformation is critical for ensuring valid long-run relationships in DOLS model , where variables need to be integrated at either I(0) or I(1). The stationarity of key economic indicators, such as GDP and renewable energy, highlights the dynamic nature of Nepal's economic and environmental growth, enabling the application of further econometric techniques like co-integration and causality tests.

Co-Integration

Co-integration is a statistical property of a collection of time series variables that indicates a long-term equilibrium relationship among them, even if the individual series themselves are non-stationary. When variables are co-integrated, they tend to move together over time, suggesting that deviations from this equilibrium are temporary (Acharya et al., 2024a; Kharel et al., 2024). This concept is crucial for economic modeling, as it allows researchers to identify and model relationships that persist despite short-term fluctuations.

Table 5.

Johansen's Cointegration test

	Trace Test		Maximum Eigenvalue Test	
No. of Cointegration vectors	**Statistic**	**5% Critical Values**	**Statistic**	**5% Critical Values**
None *	116.0700	95.75366	57.77580	40.07757
At most 1	58.29424	69.81889	23.60676	33.87687
At most 2	34.68749	47.85613	15.81428	27.58434
At most 3	18.87321	29.79707	12.69067	21.13162
At most 4	6.182539	15.49471	5.656210	14.26460
At most 5	0.526329	3.841466	0.526329	3.841466

Source: *Results from data analysis.*

The Johansen cointegration test results in Table 5 suggest the presence of a long-term equilibrium relationship among the variables. The trace test indicates one cointegrating vector, as the test statistic (116.07) exceeds the 5% critical value (95.75) at the "None" hypothesis, confirming the presence of a long-run relationship between $LNCO_2$, LNGDP, and other variables like renewable energy consumption (LNREC) and human development (LNHDI). This is crucial for economic applications, as cointegration implies that although individual variables may be non-stationary, their combined movement reflects a stable, long-term equilibrium.

The Maximum Eigenvalue test corroborates this, with one cointegrating vector (57.77 > 40.08). These results support using models like Vector Error Correction (VECM), which account for both short-run dynamics and long-run equilibrium. For Nepal, this indicates that while short-term fluctuations in GDP and emissions are expected, policies fostering renewable energy and human development could contribute to long-term environmental sustainability and economic growth.

Table 6.

Results of DOLS Cointegration

Dependent Variable: $LNCO_2$

Variable	Coeff.	Standard Error	t-Stat.	Probability
LNGDP	3.377694	0.964358	3.502532	0.0128
LNAV	2.001036	0.359805	5.561446	0.0014
LNHDI	-1.697294	1.474638	-1.150991	0.2935
LNRIC	-0.071547	0.076876	-0.930675	0.3879
LNREC	-5.818686	0.931246	-6.248280	0.0008
C	-5.124913	10.54018	-0.486226	0.6441
R-squared	0.998749	Mean dependent var		-1.871645
Adjusted R-squared	0.994578	S.D. dependent var		0.587865
S.E. of regression	0.043288	Sum squared resid		0.011243
Long-run variance	0.000710			

Source: *Results from data analysis.*

The results from the DOLS cointegration model indicate that a 1% increase in GDP per capita (LNGDP) leads to a 3.38% rise in carbon dioxide emissions ($LNCO_2$), highlighting the strong positive relationship between economic growth and environmental degradation in Nepal. This significant and large coefficient suggests that economic activities, likely driven by industrial expansion, energy consumption, and urbanization, are heavily reliant on carbon-intensive processes. As the economy grows, the demand for energy increases, much of which may still be sourced from non-renewable resources. This creates a clear trade-off: while GDP growth fosters economic development, it simultaneously accelerates environmental damage by increasing carbon emissions.

Conversely, the negative coefficient for renewable energy consumption (LNREC) shows that a 1% rise in renewable energy use cuts CO_2 emissions by 5.82%. This underscores the potential for renewable energy to mitigate the negative environmental impacts of economic development. If Nepal can shift its energy consumption towards renewables like hydropower or solar energy, it can effectively decouple economic growth from carbon emissions. In policy terms, these findings highlight the importance of promoting sustainable energy initiatives and improving energy efficiency to balance growth with environmental preservation. The results suggest that without significant investment in renewable energy, Nepal's development trajectory may come at a high environmental cost.

Table 7.

Correlation matrix of explanatory variables in levels

	LNGDP	**LNAV**	**LNHDI**	**LNRIC**	**LNREC**
LNGDP	1	-	-	-	-
LNAV	-0.9800	1	-	-	-
LNHDI	0.9904	-0.9587	1	-	-
LNRIC	0.9549	-0.9397	0.9624	1	-
LNREC	-0.8952	0.9094	-0.8458	-0.8141	1

Source: *Results from data analysis.*

The correlation matrix shows strong relationships among the explanatory variables. LNGDP and LNHDI have a highly positive correlation (0.9904), indicating that economic growth and human development progress together. However, LNREC negatively correlates with both LNGDP (-0.8952) and LNHDI (-0.8458), suggesting that increased renewable energy consumption is associated with lower economic growth and human development, potentially due to the transition costs of shifting to greener energy sources.

Table 8.

Correlation matrix of explanatory variables in first differences

	D(LNGDP)	**D(LNAV)**	**D(LNHDI)**	**D(LNRIC)**	**D(LNREC)**
D(LNGDP)	1	-	-	-	-
D(LNAV)	-0.2298	1	-	-	-
D(LNHDI)	0.4642	0.1209	1	-	-
D(LNRIC)	-0.1627	0.1272	-0.1730	1	-
D(LNREC)	0.0593	-0.0638	0.2309	0.0861	1

Source: *Results from data analysis.*

The correlation matrix of the first differences reveals varying relationships among the changes in the explanatory variables. D(LNGDP) shows a weak negative correlation with D(LNAV) (-0.2298), suggesting that increases in agricultural value added may not directly coincide with GDP growth. Additionally, the positive correlation between D(LNHDI) and D(LNREC) (0.2309) indicates that improvements in human development may be associated with changes in renewable energy consumption, highlighting a potential link between sustainable practices and social progress.

The correlation matrices presented in Tables 7 and 8 illustrate the relationships in both levels and first differences. These tables indicate that the levels exhibit very high correlations, potentially resulting from spurious correlations. To address this, we examine the data in first differences, which may estimate the residual series used in the experiment design to induce correlation; even in this form, the correlations among the variables remain notably low, ranging from 0.05 to 0.46.

Granger Causality Test

The Granger Causality Test in a DOLS framework evaluates whether one time series can predict another, taking into account both short- and long-run dynamics. It is used to assess the causal relationships between integrated variables within cointegration models (Poudel et al., 2023).

Table 9.

Pairwise Granger Causality Tests

Direction of Causality	Observations	F-Stat.	Prob.
LNGDP → $LNCO_2$	29	3.33077	0.0795
$LNCO_2$ → LNGDP		0.05757	0.8123
LNAV → $LNCO_2$	29	2.02851	0.1663
$LNCO_2$ → LNAV		4.33840	0.0472
LNHDI → $LNCO_2$	29	2.95494	0.0975
$LNCO_2$ → LNHDI		3.29380	0.0811
LNRIC → $LNCO_2$	29	0.14745	0.7041
$LNCO_2$ → LNRIC		6.25501	0.0190
LNREC → $LNCO_2$	29	3.29556	0.0810
$LNCO_2$ → LNREC		5.32866	0.0292
LNAV → LNGDP	29	0.03313	0.8570
LNGDP → LNAV		6.00680	0.0213
LNHDI → LNGDP	29	6.58210	0.0164
LNGDP → LNHDI		4.53151	0.0429
LNRIC → LNAV	29	0.73906	0.3978

Direction of Causality	Observations	F-Stat.	Prob.
LNAV → LNRIC		5.42075	0.0279
LNREC → LNRIC	29	5.32627	0.0292
LNRIC → LNREC		0.73404	0.3994

Source: *Results from data analysis.*

The pairwise Granger causality tests offer valuable understandings into the dynamic associations among the economic and environmental variables in Nepal. The null hypothesis tests reveal that LNGDP (economic growth) significantly Granger-causes $LNCO_2$ (carbon emissions) with a p-value of 0.0795, suggesting that increases in GDP precede rises in CO_2 emissions, albeit at a marginal significance level. This relationship underscores the challenge of balancing economic growth with environmental sustainability, indicating that as the economy expands, it may lead to increased carbon emissions unless there are proactive measures to promote clean energy and sustainable practices.

Conversely, $LNCO_2$ significantly Granger-causes LNREC (renewable energy consumption) with a p-value of 0.0292, suggesting that higher emissions may spur the demand for renewable energy solutions, emphasizing a reactive policy approach rather than a proactive one. Moreover, the strong causality from LNHDI (Human Development Index) to LNGDP (p = 0.0164) suggests that improvements in human development drive economic growth, which aligns with the theory that better health and education contribute to a more productive workforce. Overall, these findings highlight the intricate interplay between environmental impacts and economic growth, highlighting the need for integrated policies that foster sustainable growth while enhancing human development outcomes.

Wald Test

The Wald test, named after statistician Abraham Wald, is a hypothesis test used to assess the significance of coefficients in regression analysis or the parameters of a statistical model. It evaluates whether a particular parameter estimated from the data significantly differs from a hypothesized value, often zero. By comparing the estimated parameter to its standard error and assuming a normal distribution, the Wald test generates a test statistic. This statistic follows a chi-squared distribution under the H_0, allowing researchers to determine whether the observed deviation is statistically significant. Thus, the Wald test provides a crucial tool for understanding the relevance and reliability of specific variables or parameters within complex statistical models.

Table 10.

Wald Test Results

Test Stat.	***Value***	***Degree of freedom***	***Prob.***
F-stat.	321.4927	(5, 6)	0.0000
Chi −square	1607.463	5	0.0000
Normalized Restriction (= 0)		***Value***	***Std. Err.***
C(1)		3.377694	0.964358
C(2)		2.001036	0.359805
C(3)		-1.697294	1.474638
C(4)		-0.071547	0.076876
C(5)		-5.818686	0.931246

Source: *Results from data analysis.*

The Wald test results presented in Table 10 indicate significant relationships among the model's coefficients, suggesting that a minimum of one of the explanatory variables has a substantial effect on carbon emissions ($LNCO_2$). The F-statistic (321.49) and Chi-square statistic (1607.46), both yielding probabilities of 0.0000, strongly reject the H_0 that all coefficients are zero. This statistical significance implies that changes in variables such as GDP (C(1)), agricultural value added (C(2)), human development index (C(3)), renewable installed capacity (C(4)), and renewable energy consumption (C(5)) collectively contribute to explaining variations in carbon emissions.

The relationship between economic growth and carbon emissions, as reflected by the positive GDP coefficient (C(1) = 3.3777), and the mitigating role of renewable energy consumption, indicated by the negative coefficient (C(5) = -5.8187), highlights a complex dynamic rather than a contradiction. Economic growth in Nepal, driven by industrialization and urbanization, increases energy demand, much of which is still met by carbon-intensive sources. Meanwhile, renewable energy consumption significantly reduces emissions in regions or sectors where it is integrated, demonstrating its potential to offset environmental degradation.

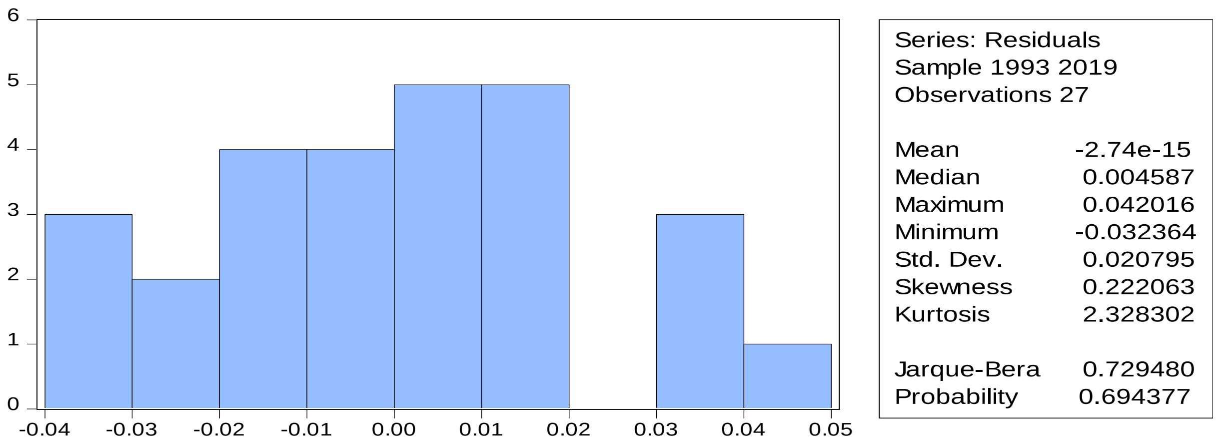
However, the slower adoption of renewable energy compared to the pace of economic expansion results in continued emissions growth overall. This dual effect underscores the need for accelerated renewable energy adoption, particularly in industrial and urban sectors, alongside integrated policies that align economic development with sustainability goals. By investing in renewable energy infrastructure and promoting sustainable practices, Nepal can effectively balance economic growth with environmental preservation.

Normality Test

A normality test determines whether a dataset follows a normal (Gaussian) distribution, which is a key assumption in many statistical models. Common tests, such as the Jarque-Bera assess this by analyzing the kurtosis and skewness of the data.

Figure 2.

Jarque-Bera Normality Test



Source: *Results from data analysis.*

The Jarque-Bera test's probability value (0.694377) exceeds the 5% significance level, suggesting that the residuals of the model follow a Gaussian distribution. This indicates that the assumption of normality for the model's variables is likely met.

Discussions

This study's findings align with the results of previous research while offering insights into Nepal's unique socio-economic and energy dynamics. Similar to Adebayo et al. (2021) and Aydoğan and Vardar (2020), the results confirm that economic growth significantly contributes to CO_2 emissions, as seen in Nepal's reliance on industrialization and urbanization to drive GDP. The negative correlation between renewable energy consumption and emissions supports the pivotal role of renewables in mitigating environmental degradation, resonating with findings from Indonesia and E7 countries. Institutional quality, as emphasized by Dam and Işik (2022) in the MENA region, is also relevant to Nepal, where policy implementation often faces challenges due to weak institutional frameworks.

Technological innovation and strong policy support, highlighted by Cheng et al. (2018) and Alavijeh and Shadmehri (2022) in OECD and EU contexts, emerge as critical drivers for emissions reduction. In Nepal, however, the lack of green financing mechanisms, inconsistent policy implementation, and limited access to technological advancements hinder the widespread adoption of renewable energy solutions. Although Regmi et al. (2024) emphasized the potential of hydropower to balance economic growth and sustainability, this study underscores the need to accelerate investment in other renewable sources, such as solar and wind energy, to diversify Nepal's energy mix.

Fundamental issues in Nepal include inadequate infrastructure for renewable energy, reliance on traditional agricultural practices, and limited awareness of energy efficiency measures. Policy shortcomings involve the lack of targeted subsidies for renewable energy projects, fragmented energy governance, and insufficient integration of renewable energy in industrial sectors. To address these challenges, Nepal must enhance institutional capacity, streamline renewable energy policies, and establish green financing initiatives to support infrastructure development and innovation. These measures are essential for achieving long-term sustainability while fostering economic growth.

Conclusions

This study examined the relationships between carbon emissions, economic growth, renewable energy consumption, and socio-economic factors in Nepal, revealing important insights. The results show that a 1% increase in GDP per capita contributes to a 3.38% rise in CO_2 emissions, highlighting the significant environmental impact of economic growth driven by industrialization and urbanization. In contrast, a 1% increase in renewable energy consumption reduces CO_2 emissions by 5.82%, underscoring the crucial role of renewable energy in mitigating environmental degradation.

These quantified findings emphasize the dual challenge Nepal faces in balancing economic growth with environmental sustainability. While economic expansion increases emissions, renewable energy offers a pathway to decouple growth from environmental harm. The study also highlights the influence of socio-economic factors. For instance, human development (LNHDI) has a nuanced role: its positive impact on quality of life indirectly increases emissions due to higher energy demand, while its negative coefficient in the model suggests that advancements in human capital can also foster sustainable practices.

Agriculture's share of GDP (LNAV) shows a diminishing contribution to emissions, reflecting Nepal's economic shift from agriculture to industrial and service sectors. Policymakers must consider these socio-economic dynamics to develop targeted strategies that address emissions holistically. The use of advanced econometric models, including ARDL and DOLS, ensures robust analysis of short- and long-term relationships among these variables, providing reliable evidence for policy formulation.

Promoting investments in renewable energy infrastructure, particularly in hydropower, solar, and wind energy, could further reduce Nepal's carbon footprint. Future research could explore the long-term impacts of diversifying renewable energy sources and conduct comparative studies with other developing countries to draw broader insights. Addressing socio-economic factors such as education, healthcare, and sustainable agricultural practices should also be integral to designing effective energy policies for sustainable growth.

References

Abdulqadir, I. A. (2020). Growth threshold-effect on renewable energy consumption in major oil-producing countries in sub-saharan Africa: A dynamic panel threshold regression estimation. *International Journal of Energy Sector Management*, *15*(3), 496–522. https://www.emerald.com/insight/1750-6220.htm

Abdulqadir, I. A. (2022). CO_2 emissions policy thresholds for renewable energy consumption on economic growth in OPEC member countries. *International Journal of Energy Sector Management*, ahead-of-print (ahead-of-print).https://doi.org/10.1108/IJESM-08-2022-0013.

Acharya, B., Poudel, O., Upadhyaya, Y. M., & Acharya, P. (2024). A comprehensive analysis of remittances and basic level government school enrollment in Nepal. *International Research Journal of MMC*, *5*(3), 86-103. https://doi.org/10.3126/irjmmc.v5i3.68503

Adebayo, T. S., Akinsola, G. D., Kirikkaleli, D., Bekun, F. V., Umarbeyli, S., & Osemeahon, O. S. (2021). Economic performance of Indonesia amidst CO_2 emissions and agriculture: A time series analysis. *Environmental Science and Pollution Research*, *28*(35), 47942–47956. https://doi.org/10.1007/s11356-021-13992-6.

Adebola Solarin, S., Al-Mulali, U., & Ozturk, I. (2017). Validating the environmental Kuznets curve hypothesis in India and China: The role of hydroelectricity consumption. *Renewable and Sustainable Energy Reviews*, *80*, 1578–1587. https://doi.org/10.1016/J.RSER.2017.07.028

Alam, M. M., Murad, M. W., Noman, A. H., Md, & Ozturk, I. (2016). Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing Environmental Kuznets curve hypothesis for Brazil, China, India and Indonesia. *Ecological Indicators*, *70*, 466–479. https://doi.org/10.1016/J.ECOLIND.2016.06.043.

Alavijeh, N. K., & Shadmehri, M. M. (2022). The role of renewable energy consumption on CO_2 emissions in EU countries: A panel data analysis. *Energy Reports*. 1-24. http://dx.doi.org/10.21203/rs.3.rs-2412489/v1

Altıntaş, H., & Kassouri, Y. (2020). Is the environmental Kuznets Curve in Europe related to the per-capita ecological footprint or CO_2 emissions? *Ecological Indicators*, 113(2020), 106187). Elsevier B.V. https://doi.org/10.1016/j.ecolind.2020.106187.

Aydoğan, B., & Vardar, G. (2020). Evaluating the role of renewable energy, economic growth and agriculture on CO_2 emission in E7 countries. *International Journal of Sustainable Energy*, *39*(4), 335-348. https://doi.org/10.1080/14786451.2019.1686380.

Bekhet, H. A., & Othman, N. S. (2018). The role of renewable energy to validate dynamic interaction between CO_2 emissions and GDP toward sustainable development in

Malaysia. *Energy Economics*, *72*, 47-61. https://doi.org/10.1016/J.ENECO.2018.03.028.

Cheng, C., Ren, X., Wang, Z., & Yan, C. (2018). The impact of renewable energy and innovation on carbon emission: An empirical analysis for OECD countries. *Journal of Cleaner Production*, *205*, 201–210. http://creativecommons.org/licenses/by-nc-nd/4.0/

Climate Links-USAID (2019). *Greenhouse Gas Emissions Factsheet: Nepal | Global Climate Change*. https://www.climatelinks.org/resources/greenhouse-gas-emissions-factsheet-nepal.

Dam, K., & Işik, C. (2022). The impacts of renewable energy and institutional quality on carbon dioxide (CO_2) emissions: Evidence from the MENA countries. *Journal of Cleaner Production*. https://www.semanticscholar.org/paper/The-impacts-of-renewable-energy-and-institutional-A-Dam-I%C5%9F%C4%B1k/340dc08dd7f822ab51317e233706b7ba4fa2ee77

Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association*, *74*(366), 427–431. https://doi.org/10.2307/2286348

Engle, R. F., & Granger, C. W. J. (1987). Co-integration and error correction: Representation, estimation, and testing. *Econometrica*, *55*(2), 251-276.

Farhani, S., & Rejeb, J. B. (2012). Energy consumption, economic growth and CO_2 emissions: Evidence from panel data for MENA region. *International Journal of Energy Economics and Policy*, *2*(2), 71-81. https://dergipark.org.tr/en/download/article-file/361164

Granger, C. W. (1969). Investigating causal relations by econometric models and cross-spectral methods. *Econometrica*, *37*(3), 424–438. https://doi.org/10.2307/1912791

Hao, L., Umar, M., Khan, Z., & Ali, W. (2020). Green growth and low carbon emission in G7 countries: How critical the network of environmental taxes, renewable energy and human capital is? *The Science of the total environment*, *752*, 141853

.https://www.semanticscholar.org/paper/Green-growth-and-low-carbon-emission-in-G7-How-the-Hao-Umar/8964fdba4a354a43afc34bdb15bfa726307d5942

Hassan, A., Yang, J., Usman, A., Bilal, A., & Ullah, S. (2023). Green growth as a determinant of ecological footprint: do ICT diffusion, environmental innovation, and natural resources matter?. *PLoS One*, *18*(9), e0287715. https://doi.org/10.1371/journal.pone.0287715

Hossain, S. (2012) An Econometric Analysis for CO_2 Emissions, Energy Consumption, Economic Growth, Foreign Trade and Urbanization of Japan. *Low Carbon Economy*, *3*, 92-105. https://doi.org/10.4236/lce.2012.323013.

Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control, Elsevier, 12*(2-3), 231-254. Retrieved from https://www.scirp.org/reference/referencespapers?referenceid=2744286

Kharel, K., Poudel, O., Upadhyaya, Y., Nepal, P. (2024). Effect of private sector credit on economic growth in Nepal. *Financial Markets, Institutions and Risks*, *8*(1), 142-157. http://doi.org/10.61093/fmir.8(1).142-157.2024

Pesaran, M. H. (2004). General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics*, *30*(3), 1–38. https://doi.org/10.1007/s00181-004-0206-3

Poudel, O. (2022). Impacts of Foreign Direct Investment on Economic Growth of Nepal: A Johansen Co-integration Analysis. Journal of Balkumari College, *11*(1), 50-64. https://doi.org/10.3126/jbkc.v11i1.53023

Poudel, O. (2023). Relationship between Defense Expenditure and Economic Growth in Nepal. *Unity Journal*, *4*(1), 208-226. http://dx.doi.org/10.3126/unityj.v4i01.52242

Poudel, O., & Sapkota, M. P. (2022). Consumer Perception toward Digital Payment System. *Management Dynamics, 25*(1), 39-50. https://doi.org/10.3126/md.v25i1.53286

Poudel, O., Kharel, K. R., Acharya, P., Simkhada, D., & Kafle, S. C. (2024). ARIMA Modeling and Forecasting of National Consumer Price Index in Nepal. *Interdisciplinary Journal of Management and Social Sciences, 5*(1), 105-118. http://dx.doi.org/10.3126/ijmss.v5i1.62666

Regmi, K., & Rehman, A. (2021). Do carbon emissions impact Nepal's population growth, energy utilization, and economic progress? Evidence from long- and short-run analyses. *Environmental Science and Pollution Research*, *28*, 55465 - 55475. https://doi.org/10.1007/s11356-021-14546-6

Regmi, K., Qiao, J., & Batala, L. K. (2024). The role of agricultural innovations, renewable energy and economic growth in the CO2 emissions of Nepal: an empirical evidence from the environmental Kuznets curve. *Environment, Development and Sustainability*, 1-24. https://doi.org/10.1007/s10668-024-04978-8

Saleem, H., Khan, M. B., & Mahdavian, S. M. (2022). The role of green growth, green financing, and eco-friendly technology in achieving environmental quality: evidence from selected Asian economies. *Environmental Science and Pollution Research*, *29*(38), 57720-57739. http://dx.doi.org/10.1007/s11356-022-19799-3

Shakya, S. R., Nakarmi, A. M., Prajapati, A., Pradhan, B. B., Rajbhandari, U. S., Rupakheti, M., & Lawrence, M. G. (2023). Environmental, energy security, and energy equity (3E) benefits of net-zero emission strategy in a developing country: A case study of Nepal. *Energy Reports*, *9*, 2359–2371. https://doi.org/10.1016/j.egyr.2023.01.055.

Stock, J. H., & Watson, M. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. *Econometrica, 61*(4), 783–820. https://doi.org/10.2307/2951763

Zhou, R. (2023). Economic growth, energy consumption and CO_2 emissions: An empirical study based on the Yangtze River economic belt of China. *Heliyon*, *9*(9), 1-13. https://doi.org/10.1016/j.heliyon.2023.e19865.