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Navigating Nepal's Economic Growth and Carbon Emissions: Insights into the Environmental Kuznets Curve (EKC)

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ABSTRACT

This research aims to employ the Autoregressive Distributed Lag (ARDL) method within the insight into the Environmental Kuznets Curve (EKC) to verify whether EKC exists in the Nepalese economy. In this research, variables were used, such as carbon emissions per capita, GDP per capita, energy use per capita, trade volume, and urbanization from 1980 to 2021, and the ARDL method was used. The data has been taken in this research except trade volume from the World Bank and the Ministry of Finance, Nepal. The data sets are converted into the natural logarithmic form to minimize the problem of heteroskedasticity. The findings provide compelling evidence for the existence of the EKC in Nepal, that economic growth has an inverted U-shaped impact on carbon emissions. In the early stages of development, economic growth leads to rising carbon emissions, but in the later stages, economic growth becomes associated with declining emissions. Besides economic growth, per capita energy consumption and urbanization emerge as significant drivers of carbon emissions. However, the trade volume is not found to be the driving factor of carbon emissions. The findings of this study have significant policy implications for global climate change issues and Nepal's transition from an underdeveloped to a developing nation. To achieve harmonious economic growth and emissions reduction, donor countries and agencies to partner with Nepal in its ambitious endeavors. This partnership can take shape through multifaceted support as fueling socio-economic progress that aligns with Nepal's commitment to reduce carbon emissions, ensuring that development and sustainability walk together. This research recommends the government of Nepal electrify the transportation landscape by incentivizing the adoption of electric vehicles, paving the way for cleaner air and a healthier planet, empowering Nepal's natural guardians by strengthening public and private forest programs, safeguarding invaluable ecosystems and biodiversity and curbing the tide of waste mismanagement through strict regulations and robust enforcement, transforming a potential threat into a source of innovation and resourcefulness. These measures, aligned with sustainable employment generation, can pave the way for a brighter and greener future for Nepal.

INTRODUCTION

Rapid economic growth of every country turns to developed at the same time, countries also produce high carbon emissions. Meanwhile, countries like Nepal are moving toward developing countries from least developing countries and cause carbon emissions less as compared to developed countries, thought it is one of the great challenges countries like Nepal. Carbon dioxide emissions on a worldwide scale are a worry for researchers and policymakers. The excessive use of coal, petroleum, and other fossil fuels, in addition to the mismanagement of plastic-related objects, are the number one human drivers of this problem. Along with their desire for rapid industrial development and economic success, nations' struggles for economic dominance are also to blame for the increase in global carbon emissions. According to Grossman & Krueger (1995), the environment has gotten worse resulting from the severe thrust for the fast rise in income, neglecting environmental preservation. However, the authors asserted that an increase in income can be exploited for the betterment of the environment. In the same reasoning as the initial view of Grossman & Krueger (1995), noted that CO_2 emissions from human activities are widely recognized as the most important sources of probable future global warming. According to studies, the impact of greenhouse gases on global ecology is not an exceptional case. To have a comprehensive understanding of the origins of greenhouse gases and their impact on global warming, it is important to possess knowledge pertaining to the physical and ecological processes that facilitate the conversion of emissions into minimum greenhouse gas levels. Mohammed et al. (2015) identified that the tendency of increasing domestic output and the emergence of foreign direct investment are the two primary long-term economic activities driving CO_2 emissions.

Wang et al. (2011) claimed that emissions fueled by accelerated industrial development are found responsible for causing global warming. On the other hand, Menyah & Wolde-Rufael (2010) as cited in Khan et al. (2020) claimed that the use of traditional energy resources causes CO_2 emissions. Shahbaz et al. (2013) also revealed that the use of fossil fuels by households and the creation of massive smoke by industries increases CO_2. Jiang et al. (2018) also noticed that the matter of carbon emissions is particularly crucial since policymakers in the least developed countries (LDCs) are becoming more and more worried about increasing dependence on the imports of energy, notably fossil fuels and rising greenhouse gases.

It is also an appalling concern of the ecologists that there is an escalating worldwide warming day by day caused by CO_2 emissions. Human activities are solely liable for carbon emissions, which cause global warming along with increased sea levels. Not only do human activities emit carbon dioxide, but also natural sources cause carbon emissions. According to Ali et al. (2020), both natural and human activities can emit CO_2 emissions. One of these sources comes from the development of urbanization, and the growing population tends to rapid urbanization. Urbanization needs infrastructure for a growing population, and human beings severely exploit the environment for their needs, triggering an imbalance in the ecosystem. In the same reasoning, According to Pant (2009), the primary cause of climate change can be linked to the industrial revolution and the extensive utilization of fossil fuels. The author further argued that agriculture is also the cause of the complications through emissions of greenhouse gases. Elum & Momodu (2017) stated that carbon emissions and environmental pollution are associated with developed countries only. However, at present, attention is diverted to developing countries due to the fast industrialization and increasing economic growth in such countries. As underdeveloped countries shift into developing status, they typically experience a period of rapid economic growth. This economic growth is often accompanied by a shift from a predominantly agricultural economy to a more industrialized economy. This shift to an industrialized economy can lead to increased carbon emissions in many ways (IPCC 2022).

Although Nepal is an underdeveloped country, it is not free from the phenomenon of climate change issue. Nepal, like other countries, contributes to carbon emissions, even though its share of global emissions is negligible. According to the World Resources Institute (2017), Nepal accounts for just a mere 0.044 percent of the global aggregate of greenhouse gas emissions. Though the share of the world's emissions is very low, Nepal should also address the climate change issue. The carbon emissions, sooner or later, will become a complicated issue if it is not addressed in time. According to Piya et al. (2019), the Nepal government had not begun addressing climate change issues until the Tenth Plan (2002-2007) despite having ratified both the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol (KP). However, the Nepal government later assured to address the climate change issue and administered the Three-Year Interim Plan (2007-2010) through the Clean Development Mechanism.

Although Nepal's per capita greenhouse gas emissions are low compared to rich industrialized nations, they have doubled in the past seven years, reaching 28,166 Gg of carbon dioxide in 2021. Nepal has submitted its second Nationally Determined Contributions (NDC) Report, third National Communication Report, and report on the technology requirements assessment two years past the deadline of 2019. As stated in the country's second NDC, the goal of Nepal is to achieve net-zero emissions by 2050 and a minimum of 55 percent decrease in carbon emissions by 2030 by reducing emissions from sectors like waste management, forestry, and power (Nepali Times 2021). Nepal, a landlocked country in South Asia, is rich in natural resources. There are eight of the world's top fourteen mountains, including Mount Everest, as well as a variety of fauna and environments. (Ministry of Forests and Soil Conservation (MoFSC 2014). However, Nepal is among the countries that are most vulnerable to the impacts of climate change and other environmental challenges on a global scale (MoFSC 2021). The Government of Nepal has made a number of commitments to address environmental issues, both domestically and internationally (Government of Nepal (GoN) (2023). Despite low current emissions, Nepal faces a unique challenge in managing future increases due to rapid economic growth as projected at 7.1% in 2023-24 by the World Bank, rising energy demand, reliance on traditional fuels like firewood, extreme climate vulnerability (MoFSC 2021), limited financial and technological resources, and complex socioeconomic and political landscapes (GoN 2023). These factors necessitate a multi-pronged approach with clean energy investments, sustainable development practices, climate resilience strategies, and international cooperation.

In 2015, Nepal ratified the Paris Agreement with the commitment to reducing carbon emissions by 23% by 2030

(Government of Nepal, Ministry of Forests and Environment (2015). The Green, Resilient, and Inclusive Development (GRID) concept was embraced by Nepal in 2021 as a national goal to steer long-term green growth and develop resilience to climate shocks (Government of Nepal, National Planning Commission, 2021). Nepal has also taken several concrete steps to implement its environmental commitments (Government of Nepal, Ministry of Forests and Environment 2022). For example, the government has invested in renewable energy, such as hydropower (Government of Nepal, Ministry of Energy, Water Resources and Irrigation 2006). It has also launched a number of programs to promote sustainable forest management and conservation (Government of Nepal, Ministry of Forests and Environment, 2019). Nepal has also been working to improve air quality and water quality in its cities (Government of Nepal, Ministry of Environment, Science and Technology, 2019, Government of Nepal, Ministry of Water Resources 2019). To implement the Paris Agreement as per the needs of the country, Nepal is committed to stepping up its climate change initiatives. Nepal aims to attain zero gas production between 2020 and 2030, followed by a period of extremely low emissions until obtaining full net-zero emissions by 2045. Nepal also wants to be acknowledged for its efforts to reduce greenhouse gas emissions. Global emissions through promoting renewable energy. The long-term strategy of Nepal strives to create a future that is inclusive, carbon-neutral, and climate-resilient through bold policy-making, social change, and technical advancement (Government of Nepal [GoN] 2021).

Global issues quickly become pressing local concerns in Nepal. Increasing temperatures are causing glaciers to melt, leading to people having to relocate and risking water sources (MoFSC 2021). Poor air quality in Kathmandu is making it difficult for people to breathe properly (MoEPE 2022). Poverty and unequal treatment of women make it especially challenging for the most vulnerable groups (Sharma & Gyawali 2012). Nepal reflects global trends but requires unique solutions to create a more positive future. Nepal's carbon footprint whispers with diverse voices, but a few shout loudest. Soaring reliance on traditional biomass (firewood) for cooking and heating dominates (MoFSC 2021), fueled by poverty and limited access to clean energy. Inefficient transport, particularly fossil-fueled vehicles, adds its rumble (GoN 2023). Industrial emissions, though modest now, could roar in future growth, demanding proactive measures (NPC 2021). Nepal's story echoes a chorus of interconnected factors requiring a conductor of sustainable solutions. Nepal, nestled amidst towering Himalayas, whispers a tale of environmental struggles. Fossil fuels roar in Kathmandu's streets**,** their fumes choking the vibrant city (MoEPE 2022). Cooking fires crackle across vast rural landscapes**,** fueled by poverty and dependence on firewood, spewing greenhouse gases into the thin mountain air (MoFSC, 2021). And in the distance, the industry's shadow looms as a potential future threat if unchecked (NPC 2021). These are the voices of Nepal's carbon conundrum, a chorus demanding sustainable solutions to ensure a vibrant future for this fragile paradise

While Nepal's current share of global emissions is minimal, its rapid economic growth and reliance on traditional energy sources raise concerns about future emissions increases. This study investigates whether Nepal can decouple its economic growth from carbon emissions and, if so, what policies and strategies are most effective. In this spirit, the present paper aims to examine the factors causing environmental deterioration in Nepal with insights into the environmental Kuznets curve (EKC) to help formulate suitable policies to minimize carbon emissions at a target level. This paper intends to answer the research query: "What is the impact of economic growth on carbon emissions in Nepal, and what are the suitable policies to minimize carbon emissions?" The research question is addressed by the verification of the Environmental Kuznets Curve (EKC) through a model based on autoregressive distributed lags (ARDL) theory. Varied studies are available in economic literature regarding the verification of EKC by ARDL models in an international context. However, the verification of EKC through this model in the Nepalese context with the latest data is not available. Hence, this study attempts to fill the methodological knowledge gap through ARDL models in EKC form with the latest data for the economy of Nepal. The survey of related literature is offered in section two, and section three talks about the research methods. The findings and discussion are presented in Section four, while the conclusions with implications are presented in Section five.

PAST STUDIES

The EKC is a hypothesis that proposes the reversal U linkage between income growth and air pollution. It states that there is a simultaneous rise in income and pollution both in the initial phase, but later on, rising income causes pollution to decrease, giving rise to an inverse U-shaped EKC. The EKC hypothesis popularized after the 1990s is based on the Kuznets (1960) theory that posits an inverted U linkage between the growth of income and income inequality. A wide range of researchers have made contributions to the EKC's theoretical underpinnings. Several studies that elaborated and clarified the EKC hypothesis are Grossman & Krueger (1991, 1995), Stern et al. (1996), Dinda (2004), and Managi et al. (2009) among the others who attempted to enrich EKC. As argued by Agras & Chapman (1999), when the economy switches from low-income to high-income, the industrial and manufacturing sectors tend to decline, and the service sector tends to increase. The service sector is less polluting in relation to the industrial and manufacturing sectors. As a result, the growth of the economy causes pollution to fall. Selden & Song (1994) argued that as countries grow economically, they become more aware of environmental pollution and the government enforces strict regulations regarding environmental protection. On the other hand, Jaffe & Palmer (1997) stated that countries develop cleaner technologies as they become economically prosperous. All these arguments of the researchers are sufficient bases for how environmental pollution decreases once a certain threshold is reached, giving rise to a reversal U-shaped EKC.

According to the arguments made by the researchers, environmental deterioration first rises with economic growth before declining as that growth accelerates. The researchers' arguments state that while nations first pay little attention to environmental preservation, as awareness grows and nations invest more in environmental protection, environmental deterioration gradually decreases. A reversal 'U' EKC resulted. As opined by Voumik (2005), the EKC theory has been used to observe the connection between environmental deterioration and economic development. It is believed that when economies expand, environmental contamination will first increase before declining once a certain income level is attained.

Similarly, Iwata et al. (2010) claimed that the linkage between the rise of income and environmental pollution is inverse U-shaped. The increase in income in the initial stage of economic expansion exacerbates harm to the environment and devastation of natural resources; however, these effects become less pronounced above a certain income level (Barbier 1997, Suri & Chapman 1998). According to Kijima et al. (2010), the EKC proposes an inverse U linkage between income and pollution, with emissions rising initially caused by economic growth but falling as investment increases in cleaning the environment.

The reversal of U-shaped EKC proposed by different researchers after 1990 is doubted by Babu & Datta (2013). The authors stated that the initial formulation of EKC has stimulated a large debate and the income-carbon emissions linkage produces an N-shaped pattern rather than reversal U. In the same manner, Selden & Song (1994), Panayotou (1997), Cole et al. (1997) and Dasgupta et al. (2002) also argued that there exists N-shaped EKC, in which the environment deteriorates with a rise in income initially, then improves, and subsequently worsens again. The N-shaped EKC hypothesis has several theoretical explanations. The first is that composition and technical effects have been relegated to the scale effect. The scale effect arises from increased production, leading to greater environmental pressure (Torras & Boyce 1998). The composition effect involves changes in economic activities as countries develop, shifting from agriculture to industry and services, potentially reducing environmental degradation (Bruyn et al. 1998). Technical effect indicates the development of new technologies to reduce environmental pollution (Dinda 2004).

Additionally, a shift can occur where the desire for clean and healthy outweighs the pursuit of economic growth as people become more environmentally aware (Allard et al. 2018). Amid (2015) demonstrated the connection between the formal and informal economy and the state of the environment. The author claimed that the informal economy plays a significant role in Tunisia, despite there being no direct connection between the formal and informal economies and the environmental weakening. The author argued that environmental contamination, which is largely caused by industrial and agro-food processing activities and is exacerbated by population growth, can be attributed to rising air pollution.

Palamalai et al. (2015) observed the linkage between emissions, trade, income, and several energy consumption sources, including coal, natural gases, crude oil, and renewable energy in India. The authors found a long-run link between the variables, as reported by the Gregory-Hansen cointegrating test and the error correction model. The findings validated the EKC hypothesis that growing economic activity raises energy use, which in turn causes a worsening of the environment. Saboori et al. (2014) investigated the connection among income, greenhouse gases, and energy use of the road transportation sector in the OECD. Their findings unveiled a clear association between the growth of income and pollution emissions, with the use of energy in the road transport sector demonstrating a more rapid response to changes in CO_2 emissions than to emission increments. The study recommended the implementation of enduring strategies focusing on energy efficiency and the transition to nuclear, renewable, and biofuel sources to significantly mitigate greenhouse gas emissions.

Alam & Adil (2019) found EKC to be invalid in India when the authors used the data of the concerned variables over the period 1991-2016. However, they identified a substantial direct link between energy supply and carbon emissions, suggesting an urgent need for India to expedite the expansion of clean and renewable energy production to curtail carbon emissions. Conversely, Shahbaz (2019) substantiated the EKC in Next-11 countries by investigating the link between air pollution and globalization through bounds testing. Zhu et al. (2016) detected the influence of foreign direct investment, economic growth, and energy use on pollution in ASEAN-5 member nations. The authors used a panel quantile regression model and detected that FDI had a favorable effect on emissions, while energy consumption had increased emissions. On the other hand, income and population size could reduce pollution in high-emission nations. The study also suggested that trade openness could mitigate air pollution, especially in low and high-emission nations.

Environmental pollution is also caused by the openness of an economy, as claimed by Davis & Calderia (2010). The authors opined that trade openness could lead to a process known as "outsourcing emissions," in which carbon-intensive goods are produced in nations with tax laws rather than in nations with strict environmental rules. However, a study by Thuy & Nguyen (2022) demonstrated that liberalization in trade in developing nations does not worsen ecological conditions. Their results provided strong evidence for two strategies to reduce carbon dioxide emissions, which are the major factors impacting the environment in addition to foreign trade, financial transparency, and the sources of renewable energy. Udeagha & Ngepah (2022), in contrast to Thuy and Nguyen, revealed that trade openness, while initially beneficial to the environment, ultimately degrades environmental quality. This study demonstrated that the scale effect pushes up carbon emissions while the technique effect helps to lessen them, supporting the occurrence of EKC.

Varied works have examined the EKC hypothesis, and the findings have usually been in favor of the theory. For example, from 1972 to 2008, Pakistan's foreign trade, GDP, use of energy, and carbon emissions were examined by Nasir & Rehman (2011). The results demonstrated that energy use and international trade directly impacted greenhouse gases and validated the EKC hypothesis. However, short-term data disproved EKC's validation in Nasir and Rehman's study. Policymakers should consider environmental issues, develop policies to support sustainable trade practices and reduce energy consumption, forecast future energy demand using different growth scenarios, and purchase the least expensive energy, according to this study. In a similar vein, Pata's (2017) study on Turkey demonstrated a reversal of the U connection between income and greenhouse gases, both in the short and long periods, over the 1974-2013 study period. It was observed that per-head energy use, GDP per head, industrialization, and financial development were the factors causing per-head carbon emissions. Conversely, it was detected that urbanization had no impact on environmental pollution.

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Lazar et al. (2019) found that income is generally associated with higher environmental deterioration, except for a few Central and Eastern European countries that saw faster growth without a decline in environmental quality between 1996 and 2015. Rahman et al. (2022) reported that consumption of the household sector accounted for above 62.39 percent of emissions in the SAARC area. India topped the list of countries with household emissions, which varied from 37.27% to 0.61%. According to a study by Sharma et al. (2019), Nepal's rising carbon emissions were mostly caused by remittances and increased GDP.

The consumption of energy and greenhouse gases in Pakistan are causally related in both directions, according to Aftab et al. (2021). Nemeth-Durko (2021) found that the primary drivers of carbon emissions in Hungary were urbanization and power use, with environmental degradation being a further consequence of growth in the economy. According to Gonzalez-Sanchez and Martin-Ortega (2020), the primary factors influencing the rise in carbon emissions are GDP and final energy intensity. The primary drivers of this trend are the rise in energy efficiency and the shift to a service-oriented economy. The authors further argued that the rise in carbon emissions over the study period is not primarily attributable to rising gas prices. They also mentioned that countries have different levels of variability in the factors affecting carbon emissions, and the carbon emissions in Europe can be reduced through the development of renewable energy. Ali et al. (2020), however, held a different viewpoint. The building industry is one of the primary drivers of global emissions, according to the authors' findings. The majority of the energy used in building and operation comes from fossil fuels. Enforcing rules and policies and introducing low-carbon technologies are two ways the building industry can lessen its effect.

Ngarava (2021) investigated the relationship between South Africa's economic diversification and environmental deterioration. By using the ARDL-ECM approach with annual data, the author found that economic diversification and emissions had a one-way causal relationship, but there was no long-term association between the variables under study. GDP, population, foreign direct investment, and trade balance were the independent variables. However, when Sharma et al. (2019) employed ARDL models for the Nepalese economy, they found the surprising result that foreign aid was driving carbon emissions to decrease. According to the authors, increasing foreign aid can effectively reduce Nepal's carbon emissions. Khan et al. (2021) conducted an analysis spanning from 1985 to 2020 and employing a dynamic-stimulated ARDL. The authors found a direct link between GDP and environmental pollution both in the short-run and long-run. However, they detected an inverse association between GDP square and ai-pollution. The study found the presence of EKC in the US economy. The authors advocated the importance of institutional quality to improve environmental quality. The authors also underscored the need for a comprehensive national energy policy for cleaning the environment.

Examining the period from 1971 to 2016 in India, Kareldla et al. (2021) investigated the impact of the manufacturing industry, international trade, and income growth on CO_2 emissions using the ARDL bounds test approach. Their findings disclosed a sustained positive correlation between carbon emissions and all three explanatory variables. While international trade was identified as reducing CO_2 emissions, the manufacturing industry and GDP exhibited a significant positive long-term impact. Conversely, Destek & Sinha (2020) challenged the validity of the EKC within OECD nations. They argued that non-renewable energy exacerbates environmental degradation, while renewable energy serves to alleviate ecological damage. Their advocacy urged governments to prioritize the adoption of renewable energy to mitigate environmental deterioration.

Tenaw & Beyene (2021) applied a sustainability-focused EKC framework to scrutinize the link between environmental quality and development in 20 Sub-Saharan African countries from 1990 to 2015. While supporting a modified EKC hypothesis, the study emphasized the importance of natural resource endowment. Long-term detrimental consequences on the environment were attributed to trade openness and energy use, prompting the recommendation that environmental sustainability policies align with economic development goals. Similar insights were provided by Khan & Amhad (2021), who, using econometric techniques, underscored the positive impact of FDI and international trade on environmental pollution in emerging countries while highlighting the negative impact of renewable energy use on the environment in both developed and developing nations. The authors advised careful regulation of FDI and international trade in developing nations and the promotion of renewable energy use globally.

Hongxing et al. (2021) explored the impact of international trade, urbanization, energy use, and pollution on income growth in Belt and Road Initiative (BRI) economic corridors. Establishing a two-way causality between growth of income and consumption of energy, the study recommended government interventions, such as tax incentives, to foster clean energy technology and infrastructure. Numan et al. (2022) explored the connection between pollution and economic complexity, challenging the N-shaped EKC theory. While findings did not support the theory for all income categories in Model 1, while Model 2 suggested an N-shaped EKC, emphasizing an inverse link between the use of renewable energy and ecological footprint. This study advocated for ecologically sound energy sources to combat global warming. Voumik et al. (2022) focused on Bangladesh, utilizing population growth, use of energy, and growth of income to assess the EKC hypothesis validity from 1971 to 2020. This study supports the EKC theory, emphasizing the need for Bangladesh to shift away from nonrenewable energy sources for environmental and economic benefits.

Huang & Guo (2022) investigated the influence of fiscal improvement on decoupling carbon from GDP growth across six regions from 1995 to 2020. While effects varied by region. Population growth consistently contributes to carbon emissions. The authors urged the development of a green financial system in regions with successful decoupling and a swift transition to new economic development models in other areas. Jiang et al. (2022) proposed that reducing the political risk index and increasing the budget for environment-related research and development significantly lowered the pollutions arising from consumption in the G7 nations. Export promotion, lower political risk, increased research and development budgets, and discouraging imports were recommended as measures to minimize CO_2. However, Chen et al. (2022) identified a reversal U association between urbanization and pollutions, with urbanization increasing emissions and government effectiveness positively contributing. The authors suggest promoting urbanization and improving government efficiency to combat carbon emissions and global warming.

Pena et al. (2022) established a persistent connection between pollution, GDP, FDI, and renewable energy in Philippines. Despite challenging EKC hypothesis, the research proposed legislative measures to diminish CO_2 emissions and accomplish sustainable development objectives. The prioritization of renewable energy utilization and the attraction of FDI were suggested strategies in alignment with sustainable development goals. Examining China's data from 1990 to 2019, Ozkan et al. (2023) scrutinized the EKC theory, "pollution haven theory," and "pollution halo theories." Their findings revealed a decline in environmental quality concurrent with a rise in real GDP, supporting the "pollution haven theory's," the adverse impacts of FDI. Trade openness and energy efficiency were linked to both long- and short-term enhancements in environmental quality, underscoring the critical importance of incorporating environmental considerations into policy decisions, particularly in light of China's 2050 climate objectives.

Shen et al. (2023) used a VAR model for carbon emissions and a Tapio decoupling score to scrutinize the decoupling between income growth and air pollutions in China from 1997 to 2019. The authors observed that different economic regions had varying degrees of decoupling, with the eastern and western regions having a more optimal state of decoupling than the center and north-eastern regions. It was found that the renewable energy consumption slowed the rise in carbon emission intensity across the board, with the western region seeing the biggest reductions. The authors came to the conclusion that while sustaining steady economic growth, achieving carbon neutrality can be facilitated by increasing each region's share of renewable energy consumption. Using moments quantile regression as a methodology, Razzaq et al. (2023) revealed that while tourist expansion had an asymmetric impact on air pollution, but it caused a positive influence on growth for the top ten GDP economies between 1995 and 2018. While tourism had a relatively higher negative environmental impact on less developed countries, it had a relatively greater positive influence on growth of developed countries. Conversely, green innovation has been found to be reducing the air pollution and promote growth, particularly in developed countries.

Utilizing the Dynamic Ordinary Least Squares (DOLS) method, Raihan et al. (2023) explored the impacts of the growth of income, tourism, agriculture output, and energy consumption (both from fossil fuels and renewable sources) on air pollution in Egypt during 1990-2019. It was observed that tourism, income growth, and the use of fossil fuels caused pollution. In contrast, the renewable energy and increased agricultural goods were identified as mitigating factors, reducing air pollution and improving environmental quality. To promote environmental sustainability in Egypt, the researchers recommended the adoption of a low-carbon economy, increased use of renewable energy, adoption of eco-friendly travel practices, and implementation of climate-smart agriculture. In a separate study, Jiao et al. (2023) employed STIRPAT and scenario analysis to investigate air pollution in Guizhou, China, from 1990 to 2020. The findings indicated a growth in coal-related emissions, which are now exhibiting signs of decoupling from economic expansion. The authors suggested that significant reductions in emissions could be achieved through decreased energy use, enhanced efficiency, and greater reliance on renewable energy sources.

Mitic et al. (2023) explored the link between air pollution, income growth, easily accessible energy, and employment in Southeast European nations using data from 1995 to 2019. They identified a substantial link between employment and accessible energy, along with a short-term two-way causal association between pollutions and employment. This study highlights a coherent directionality among GDP, employment, and energy accessibility, emphasizing the critical roles of employment and energy consumption in driving economic development. The findings underscored the presence of a short-term direct feedback loop between pollutions and economic growth. As per Ali et al. (2023), the consumption of nonrenewable energy negatively impacted the environment, while renewable energy positively influenced the growth in developing Asian nations. The evidence supporting a reciprocal link between renewable energy and economic growth aligned with the feedback hypothesis. This underscored the viability of enhancing REC as a feasible strategy to mitigate carbon emissions, enhance energy security, and expedite economic growth in these nations. In the context of Vietnam, Raihan (2023), employing ARDL and VECM, identified a link between GDP growth, energy use, and pollution. Conversely, an increase in agricultural productivity demonstrated a less worsening of the environment. These promising findings underscore the potential of sustainable agriculture to reduce missions, offering policy recommendations to address Vietnam's CO_2 emissions through avenues such as low-carbon economic development, promotion of renewable energy, and implementation of sustainable agriculture practices.

Itoo & Ali (2023) employed ARDL, FMOLS, DOLS, and CRR approaches to analyze the long-term effects on air pollution in India. The authors found that the depletion of natural resources, industrial output, and remittance inflow had a small, negative influence, while energy consumption, national income, and population increase had a favorable and significant influence. This study detected reversal U-shaped EKC was not valid for India. To mitigate pollution in India, policymakers are appealed to prioritize slowing down population growth, national income growth, and energy demand, while discouraging the depletion of natural resources, industrial output, and remittance inflows. Bao & Lu (2023) utilized panel data analysis with fixed effects to investigate the likelihood of reversal U linkage between GDP and the generation of building waste in 27 European economies from 2000 to 2020. The study suggested that building waste management could be evaluated using the EKC. The authors argued that achieving sustainable development goals requires policymakers to simultaneously focus on promoting both economic growth and environmental conservation.

Thus, most studies have reached the consensus that income growth is the primary driver of air pollution. This comes as a result of the countries' unquenchable thirst for rapid economic growth. As a result, they give economic growth more importance than environmental protection. Instead of emphasizing sustainable development, they prioritize development. In addition, it has been concluded that a heavy reliance on fossil fuels, electricity, and urbanization all contribute to carbon emissions.

MATERIALS AND METHODS

Models and Variables

Grossman & Krueger (1991, 1995) asserted that there is a linkage between environmental deterioration and income per head. Early economic growth is linked with rising pollutant emissions and falling environmental quality. However, above a certain per capita income threshold, this tendency reverses, with economic growth being followed by improving environmental conditions, resulting in an inverted U-shaped EKC (Arouri et al. 2013). Equation (1), which represents the EKC function, was presented as:

$$C_t = f(Y_t, Y_t^2, E_t, T_t, U_t) \quad \dots (1)$$

The non-linear algebraic form of the EKC is represented through the equation (1), where C_t is the carbon emissions per head treated as explained variable and Y_t the GDP per head, Y_t^2 square of GDP per head, E_t energy use per head, T_t the volume of trade and U_t The rate of urbanization as an explanatory variable.

Datta & De (2021) proposed a random effect model based on the Hausman test to observe the behavior of EKC. Compared to Arouri et al. 2013 the model put forward by Datta and De differs slightly. Equation (2) presents the model as:

$$C_{it} = \gamma_i + \theta_1 Y_{it} + \theta_2 Y_{it}^2 + \theta_3 Y_{it}^3 + \theta_4 P_{it} + \theta_5 T_{it} + \varepsilon_{it} \quad \dots (2)$$

where, where the notations have the same meaning as in equation (1), and $\mathcal{E}_{it}$ stands for residuals.

Equation (2) implies that carbon emissions are caused by the growth of GDP, urbanization, and volume of trade, also known as the openness of the economy. Rich countries are more likely than poor countries to suffer environmental damage, according to the cross-country study of Datta and De, as suggested by the Hausman test. Natural resources were thought to be utilized far more quickly in rich countries because of the massive production and consumption, which accelerates the degradation of their environments.

The present study employs secondary data on per-capita carbon emissions (in tons), Gross Domestic Product (GDP) per head (in US dollars), square of the GDP per head, energy use per head in terawatt-hours, trade volume as percentage of GDP and percentage of urban population over the period 1980-2021. The reason behind choosing the starting year 1980 for the data is that firstly all are unavailable from before 1980. Secondly, the 1980s witnessed the acceleration of globalization, opening up new trade opportunities for Nepal and facilitating access to foreign markets (Adhikari 2010). The required data on the variables are taken from the World Bank, World Resource Institute for carbon emissions, World Bank National Account Data for GDP per capita, World Bank, IEA Statistics for energy consumption per head, World Bank, United Nations Population Division for urbanization and Economic Survey of Nepal, Ministry of Finance for trade volume. The data are transformed into the natural logarithmic form with the help of Eviews software to minimize the problem of heteroskedasticity. The data sets after logarithmic transformation are denoted by $LnCE_t$ for carbon emissions per head, LnY_t for GDP per head, LnY_t^2 for

Table 1: Detailed information regarding the data.

Data Sets	Measurement	Nature	Source	Notation	Logarithmic Form
Carbon emissions per Capita	Tons	Secondary	WB, WRI	EC_t	$LnEC_t$
GDP Per capita	US Dollar	Secondary	WB National Account	Y_t	LnY_t
Energy use per capita	Terawatt-hrs	Secondary	WB, IEA Statistics	EC_t	$LnEC_t$
Urbanization	Percentage of urban population	Secondary	WB, United Nations Population Division	U_t	LnU_t
Trade volume	Percentage of GDP	Secondary	Ministry of Finance, Nepal	TV	$LnTV$

the square of GDP per head, $LnEC_t$ for energy consumption per head, $LnTV$ for trade volume, and LnU_t for a percentage of the urban population (a proxy for urbanization).

Table 1 presents detailed information regarding the nature and source of data and cleaning the data through log transformation.

The present study takes into consideration the Environmental Kuznets Curve (EKC) function as:

$$LnCE_t = f(LnY_t, LnY_t^2, LnEC_t, LnTV\ LnU_t) \quad \ldots (3)$$

Equation (3) represents the non-linear function form of EKC with $LnCE_t$ as the dependent variable and $LnY_t, LnY_t^2, LnEC_t, LnTV$ and LnU_t as explanatory variables. Equation (3) can be expressed in algebraic non-linear form as:

$$LnEC_t = \gamma_i + \delta_i LnY_{it} + \theta_i LnY_{it}^2 + \mu_i LnEC_{it} + \sigma_i LnTV$$
$$+ \rho_i LnU_{it} + \varepsilon_{it} \quad \ldots (4)$$

For stability of the EKC function, the coefficient of LnY_{it} is expected to be positive, whereas the coefficient of ${LnY_{it}}^2$ to be negative. Likewise, the coefficient of $LnEC_t$,$LnTV$ and LnU_t should also be positive. The positive coefficients imply that increases in GDP, energy use, and urbanization are responsible factors causing air pollution. Positive coefficient of LnY_{it} results in the part of EKC, which is monotonically increasing. Conversely, the negative coefficient of ${LnY_{it}}^2$ gives rise to a monotonically decreasing part of the EKC, and in general, the EKC is inverted U-shaped.

According to Sinha & Datta (2013), various types of environmental-economic relationships can be tested using equation (2). The following are the four possibilities for the income-carbon link.

a) The income-carbon link is linear and monotonically increasing as $\theta_1 > 0$ and $\theta_2 = \theta_3 = 0$, which indicates that rising incomes are the cause of increasing carbon emissions.
b) It demonstrates a monotonically declining linear income-carbon link as $\theta_1 > 0$ and $\theta_2 = \theta_3 = 0$.
c) The income-carbon link is shown to be quadratic as $\theta_1 > 0$ and $\theta_2 > 0$ and $\theta_3 > 0$. It gives an inverted U-shaped EKC. When the derivative of equation (2) is set to zero, it reveals the turning point of EKC. Now, equation (2) is converted as: $Y_t = -\frac{\theta_1}{2\theta_2}$
d) It reveals the N-shaped figure as a cubic polynomial when $\theta_1 > 0$ and $\theta_2 > 0$ and $\theta_3 > 0$..

Econometric Methods

The present study employs econometric methods to verify whether GDP is responsible for causing carbon emissions in Nepal. This study utilizes ARDL models, an econometric model, to examine whether EKC is valid. But before employing ARDL models, the present study checks the stationarity to identify whether the concerned variables are integrated of order one, zero, or a mixture of both order one and zero through the unit root test.

Phillips-Perron (PP) Unit Root Test

The unit root test known as Phillips-Perron (PP) was first introduced by Phillips & Perron (1988). It is a non-parametric statistical test that can be used to check the stationarity of the data sets under study. With the help of this test, the data sets under study can be checked as stationary or non-stationary, and their order of integration as $I(1)$ or $I(0)$ can be identified.

The Dickey-Fuller test equation without augmentation is estimated by the PP test:

$$\Delta y_t = \beta y_{t-1} + x_t'\gamma + \varepsilon_t \quad \ldots (5)$$

Where, Δy_t is the first-order difference of the variable whose unit root is to be tested y_{t-1}, is the lagged regressor, x_t is an exogenous explanatory variable, typically consisting of a constant and/or a trend, γ is the coefficient of exogenous variables, and ε_t is the white noise error term.

The assumption of the null is: "variable has a unit root," i.e., β=1. The assumption of null is not rejected, and hence, the variable is non-stationary. But, if the value of β is less than 1, the variable will be stationary. More precisely, when the value of the test statistic in absolute form is larger than the critical value in absolute form, then the assumption of the null is not accepted, and hence, the variable becomes stationary. Otherwise, the null is accepted, and the variable becomes non-stationary, having a unit root.

Autoregressive Distributed Lags (ARDL) Models

There are different techniques for observing the long-run relationship between and among the variables. For this purpose, different types of cointegration tests like those suggested by Johansen (1988, 1991) and Johansen-Juselius (1990), the Engle-Granger test (1987), and the modified OLS technique by Phillips and Hansen (1990) are frequently employed. These methods suffer from minimal sample quality and have limited power because they need first-order integration of the variables. Consequently, because of their effectiveness-particularly when handling variables with varying integration orders, the Autoregressive Distributed Lag (ARDL) models have become more popular.

Pesaran et al. (1999) and Pesaran & Shin (1995) introduced the ARDL cointegration approach. This method facilitates the identification of long-term linkage among variables with different integration orders, such as *I*(0), *I*(1), or a combination thereof. According to Nkoro & Uko (2016), the ARDL technique determines cointegrating vectors that signify the enduring associations between underlying variables. Subsequently, the ARDL model can be transformed into ECM, illustrating how variables adjust to their long-term equilibrium in the short period. Kripfganz & Schneider (2018) stated that autoregressive distributed (ARDL) models have become more and more common as a means of analyzing their relationships over both the short and long term. The ARDL models, under a single equation framework, are influential techniques for comprehending how time series variables interact dynamically. It is reasonable for the current value of the explanatory variables to depend on their past values in addition to the previous values of the regressors. Stationary, non-stationary, or a mix of the two kinds of data will be included in the single equation framework. With the use of error-correcting procedures, we may use ARDL models to explore the impacts in the short-run and long-run. ARDL models can be used to examine cointegration, the term used to observe links between the variables in the long term.

Here, the ARDL econometric models, specifically the ARDL bound testing process, are predominantly employed to apply the EKC function. These models assess whether economic growth and additional factors (such as energy use, urbanization, and openness) cause environmental pollution in the Nepalese economy. Equation (6) outlines the ARDL model used in this work, based on the methodologies of Pesaran & Shin (1995), Pesaran & Shin (1997), Pesaran & Shin (1998), Pesaran et al. (1999), Pesaran & Shin (2001) and Pesaran et al. (2001).

We have is the dependent variable, and $LnY_t, LnY_t^2, LnEC_t, LnTV$ and LnU_t are the explanatory variables. The $ARDL(p, q, r, s, m, n)$ model can be expressed as:

$$LnCE_t = \beta_0 + \sum_{i=1}^{p} \alpha_i LnCE_{t-i} + \sum_{j=1}^{q} \gamma_j LnY_{t-j} + \sum_{k=1}^{r} \delta_k LnY_{t-k}^2 + \sum_{l=1}^{s} \rho_l LnEC_{(t-l)} + \sum_{m=1}^{u} \sigma_u LnTV_{t-u} + \sum_{n=1}^{v} \theta_n dLnU_{t-n} + \varepsilon_t \quad \text{....(6)}$$

where, $p, q, r \ldots n$ are the lags of regressand $LnCE_t$ and regressors $LnY_t, LnY_t^2, LnEC_t, LnTV$ and LnU_t respectively. The parameters $\alpha_i s, \gamma_j s, \delta_k s \ldots \theta_l s$ are the coefficients of regressors, and e_t is a disturbance.

Equation (6) in error correction term can be recast as:

$$dLnCE_t = \alpha Z_{t-1} + \beta dLnY_t + \sum_{j=1}^{q} \gamma_j dLnY_{t-j} + \pi dLnY_t^2 + \sum_{k=1}^{r} \delta_k dLnY_{t-k}^2 + \sigma dLnEC_t + \sum_{l=1}^{s} \rho_l dLnEC_{(t-l)} + \sigma dLnTV + \sum_{m=1}^{u} \sigma_u dLnTV_{t-u} + \varphi dLnU_t + \sum_{n=1}^{v} \theta_m dLnU_{t-m} + \varepsilon_t \quad \text{...(7)}$$

According to Shrestha & Bhatta (2018), the lagged variable coefficients of the ARDL model (equation 7) reflect short-run dynamics, but the unlagged variable coefficients of the same equation indicate the long-run link among the variables. The assumption that the null is: $\beta + \pi + \rho + \sigma + \varphi = 0$. It indicates that the variables do not cointegrate. According to Pesaran et al. (2001), the bound test is employed to observe the cointegrating link among the variables using (1) or *I*(0) variables.

RESULTS AND DISCUSSIONS

Covariance and Correlation Analysis

Table 2 presents the covariance and correlation matrix with corresponding t-statistic and probability values.

Descriptive Statistics

Table 3 presents descriptive statistics of the variables under study.

Phillips-Perron (PP) Unit Root Test

The PP unit root test results are portrayed in Table 4.

Based on Table 2, almost all variables except LnU_t are found to be insignificant at 0.05 level, and hence, these are non-stationary at level forms, and they are significant at first differences representing stationary

Table 2: Covariance and correlation matrix with t-statistic and probability values.

Covariance Correlation t-Statistic Probability	$LnCE_t$	LNY_t	$LnEC_t$	LnY_t^2	$LnTV$	LnU_t
$LnCE_t$	0.576230					
	1.000000					
	-					
	-					
LNY_t	0.521040	0.544616				
	0.930096	1.000000				
	16.01466	-				
	0.0000	-				
$LnEC_t$	0.543688	0.500451	0.536501			
	0.977836	0.925829	1.000000			
	29.53769	15.49300	-			
	0.0000	0.0000	-			
LnY_t^2	6.231673	6.529172	5.941515	78.40887		
	0.927094	0.999149	0.916071	1.000000		
	15.64308	153.1837	14.44769	-		
	0.0000	0.0000	0.0000	-		
$LnTV$	0.082279	0.041501	0.081595	0.462368	0.042952	
	0.522993	0.271346	0.537506	0.251949	1.000000	
	3.880743	1.783036	4.031367	1.646581	-	
	0.0004	0.0822	0.0002	0.1075	-	
LnU_t	0.268100	0.247970	0.270263	2.925738	0.045268	0.140151
	0.943409	0.897544	0.985605	0.882580	0.583450	1.000000
	17.99179	12.87425	36.87034	11.87234	4.543575	-
	0.0000	0.0000	0.0000	0.0000	0.0001	-

variables. The variables except for LnU_t are I(1), and LnU_t is stationary at the level and is $I(0)$. Now, the mixture of $I(1)$and $I(0)$ variables are suitable for carrying out the ARDL model as a representation of the linkage between the variables with the integration of different orders.

Table 3: Descriptive statistics of the variables.

	$LnCE_t$	LnY_t	$LnEC_t$	LnY_t^2	$LnTV_t$	LnU_t
Mean	4.775905	5.766938	6.260464	33.80219	3.744311	2.516472
Median	4.743986	5.443121	6.414101	29.62864	3.793570	2.615148
Maximum	6.234411	7.114277	7.469654	50.61293	4.159508	3.044999
Minimum	3.688879	4.826189	4.927254	23.29210	3.404525	1.806812
Std. Dev.	0.768300	0.746927	0.741341	8.962214	0.209761	0.378906
Skewness	0.298046	0.616132	-0.078791	0.698375	-0.079685	-0.364943
Kurtosis	2.172809	1.829480	1.983804	1.924163	2.028316	1.813816
Jarque-Bera	1.819249	5.055034	1.850600	5.439585	1.696744	3.394589
Probability	0.402675	0.079857	0.396412	0.065888	0.428111	0.183178
Sum	200.5880	242.2114	262.9395	1419.692	157.2611	105.6918
Sum Sq. Dev.	24.20168	22.87389	22.53305	3293.172	1.803992	5.886359
Observations	42	42	42	42	42	42

Table 4: Phillips-Perron unit root test.

Variables	t-statistics	Critical statistics at 5% Level	Probability Value
$LnCE_t$	0.1456	-2.9350	0.9655
$dLnCE_t$	-7.4824	-2.9369	0.0000
LnY_t	0.9131	-2.9350	0.9947
$dLnY_t$	-5.4730	-2.9369	0.0000
LnY_t^2	1.2492	-2.9350	0.9980
$dLnY_t^2$	-5.0585	-2.9369	0.0001
$LnEC_t$	-1.6223	-2.9350	0.4623
$dLnEC_t$	-8.4145	-2.9369	0.0000
$LnTV$	-1.8533	-2.9350	0.3504
$dLnTV$	-5.5347	-2.9369	0.0000
LnU_t	-4.1029	-2.9350	0.0026

Optimal Selection of Lags for ARDL Models

It is necessary to include optimal lag/s in both dependent and independent variables for the execution of suitable *ARDL* models. We select the appropriate lags that must be included in the variables under consideration using the Akaike information criterion (Pesaran & Shin 1999, Pesaran et al. 2001, Lutkepohl 2005, Narayan 2005). Fig.1 shows the optimal lags that must be included in the variables based on equations (6). The figure suggests *ARDL*(1,3,3,2,0,3) model as a suitable model for the autoregressive distributed lags as reported by the minimum value under the Akaike information criterion.

ARDL Results

The results of the ARDL (1,3,3,2,0,3) approach are presented in Table 5, showcasing the coefficients of LnY_t at a lag of two, which stands at 6.8731. This result holds significance at the 5 percent level, suggesting that as GDP per head was raised by 1 percent two years back, it caused the release of the carbons by 6.87 percent in the current period. The relationship between economic growth and carbon emissions in the present study supports Panayotou (1993), Selden & Song (1994), Grossman & Krueger (1995), Pesaran & Shin (1999), Lutkepohl (2005) and Narayan (2005). This signals that the growth of GDP is one of the drivers of carbons in Nepal. Conversely, the coefficient of at a lag of two is -0.5713, which is significant at 0.05 level. As reported by this negative coefficient, it can be concluded that the EKC turns down when it reaches the maximum point. The positive and negative coefficient of and respectively provide sufficient evidence supporting the prevalence of the EKC in Nepal. The findings of the reversal U-shaped EKC support Panayotou (1993), Grossman & Krueger (1994), Stern (2004) and Wang et al. (2016).

Examining the coefficient of $LnEC_t$ At a lag of zero, it stands at 0.7430 and is also significant at less than the 1%

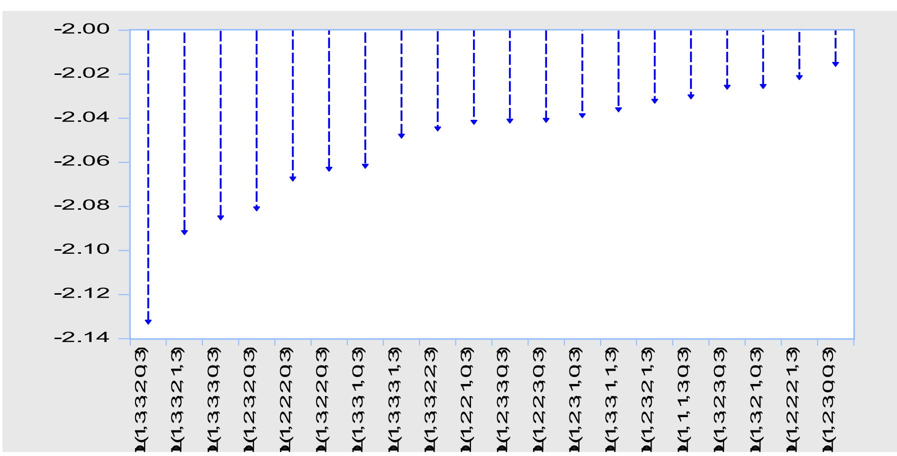

Fig. 1: Selection of optimal lag(s) by Akaike information criterion.

level. This implies a one percent rise in energy use leads to a 0.7430 percent rise in carbon emissions. Consequently, energy use is identified as another contributor to carbon emissions. The result from the present study regarding energy use and carbon emissions supports Nasir & Rehman (2011), Saboori et al. (2014), Pata (2017), Alam & Adil (2019), Gonzalez-Sanchez & Martin-Ortega (2020), Raihan et al. (2023) and Mitic et al. (2023). However, the coefficient of $LnTV_t$ is not significant, exhibiting that Nepalese openness does not influence environmental contamination. However, the coefficients of LnU_t At lags zero and two are positive and also significant at 0.05 level, suggesting that an expansion of urbanization results in an adverse effect on the environment in Nepal. The impact of urbanization on carbon emissions of the present study supports Wu et al. (2016), Musah et al. (2020), Adebayo et al. (2021) and Wang et al. (2021).

It is evident given the positive and negative coefficient of LnY_t and LnY_t^2 that the reversal u-shaped EKC is prevalence in Nepal. This suggests that increasing carbon emissions are primarily driven by GDP, while a subsequent rise in GDP becomes a secondary factor contributing to decreasing carbon emissions. Consequently, besides income growth, variables such as energy use and the rate of urbanization emerge as significant factors causing environmental pollution in the Nepalese economy.

Table 5: ARDL (1, 3, 3, 2, 0, 3) model with dependent variable $dLnCE_t$

Regressors	Parameters	SE	t-Statistic	Probability
$LnEC_t(-1)$	0.3925	0.1833	2.1412	0.0441
LnY_t	0.4837	2.0410	0.2370	0.8149
$LnY_t(-1)$	-7.4549	2.2512	-3.3114	0.0033
$LnY_t(-2)$	6.8731	2.2612	3.0395	0.0062
$LnY_t(-3)$	-2.5693	1.7043	-1.5075	0.1466
LnY_t^2	-0.0207	0.1701	-0.1218	0.9042
$LnY_t^2(-1)$	0.5937	0.1912	3.1048	0.0054
$LnY_t^2(-2)$	-0.5713	0.1904	-2.9999	0.0068
$LnY_t^2(-3)$	0.2344	0.1428	1.6412	0.1156
$LnEC_t$	0.7430	0.1814	4.0942	0.0005
$LnEC_t(-1)$	-0.2823	0.2477	-1.1394	0.2674
$LnEC_t(-2)$	-0.3556	0.2153	-1.6513	0.1135
$LnTV_t$	-0.1025	0.1882	-0.5450	0.5915
LnU_t	12.9240	5.2835	2.4460	0.0233
$LnU_t(-1)$	-21.6748	9.2087	-2.3537	0.0284
$LnU_t(-2)$	20.0657	8.1889	2.4503	0.0231
$LnU_t(-3)$	-10.1895	4.1309	-2.4666	0.0223
β_0	6.8043	6.7467	1.0085	0.3247

In 1990, Nepal transitioned to a multiparty democracy and adopted economic liberalization policies. This led to a surge in FDI and foreign aid, along with a dramatic increase in trade. The resulting economic growth and rapid industrialization ushered in a new era of urbanization, which in turn drove up carbon emissions. Hence, Nepal's carbon emissions increased substantially after the 1990s due to the rise of urbanization.

Once the ARDL model is applied, this study employs the bound tests and ECM to observe the long-run link among the variables. The findings from the ARDL bound test are outlined in Table 3, whereas Table 6 presents the results of ECM within the framework of ARDL (1, 3, 3, 2, 0, 3).

In Table 6, the ARDL bounds test adheres to an F-statistic which is 3.3960, and it exceeds the critical value of F-distribution 3.38 as proposed by Pesaran & Timmermann (2005) at a 0.05 significant level for both I(0) and $I(1)$. Consequently, the assumption of null "no cointegration," is rejected, representing a cointegration among the variables. As indicated by the bound test results, there exists a long-run link among the variables. In simpler terms, the variables, namely, $dLnCE_t, dLnY_t, dLnY_t^2, dLnEC_t$ $LnTV_t$ and LnU_t exhibit a linkage among them eventually. This result for the Nepalese economy supports the study by Raihan & Tuspekova (2022).

The ECM is the component of ARD, which is employed to observe the dynamics of the variables (Pesaran & Shin 1999, Pesaran et al. 2001, Narayan 2005, Narayan & Smyth 2005). Through this model, this study has explored the linkage among a set of variables $dLnCE_t, dLnY_t, dLnY_t^2, dLnEC_t$ $LnTV_t$ and LnU_t. This test also focuses on how the variables impact the dynamics of the EKC hypothesis. The test results are portrayed in Table 7. The significance of the coefficients for $dLnY_t$ and $dLnY_t^2$ at lag of two for each is confirmed at the 0.05 level, with opposing signs: positive and negative, respectively. This observed pattern strongly suggests the presence of a reversal EKC in the Nepalese economy. Specifically, it implies that when the economy initially grows, environmental degradation increases. However, above a certain point, a further rise in income results in a decreased environmental impact on the economy of Nepal.

Table 6: Results from ARDL (1, 3, 3, 2, 0, 3) bound to test for cointegration.

	Value	Level of Significance		
F-statistic	3.3960	10%	2.08	3.00
k	5	5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.15

Moreover, the coefficients of $dLnEC_t$ At lags zero and one are both positive, and these are also observed to be statistically significant, underscoring the role of energy consumption as a driving factor behind carbon emissions in Nepal. In the same manner, the coefficients of LnU_t Lag zero and lag two also exhibit statistical significance at least at 0.05 level, indicating that urbanization is a key contributor to carbon emissions. The variables $dLnY_t, dLnY_t^2, dLnEC_t$ and LnU_t Demonstrate short-run negative impacts on the environment, suggesting their potential to influence environmental policy and sustainability efforts in Nepal.

It is implied that short-run disturbances have a considerable impact on the long-term equilibrium link among the variables by the *ECT* coefficient of Z_t At lag one, which is negative and highly significant. To put it simply, these short-term shocks have a substantial effect on the long-term dynamics of the variables that are being studied. The error correction term coefficient is -0.6074, signifying that approximately 60.74% of the adjustment toward equilibrium occurs within a single period. The error correction modeling results of the present study are comparable to findings by Engle & Granger (1987), Pesaran & Shin (1997), Shahbaz et al. (2013), Adebayo (2020) and Adebayo (2021). In the study of Adebayo (2020) and Adebayo (2021), the ECMs' coefficients are negative and statistically significant, illustrating that prior periods' errors can be corrected by subsequent periods.

This finding indicates that the system experiences rapid correction when deviations from the long-run growth path arise from short-term perturbations. In other words, short-run fluctuations cause the dependent variable to deviate from its long-run trajectory, and approximately 60 percent of this deviation is adjusted in the succeeding period.

Table 7: Error correction modeling under ARDL (1, 3, 3, 2, 0, 3).

Regressors	Parameters	SE	t-Statistic	Probability
$dLnY_t$	0.483798	1.222331	0.395800	0.6962
$dLnY_t(-1)$	-4.303802	1.231139	-3.495788	0.0022
$dLnY_t(-2)$	2.569356	1.089471	2.358351	0.0281
$dLnY_t^2$	-0.020734	0.101044	-0.205203	0.8394
$dLnY_t^2(-1)$	0.336823	0.102104	3.298825	0.0034
$dLnY_t^2(-2)$	-0.234496	0.090047	-2.604147	0.0166
$dLnEC_t$	0.743091	0.124315	5.977467	0.0000
$dLnEC_t(-1)$	0.355689	0.129867	2.738864	0.0123
$dLnU_t$	12.92401	3.184740	4.058105	0.0006
$dLnU_t(-1)$	-9.876227	4.488939	-2.200125	0.0391
$dLnU_t(-2)$	10.18952	3.174901	3.209398	0.0042
$Z_t(-1)$	-0.607487	0.109883	-5.528484	0.0000

In conclusion, the error correction modeling results presented in Table 7 give a significant revelation into the dynamics of environmental factors in the Nepalese economy. These findings have implications for understanding the association among income, energy use, urbanization, and pollution. The identification of an EKC pattern highlights the potential for policy interventions to promote sustainability and mitigate environmental impact.

Diagnostics and Stability Tests

The fitted ARDL models require an assessment of residual stability and diagnostic properties through serial correlation and heteroskedasticity tests. The serial correlation is examined using the Breusch-Godfrey (BG) approach (Evans & Patterson 1985), while heteroskedasticity is tested using the Breusch-Pagan-Godfrey (BPG) approach (Dufour et al. 2004). Additionally, Ramsay's RESET test (Ramsey 1969) is employed to gauge the stability of the estimated models. The results of the tests are portrayed in Table 8.

The serial correlation LM test under the BG method consists of the F-statistic $(T \times R^2)$ value, and the χ^2 value, all of which are insignificant. The assumption of null, "no serial correlation," is accepted, indicating that the residuals in the ARDL models do not exhibit serial correlation. Similarly, the F-statistic, $(T \times R^2)$ value, and the χ^2 value under the BPG method is also insignificant. The assumption of the null "no heteroskedasticity" is not rejected, affirming that the residuals do not exhibit heteroskedasticity. Ramsey's RESET test yields a non-significant F-statistic as well. Consequently, the fitted ARDL model is deemed robust and demonstrates linearity, as suggested by Ramsey's RESET test.

CONCLUSIONS

As per the findings derived from ARDL models in this study, the main driving factors for air pollution in Nepal are identified as increased urbanization, escalating energy use, and growth of income. The models suggest the presence of a reversal U Environmental Kuznets Curve in Nepal during the study period. The environmental deteriorations in Nepal

Table 8: Results of serial correlation, heteroskedasticity, and Ramsey's RESET test for ARDL models.

Description	B-G Serial Correlation	B-P-G Heteroskedasticity	Ramsey's RESET
F-statistic	0.1703	0.8582	0.3309
DF	(2,19)	(17, 21)	(1, 20)
Probability	0.8447	0.6216	0.5715
$T \times R^2$	0.6868	15.9876	
χ^2(Probability)	0.7093	0.5247	

are found to have been caused by the country's desire for rapid economic growth. The ARDL models reveal that environmental pollutions are found to be increasing with the rise in GDP in the initial phase when the level of GDP growth is low. The economy is concentrated on achieving high and higher economic growth, giving less attention to environmental protection. But when certain maximum growth is achieved after a rise in economic growth causes carbon emissions to decrease. It is because the country has pressure from everywhere to minimize carbon emissions and protect the environment.

Consequently, the government opts the measures to minimize carbon emissions. So, along with an increase in economic growth, carbon emissions start decreasing through government commitments at the international level as well as the awareness of the government itself for cleaning the environment. Thus, carbon emissions decrease with the rise of GDP growth in the later stage. Nepal is more serious about environmental issues in the later years. Various efforts have been made on the part of the government to reduce carbon emissions. The common people are more environmentally conscious, and they are also contributing to reducing carbon emissions through afforestation and garbage management.

Nepal, an underdeveloped country, seeks to accelerate economic growth to graduate from its current status and join the League of Developing Nations. However, this economic growth must be harmonized with the need to reduce carbon emissions and protect the environment. In this context, Nepal should shift its focus towards prioritizing a green GDP over GDP, placing environmental sustainability at the forefront of its development agenda. To ensure a holistic and inclusive approach, it is paramount to discourage rural-to-urban migration, concentrating efforts on rural infrastructure development and employment generation. This transition necessitates a concerted effort on multiple fronts, where three layers of government take a leading role. Nepal should increase hydropower exports to reduce the trade deficit through the completion of ongoing hydro-projects very soon. Nepal should pivot towards electric vehicles, incentivizing the shift with reduced customs duties and subsidies while phasing out older gasoline vehicles. To encourage electric vehicles, the government should facilitate the establishment of charging stations sufficiently.

Additionally, Nepal should strengthen its public and private forest programs and enact strict regulations regarding well management of waste. The government should introduce waste management policies that create employment opportunities. Lastly, the creation of green cities and the promotion of organic farming will be pivotal in driving sustainable development while ensuring a brighter and greener future for Nepal. To achieve harmonious economic growth and emissions reduction, we also urge donor countries and agencies to partner with Nepal in its ambitious endeavors. This partnership can take shape through multifaceted support as fueling socio-economic progress that aligns with Nepal's commitment to reduce carbon emissions, ensuring that development and sustainability walk hand-in-hand.

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