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Testing the validity of EKC hypothesis using CO_2 emissions and ecological footprint in Nigeria: The role of financial development

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ABSTRACT

This study examines the Environmental Kuznets Curve (EKC) Hypothesis in Nigeria by analysing carbon dioxide emissions and ecological footprint from 1991 to 2022. Using the autoregressive distributed lag (ARDL) bounds test for cointegration and the Toda-Yamamoto causality approach, findings reveal a positive correlation between economic growth and both CO_2 emissions and ecological footprint, indicating that environmental impacts rise with economic growth. An inverted U-shaped relationship is observed between economic growth and CO_2 emissions, suggesting a threshold beyond which further growth could reduce emissions. Financial development, trade openness, and urbanization significantly influence CO_2 emissions and ecological footprint, underscoring the need for sustainable policies. Key recommendations include promoting sustainable urbanization, encouraging green investments through financial regulations, monitoring trade activities, and incentivizing renewable energy adoption. Utilizing green financial products like Sukuk for funding priority infrastructure projects could enhance renewable energy use, environmental sustainability, and financial sector growth in Nigeria. These findings emphasize the urgency for policy interventions to align economic growth with environmental sustainability, ensuring a balanced approach to development while mitigating adverse ecological impacts.

Contribution/ Originality: This study contributes to the existing literature as the first to examine the Environmental Kuznets Curve (EKC) Hypothesis in Nigeria by analysing carbon dioxide emissions and ecological footprint as indicators of environmental degradation.

1. INTRODUCTION

Most developed and developing, are prioritizing sustainable growth that is influenced by various factors, especially carbon dioxide (CO_2) emissions that arise from increased usage of fossil fuels, industrial activity, and deforestation. In particular, increase in industrial activities and energy (fossil fuels) consumption by certain tools and equipment require significant amount of energy to operate and maintain., hence the resultant increase in (CO_2) emissions that contribute to the rise of greenhouse gases in the atmosphere, global warming and climate change that are increasingly impacting the lives of humans, animals, and plants (Lin et al., 2018; Liu, Kim, Liang, & Kwon, 2018). The growth trajectory of the global carbon dioxide emissions showed that it rose by 1.4% in 2012 due to the world's economic growth, reaching a total of 34.5 billion metric tons (Bano, Zhao, Ahmad, Wang, & Liu, 2018; Behket, Abughazalah, & Hassan, 2017). As of 2021, global carbon dioxide emissions have reached a record high of

147.2 billion metric tons ($GtCO_2$) (Bhat, Sofi, & Sajith, 2023; Fatima, Hussain, & Usman, 2021; Rafique, Fatima, & Shahzad, 2021; Shahzad, Alam, & Khan, 2021).

Nigeria, like the rest of the world, is facing the harmful effects of high carbon emissions (Ameyaw & Yao, 2018). In 2022, carbon emissions from the power sector in Nigeria totaled approximately 11.8 million metric tons of carbon dioxide equivalents, showing a slight decrease compared to the previous year. The highest level of emissions from electricity generation in the country was recorded in 2014, reaching nearly 12.8 million metric tons of CO_2 equivalents. Fossil CO_2 emissions in Nigeria amounted to 122,750,410 tons in 2022, marking a decrease of -0.35% from the previous year, which translates to a reduction of -432,900 tons compared to 2021 when emissions were 123,183,310 tons. The per capita CO_2 emissions in Nigeria stood at 0.56 tons per person based on a population of 223,150,896 in 2022, a decrease of -0.01 from the 2021 figure of 0.56 CO_2 tons per person, representing a -2.4% change in CO_2 emissions per capita (Nadabo, Salisu, Maigari, & Suleiman, 2023).

From the forgoing scenario, Nigeria may not be able to completely eliminate the use of fossil fuels, but it must reduce its reliance on them to address the environmental pollution they cause. The burning of fossil fuels releases carbon dioxide, a major contributor to global warming. This has led to the melting of polar ice caps, flooding in low-lying areas, and rising sea levels. If these trends continue, there could be severe impacts on food access and mortality rates (Ogundipe, Obi, & Ogundipe, 2020). Greenhouse gas emissions from fossil fuels have also been linked to more frequent and severe climate events in oil-producing countries worldwide. Therefore, the increasing consumption of fossil fuels poses a significant risk in the future (Kabuga, 2018).

However, the ecological footprint (EFP) has recently emerged as an alternative measure. EFP assesses the ecological resources required by a population to produce the natural resources it consumes and to absorb its waste, especially carbon emissions (Global Environment Outlook 4, 2007). Developed by Wackernagel and Rees (1998) EFP is considered a more comprehensive indicator of environmental degradation as it encompasses six components: cropland, grazing land, fishing grounds, forest land, built-up land, and carbon footprint (Jalil & Feridun, 2011). Nigeria has faced an ecological deficit since the 1970s, reflecting unsustainable resource consumption (Udemba, 2020). This underscores the importance of identifying the factors driving EFP and CO2 emissions to formulate effective policies that balance environmental sustainability with economic growth (Alimi & Alege, 2016).

Several studies have explored the nexus between economic growth, financial development, and environmental sustainability. Some research suggests that higher economic growth is linked to increased environmental pollution due to heightened consumption and production activities, leading to more pollution and strain on ecological resources (Abid, Hassan, Ur Rehman, & Bashir, 2021; Behket et al., 2017; Ozturk & Acaravci, 2013; Shahbaz, Balsalobre-Lorente, & Sinha, 2019; Tamazian & Rao, 2010). However, other studies indicate that economic growth can actually contribute to maintaining and enhancing environmental quality (Alege, Olatubi, & Olanrewaju, 2016; Bekar, 2018; Omri, Daly, Rault, & Chaibi, 2015; Ozturk & Acaravci, 2013; Rjoub, Odugbesan, Adebayo, & Wong, 2021; Zakari, Abubakar, & Abdullahi, 2022). These findings align with the World Bank emphasis on achieving a "win-win" situation where economic growth is linked to a clean environment. In the same vein, study such as Panayotou (1997) argued that the level of economic growth itself may not be the primary factor in environmental degradation, but instead what matters are policies and institutions.

The impact of economic growth on carbon dioxide emissions remains inconclusive in the literature, but the introduction of additional variables has added complexity to the relationship (Shahbaz, Khan, & Tahir, 2013). For instance, financial development has become a common variable in studies on environmental issues and economic growth; with some researchers suggesting that it reduces CO_2 emissions and improves environmental sustainability (Jalil & Feridun, 2011; Lee, 2013; Li, Zhang, & Ma, 2015; Shahbaz, Hye, Tiwari, & Leitão, 2013; Tamazian, Chousa, & Vadlamannati, 2008). Conversely, others argue that financial development increases CO_2 emissions and reduces environmental quality (Maji, Habibullah, & Saari, 2017; Nadabo & Salisu, 2023) while some studies show mixed results (Chang, 2015; Onanuga, 2017). In Turkey, Ozturk and Acaravci (2012) found an insignificant relationship between financial development and CO_2 emissions.

Further, there are few studies that used time series and ARDL bounds test for cointegration approach to investigate the relationships between CO_2 emissions, economic growth, and financial development and other regressors (Nadabo & Salisu, 2023; Wudil & Tsauni, 2019; Zakari et al., 2022) but such studies have some methodology issues that are likely to affect the authenticity and/or validly of their results. This study, therefore, attempted to fill in the gaps of previous studies by examines the validity of the Environmental Kuznets Curve (EKC) hypothesis in Nigeria by analysing CO_2 emissions and ecological footprint (EFP) as indicators of environmental degradation. It used the ARDL model and Toda and Yamamoto (1995) (T-Y) non-causality approach.

The reminder of this paper is organized as follows. Section 2 presents the literature review, Section 3 highlights the data and methodology, Section 4 presents and discusses finding of the study while Section concludes the study.

2. LITERATURE REVIEW

2.1. Theoretical Literature

The environmental Kuznets curve (EKC) developed by Kuznets (1955) investigates the relationship between carbon dioxide emissions and economic growth. It suggests a U-shaped relationship, where environmental degradation initially increases during early economic growth, but declines as countries develop further. While some studies support this theory, others have found a more adverse relationship. This study aims to provide a better understanding of the interplay between economic growth, environmental sustainability, and other macroeconomic factors in Nigeria from 1991-2022.

2.2. Empirical Literature Review

The EKC hypothesis has been extensively studied in various countries using different econometric methods and time periods. Tables 1, 2, and 3 summarize the literature on the EKC hypothesis with mixed results. Some studies use CO_2 emissions to measure environmental degradation (Abul & Satrovic, 2022; Arango Miranda, Hausler, Romero Lopez, Glaus, & Pasillas-Diaz, 2020; Gao, Xu, & Zhang, 2021; Isik, Ongan, & Ozdemir, 2019) while others use ecological footprint (EFP) as a proxy for environmental pollution (Caglar, Mert, & Boluk, 2021; Destek & Sarkodie, 2019; Dogan, Ulucak, Kocak, & Isik, 2020). Some studies consider both CO_2 emissions and EFP as indicators of environmental degradation (Altıntaş & Kassouri, 2020; Ansari, 2022; Bello, Solarin, & Yen, 2018; Mrabet & Alsamara, 2017). Table 1 presents studies challenging and supporting the EKC hypothesis, while Table 3 shows mixed results. Kivyiro and Arminen (2014) found an inverted U-shaped relationship between economic growth and CO2 emissions in Sub-Saharan African countries. Kostakis, Lolos, and Sardianou (2017) identified a similar link in Singapore. Liu et al. (2018) revealed an inverted U-shaped relationship in Korea and Japan. Destek and Sarkodie (2019) confirmed the EKC hypothesis in panel estimation but observed a U-shaped relationship in five countries. Churchill, Inekwe, Ivanovski, and Smyth (2020) found evidence of the EKC hypothesis in some Organisation for Economic Co-operation and Development. (OECD) countries. Churchill, Inekwe, Ivanovski, and Smyth (2018) supported the EKC hypothesis in several US states. Arango Miranda et al. (2020) confirmed the EKC hypothesis for Mexico and the U.S.A.

Different environmental indicators yield varying results in studies on the Environmental Kuznets Curve (EKC) hypothesis. Mrabet and Alsamara (2017) identified an inverted U-shaped relationship between income and ecological footprint (EF) in Qatar. Similarly, Solarin, Al-Mulali, Musah, and Ozturk (2017) analyzed environmental degradation in Malaysia using multiple indicators and found an inverted U-shaped relationship with income for most of them. Altıntaş and Kassouri (2020) reported a similar relationship between income and EF in European countries, while Ansari (2022) provided evidence supporting the EKC hypothesis in Association of Southeast Asian Nations (ASEAN) countries using EF. Aşıcı and Acar (2016) found an inverted U-shaped relationship between income and ecological footprint of production (EFP) in a panel of countries. However, Wang, Kang, Wu, and Xiao (2013) did not observe an inverted U-shaped relationship for ecological footprint of consumption (EFC) or EFP in 150 countries.

Studies also examined the EKC hypothesis based on income levels. Al-Mulali, Choong, Low, and Mohammed (2015) found it valid for upper-middle and high-income countries but not for lower-middle and low-income groups from 1980 to 2008. Ozturk, Al-Mulali, and Saboori (2016) confirmed this pattern for middle- and high-income countries. Destek, Ulucak, and Dogan (2018) categorized 45 countries by income levels and validated the EKC hypothesis for all groups between 1961 and 2013.

Table 1. Summary of some empirical studies concluding that the EKC hypothesis is not valid.

Author(s)	Period	Country	Environmental variable(s)	Methodology
Bagliani, Bravo, and Dalmazzone (2008)	2001-2001	141 countries	EFP	OLS, weighted LS
Wang et al. (2013)	2005-2005	150 countries	EFP	Spatial econometric method
Chandran and Tang (2013)	1971–2008	ASEAN-5 countries	CO_2	Johansen cointegration,
Hervieux and Darné (2015)	1961–2007	7 Latin American countries	EFP	OLS
Mert and Bölük (2016)	2002–2010	21 Kyoto Annex countries	CO_2	PMG, panel causality
Bakirtas and Cetin (2017)	1982–2011	MIKTA countries	CO_2	PVAR, GC, system GMM
Hassan, Baloch, Mahmood, and Zhang (2019)	1971–2014	Pakistan	EFP	ARDL with structural breaks
Caglar et al. (2021)	The beginning changes–2014	Top 10 pollutant countries	EFP	Panel ARDL
Halliru, Loganathan, Hassan, Mardani, and Kamyab (2020)	1970-2017	ECOWAS	CO_2	PQARDL

Table 2. Summary of some empirical studies concluding that the EKC hypothesis is valid.

Author(s)	Period	Country	Environmental variable(s)	Methodology
Tang and Tan (2015)	1976–2009	Vietnam	CO_2	VECM
Sharif, Baris-Tuzemen, Uzuner, Ozturk, and Sinha (2020)	1965Q1–2017Q4	Turkey	CO_2	QARDL
Solarin et al. (2017)	1980–2012	Ghana	CO_2	ARDL
Destek et al. (2018)	1980–2013	15 EU countries	EFP	Panel mean group
Shujah-ur-Rahman, Chen, Saud, Saleem, and Bari (2019)	1991–2014	16 CEE countries	EFP	DSUR
M. A. Destek et al. (2018)	1961–2013	45 countries	EFP	CUP-FM, BC
Shahbaz et al. (2019)	1990–2015	MENA countries	CO_2	GMM
Ahmed and Wang (2019)	1971–2014	India	EFP	ARDL
(2020)	2000–2019	U.S.A.	CO_2	QARDL
Saqib and Benhmad (2021)	1995–2015	22 European countries	EFP	Panel data
Balsalobre-Lorente, Leitão, and Bekun (2021)	1995–2015	Portugal, Italy, Greece, and Spain	CO_2	Panel data
Gao et al. (2021)	1995–2010	18 Mediterranean countries	CO_2	Panel data
Abul and Satrovic (2022)	1995–2014	10 Southeastern European countries	CO_2	Panel data

Table 3. Summary of some empirical studies having mixed results.

Author(s)	Period	Country	Environmental variable(s)	Methodology
Kivyiro and Arminen (2014)	1971–2009	6 Sub-Saharan African countries	CO_2	ARDL
Al-Mulali et al. (2015)	1980–2015	93 countries	EFP	Panel FE, GMM
Ozturk et al. (2016)	1988–2008	144 countries	EFP	GMM
Aşıcı and Acar (2016)	2004–2008	116 countries	EFP	Panel FE
Kostakis et al. (2017)	1970–2010	Brazil, Singapore	CO2	ARDL, FMOLS, OLS
Mrabet and Alsamara (2017)	1980–2011	Qatar	CO2, EFP	GH, H-J tests, ARDL
Liu et al. (2018)	1990–2013	Japan, Korea, & China	EFP	VECM
S.A. Churchill et al. (2018)	1870–2014	20 OECD countries	CO_2	Panel data
Bello et al. (2018)	1971–2016	Malaysia	EFP, CO_2	ARDL, GC
Isik et al. (2019)	2000–2019	10 US states	CO_2	Panel data
Destek and Sarkodie (2019)	1977–2013	11 countries	EFP	AMG, panel causality
Altıntaş and Kassouri (2020)	1990–2014	14 EU countries	CO_2, EFP	IFE, D-CCE, panel causality
Arango Miranda et al. (2020)	1990–2016	Canada, Mexico, and U.S.A.	CO_2	Panel data
Ansari (2022)	1991–2016	ASEAN countries	CO2, EFP	FMOLS, PMG

Note: OLS – Ordinary least squares, PMG – Pooled mean group, PVAR – Panel vector autoregressive model, GC – Granger causality, GMM – Generalized method of moments, PQARDL – Panel quantile autoregressive distributed lag, VECM – Vector error correction model, DSUR – Double-stage least squares (DSLS) with SUR, CUP-FM – Cross-sectional unit panel with fixed effects model, BC – Baysian cointegration, FE – Fixed effects, GH – Greene-Hensher model, H-J – Hausman-Taylor model, IFE – Integrated fixed effects and D-CCE – Dynamic common correlated effects.

Based on the empirical studies presented in Tables 1, 2, and 3, there are opportunities for further study and contributions in testing the Environmental Kuznets Curve (EKC) hypothesis using CO_2 emissions and Ecological Footprint (EF) in Nigeria, with a specific focus on the impact of financial development. Investigating how financial development influences the relationship between economic growth, CO_2 emissions, and EF could offer valuable insights. By exploring the effects of financial development on the EKC hypothesis in the Nigerian context, this study shed light on the mechanisms through which financial development impacts environmental degradation. Addressing these gaps and making these contributions could enhance our understanding of the interplay between economic growth, environmental degradation, and financial development in Nigeria, thereby enriching the discourse on the validity of the EKC hypothesis. This study aims to fill this research void by utilising the ARDL and Toda and Yamamoto (1995) non-causality approach to analyse the validity of EKC in Nigeria using CO_2 emissions and ecological footprint.

3. METHODOLOGY

3.1. Theoretical framework and Model Specification

Pursuant to the objectives of this study, we adopt and expanded the environmental Kuznets curve (EKC) hypothesis as theoretical model. It dwells on the trade-off between carbon dioxide emissions (CO_2), ecological footprint and economic growth (GDP), and the functional form of the model is as follows;

$$E = (Y, Y^2) \qquad (1)$$

Where E is an environmental indicator, F stands for function, Y is income, Y^2 is the square of income (economic growth).

In this regard, Equation 1 is modeled to incorporate other explanatory variables that would influence environmental quality such as domestic credit to the private sector, urbanisation, and renewable energy consumption.

$$CO_{2t} = (GDP_{t,} GDP^2{}_{t,} DCPS, URB_{t,} TOP_t) \quad (2)$$
$$EFP_{2t} = F(GDP_{t,} GDP^2{}_{t,} DCPS_{t,} URB_{t,} TOP_t) \quad (3)$$

In Equation 2 and 3 economic growth proxy by Gross Domestic Product Per Capita (GDPPC), financial development measured by domestic credit to the private sector ($DCPS$) proxy financial development, urbanization proxy by urban population, and trade openness (TOP) are included in the model to capture their impact on CO_2 emissions and ecological footprint (EFP). Additionally, a squared term for GDP_t^2 is included to investigate whether there is a nonlinear relationship between economic growth and CO_2 emissions, as well as economic growth and ecological footprint (EFP) potentially following an inverted U-shaped pattern.

The functional relationship among carbon dioxide emissions, ecological footprint and its determinants in Equation 2 and 3 can be represented in the mathematical model in Equation 4 and 5.

$$CO_{2t} = a_0 + a_1 GDPPC_t + a_2 GDPPC_t{}^2 + a_3 DCPS_t + a_4 URB_t + a_5 TOP_t \quad (4)$$
$$EFP_{2t} = a_0 + a_1 GDPPC_t + a_2 GDPPC_t{}^2 + a_3 DCPS_t + a_4 URB_t + a_5 TOP_t \quad (5)$$

Based on Equation 4 and 5, the baseline stochastic model of this study is specified as follows:

$$CO_{2t} = a_0 + a_1 LNGDPPC_t + a_2 LNGDPPC_t{}^2 + a_3 DCPS_t + a_4 URB_t + a_5 TOP_t + \varepsilon_t \quad (6)$$
$$EFP_{2t} = a_0 + a_1 LNGDPPC_t + a_2 LNGDPPC_t{}^2 + a_3 DCPS_t + a_4 URB_t + a_5 TOP_t + \varepsilon_t \quad (7)$$

Where: CO_2 represents carbon dioxide emissions, EFP represent ecological footprints, GDP represents economic growth, $DCPS$ refers to domestic credit to the private sector, URB refers urbanisation, and TOP represent trade openness. Also, LN, stands for natural logarithm, $a_{0,}$ is the constant term while a_1 to a_5 are the parameters of the model to be estimated, ε_t is the disturbance term (That is assumed to be white noise).

Therefore, following Pesaran, Shin, and Smith (2001) Equation 6 and 7 was subsequently transformed into an ARDL model, along with its restricted error correction (ECT) version as represented in Equations 8, 9, 10 and 11, respectively.

$$\Delta(CO_2)_t = a_0 + a_1(\mathrm{CO_2})_{t-1} + a_2\mathrm{LN(GDPPC)}_{t-1} + a_3\mathrm{LN(GDPPC^2)}_{t-1} + a_4(DCPS)_{t-1} + a_5(\mathrm{URB})_{t-1} + a_6\mathrm{LN(TOP)}_{t-1} + \sum_{i=1}^{p}\beta_1\,\Delta(CO^2)_{t-i} + \sum_{i=0}^{q}\beta_2\,\Delta\,\mathrm{LN}(GDPPC)_{t-i} + \sum_{i=0}^{r}\beta_3\,\Delta\,\mathrm{LN}(GDPPC^2)_{t-i} + \sum_{i=0}^{s}\beta_4\,\Delta(DCPS)_{t-i} + \sum_{i=0}^{t}\beta_5\,\Delta(URB)_{t-i} + \sum_{i=0}^{u}\beta_6\,\Delta\,LN(TOP)_{t-i} + \mu_t \quad (8)$$

Where: $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, and\ \beta_6$ are short run parameters estimated, Δ denotes first difference, ln means logarithm and p, *q*, *r*, *s t*, *u* are the optimal lag length for the short run ARDL model.

In order to obtain the short-run coefficients, we specified and estimated the following ARDL-ECM:

$$\Delta(CO_2)_t = \sum_{i=1}^{p}\beta_1\,\Delta(CO^2)_{t-i} + \sum_{i=0}^{q}\beta_2\,\Delta\,\mathrm{LN}(GDPPC)_{t-i} + \sum_{i=0}^{r}\beta_3\,\Delta\,\mathrm{LN}(GDPPC^2)_{t-i} + \sum_{i=0}^{s}\beta_4\,\Delta(DCPS)_{t-i} + \sum_{i=0}^{t}\beta_5\,\Delta(URB)_{t-i} + \sum_{i=0}^{u}\beta_6\,\Delta\,LN(TOP)_{t-i} + \beta_8\,ECT_{t-1} + \mu_t \quad (9)$$

Where: β_8 is the coefficient of correction term ECT_{t-1} in the ECM-ARDL model specified in Equation 8. It is important to note that ECT_{t-1} represents the long run dynamics of all the variables attached the coefficients $a_1 - a_7$ in Equation 9.

$$\Delta(EFP)_t = a_0 + a_1(\mathrm{EPF})_{t-1} + a_2\mathrm{LN(GDPPC)}_{t-1} + a_3\mathrm{LN(GDPPC^2)}_{t-1} + a_4(DCPS)_{t-1} + a_5(\mathrm{URB})_{t-1} + a_6\mathrm{LN(TOP)}_{t-1} + \sum_{i=1}^{p}\beta_1\,\Delta(CO^2)_{t-i} + \sum_{i=0}^{q}\beta_2\,\Delta\,\mathrm{LN}(GDPPC)_{t-i} + \sum_{i=0}^{r}\beta_3\,\Delta\,\mathrm{LN}(GDPPC^2)_{t-i} + \sum_{i=0}^{s}\beta_4\,\Delta(DCPS)_{t-i} + \sum_{i=0}^{t}\beta_5\,\Delta(URB)_{t-i} + \sum_{i=0}^{u}\beta_6\,\Delta\,LN(TOP)_{t-i} + \mu_t \quad (10)$$

Where: $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, and\ \beta_6$ are short run parameters estimated, Δ denotes first difference, ln means logarithm and p, *q*, *r*, *s t*, *u* are the optimal lag length for the short run ARDL model.

In order to obtain the short-run coefficients, we specified and estimated the following ARDL-ECM:

$$\Delta(EFP)_t = +\sum_{i=1}^{p}\beta_1\,\Delta(CO^2)_{t-i} + \sum_{i=0}^{q}\beta_2\,\Delta\,\mathrm{LN}(GDPPC)_{t-i} + \sum_{i=0}^{r}\beta_3\,\Delta\,\mathrm{LN}(GDPPC^2)_{t-i} + \sum_{i=0}^{s}\beta_4\,\Delta(DCPS)_{t-i} + \sum_{i=0}^{t}\beta_5\,\Delta(URB)_{t-i} + \sum_{i=0}^{u}\beta_6\,\Delta\,LN(TOP)_{t-i} + \beta_7\,ECT_{t-1} + \mu_t \quad (11)$$

Where: β_8 is the coefficient of correction term ECT_{t-1} in the ECM-ARDL model specified in Equation 10. It is important to note that ECT_{t-1} represents the long run dynamics of all the variables attached the coefficients $a_1 - a_7$ in Equation 11.

The decision to employ the ARDL bounds test for cointegration is because it offers a unique approach to examine the short and long-run relationships between variables unlike the other methods such as Engle and Granger (1987) and Johansen (1991). In addition these conventional methods, the ARDL approach does not impose any restrictions on the order of integration of the variables, allowing it to be used with variables that are I(0), I(1), or mutually cointegrated. Additionally, the ARDL model can be effectively utilised with small sample sizes, as low as thirty observations, and it can simultaneously generate both long-run and short-run coefficients (Pesaran, Pick, & Timmermann, 2011).

3.2. Toda and Yamamoto (1995) Approach to Causality

The Toda-Yamamoto (T-Y) causality approach was used to study the causal relationship between ecological footprint, economic growth, and domestic credit to private sector proxy financial development, urbanization, and trade openness. This is because the approach offers a robust alternative to traditional causality tests and involves estimating a VAR model in levels and testing general restrictions on the parameter matrices, regardless of the integration order of the variables. The optimal VAR order is determined using Akaike Information Criterion (AIC) and a VAR (k+dmax) model is recommended for testing causality among the variables.

$$\Delta EFP_t = \omega_y + \sum_{i=1}^{k+m} \in_y \Delta EFP_{t-1} + \sum_{i=1}^{k+m} \tau_y \Delta lnGDPPC_{t-1} + \mu_{ty} \quad (12)$$

$$\Delta lnGDPPC_t = \omega_X + \sum_{i=1}^{k+m} \in_x \Delta lnGDPPC_{t-1} + \sum_{i=1}^{k+m} \tau_x \Delta EFP_{t-1} + \mu_{tx} \quad (13)$$

$$\Delta DCPS_t = \omega_X + \sum_{i=1}^{k+m} \in_x \Delta DCPS_{t-1} + \sum_{i=1}^{k+m} \tau_x \Delta EFP_{t-1} + \mu_{tx} \quad (14)$$

$$\Delta URB_t = \omega_y + \sum_{i=1}^{k+m} \in_y \Delta URN_{t-1} + \sum_{i=1}^{k+m} \tau_y \Delta EFP_{t-1} + \mu_{ty} \quad (15)$$

$$\Delta lnTOP_t = \omega_y + \sum_{i=1}^{k+m} \in_y \Delta lnTOP_{t-1} + \sum_{i=1}^{k+m} \tau_y \Delta EFP_{t-1} + \mu_{ty} \quad (16)$$

The Toda-Yamamoto causality approach specified in Equations 12-16 utilises a first-difference operator (Δ) to examine the relationship between variables. The maximum order of integration (k) determines the number of times a variable is differenced to achieve stationarity. The optimal lag length (m) is determined using a lag selection method based on Vector Autoregressive (VAR) approach.

3.3. Data, Description and Measurement of Variables

The data which spanned from 1991-2022, were sourced from the World Bank (2023). It consisted of variables such as carbon dioxide emissions (CO_2) measured in kg, per capita real GDP is a proxy for economic growth, financial development measured by domestic credit to the private sector ($DCPS$), ecological footprint (EFP) and trade openness (TOP).

4. RESULTS AND DISCUSSIONS

This section presents and discusses the results of the study.

4.1. Descriptive Statistics

Table 4 presents descriptive statistics for seven variables. Urbanization (URB), carbon dioxide emissions (CO2), domestic credit to the private sector (DCPS), ecological footprint (EFP), the natural logarithm of GDP per capita (LNGDPPC), and the natural logarithm of trade openness (LNTOP). The mean values indicate average levels for each variable, with urbanization at 40.079%, CO2 emissions at 0.683, and DCPS at 2.286, among others. The data generally shows low variability, as reflected by relatively small standard deviations. Skewness and kurtosis suggest mostly normal distributions, with minor deviations in urbanization and EFP. The Jarque-Bera test supports the assumption of normality for most variables, with p-values above 0.05, indicating no significant deviation from normal distributions. These statistics provide a foundational understanding of the dataset, supporting further analysis and insights into the relationships between these economic and environmental indicators.

Table 4. Descriptive statistics.

Variables	URB	CO_2	DCPS	EFP	LNGDPPC	LNTOP
Mean	40.079	0.683	2.286	1.021	7.574	12.527
Median	39.509	0.671	2.239	1.034	7.592	12.544
Maximum	51.958	0.916	2.977	1.205	7.893	12.846
Minimum	30.176	0.491	1.657	0.808	7.264	12.217
Std. dev.	6.913	0.123	0.319	0.099	0.238	0.238
Skewness	0.195	0.325	0.269	-0.314	-0.052	-0.052
Kurtosis	1.711	1.817	2.539	2.613	1.349	1.349
Jarque-Bera	2.267	2.277	0.626	0.681	3.420	3.421
Probability	0.322	0.320	0.731	0.711	0.181	0.181
Sum	1202.382	20.494	68.576	30.616	227.229	375.805
Sum sq dev.	1386.220	0.442	2.951	0.289	1.644	1.643
Obs.	30	30	30	30	30	30

The Table 5 correlation matrix reveals several key relationships among the variables. Urbanization (URB) is strongly positively correlated with both Gross Domestic Product Per Capita (LNGDPPC) and Trade Openness (LNTOP), suggesting that more urbanized areas tend to have higher economic productivity and greater engagement in trade. Conversely, Carbon Dioxide Emissions (CO_2) show a strong negative correlation with both Trade Openness (LNTOP) and Gross Domestic Product Per Capita (LNGDPPC), implying that higher trade openness and greater economic productivity are associated with lower CO2 emissions.

4.2. Correlation Analysis

Table 5. Correlation matrix for the six variables.

Variables	URB	CO_2	DCPS	EFP	LNTOP	LNGDPPC
URB	1					
CO_2	-0.858	1				
DCPS	0.736	-0.832	1			
EFP	-0.482	0.195	-0.162	1		
LNTOP	0.918	-0.824	0.769	-0.321	1	
LNGDPPC	0.930	-0.863	0.748	-0.330	0.439	1

However, Domestic Credit to the Private Sector (DCPS) is strongly positively correlated with Urbanization (URB), Trade Openness (LNTOP), and Gross Domestic Product Per Capita (LNGDPPC), reflecting that more credit availability is associated with greater urbanization, trade openness, and economic productivity. Ecological Footprint (EFP) displays a moderate negative correlation with Urbanization (URB) and weak negative correlations with Trade Openness (LNTOP) and Gross Domestic Product Per Capita (LNGDPPC), suggesting that more urbanized and economically productive country might have a slightly smaller ecological footprint.

4.3. Results of Unit Root Tests

Before estimating the chosen model(s) of the study, it is important to conduct the conventional Dickey and Fuller (1981) and Phillips and Perron (1988) tests to investigate the stationarity and order of integration of the data set otherwise, the regression results may be unreliable or spurious.

The results for the unit root tests shown in Table 6 suggests that all variables, except for URB exhibited a unit root at the level indicating that only URB was stationary, while the remaining variables were non-stationary at the level. However, after taking the first difference, the remaining variables became stationary. Consequently, the unit root results indicated that the variables of the study are a mixture of I(1) and I(0). These results also imply that the variables are stationary and have no trend, justifying the use of the ARDL bounds test approach for cointegration in this study.

Table 6. Results of unit root tests.

Variables	ADF with constant only		PP with constant only		Stationarity status
	Level	First difference	Level	First difference	
URB	-3.235*	-1.6388	-3.229*	-1.638	I(0)
CO_2	-1.440	-5.497***	-1.291	-8.033***	I(1)
DCPS	-1.281	-5.095***	-2.175	-9.287***	I(1)
EFP	-0.038	-5.254***	-0.037	-5.252***	I(1)
LNGDPPC	-2.246	-2.701*	-0.643	-2.679*	I(1)
LNTOP	-2.321	-2.919*	-0.610	-2.8913*	I(1)

Note: *** and * denote significance at 1% and 10% respectively.

4.4. ARDL Bounds Test for Cointegration

The result for the ARDL tests is shown in Table 7.

Table 7. Cointegration result.

Dependent variables	Functions				F-statistics	
CO_2	F(CO_2/lnGDPPC, lnGDPPC², DCPS, URB, lnTOP)				12.675***	k = 5
EFP	F(EFP/lnGDPPC, lnGDPPC², DCPS, URB, lnTOP)				7.374***	k = 4
Critical bounds values						
Significance	10%		5%		1%	
Order of integration	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
CO_2	3.507	5.122	2.618	3.864	2.218	3.314
EFP	2.431	3.091	3.481	4.571	4.411	5.851

Note: *** indicates rejection of the null hypothesis of no cointegration at 1% level of significance.

After confirming that the variables were stationary, a cointegration test was conducted using the bounds testing approach. The results in Table 7 show that the F-statistic (12.675) is compared with the critical values for the bounds test. Since 12.675 > 5.122 (the 10% critical value for I(1)), it indicates that there is strong evidence of a long-run relationship between CO_2 and the regressors (LNGDPPC, LNGDPPC², DCPS, URB, LNTOP) at the 10% significance level. Whereas, the F-statistic (7.374) is compared with the critical values for the bounds test since 7.374 > 5.851 (the 1% critical value for I(1)), it indicates that there is strong evidence of a long-run relationship between EFP and the regressors (LNGDPPC, LNGDPPC², DCPS, URB, LNTOP) at the 1% significance level.

4.5. ARDL Long Run Estimates

Table 8. Long and short run ARDL estimates.

	Dependent variable (CO_2)			Dependent variable (EFP)		
Variable	Coefficient	t-statistic	Prob.	Coefficient	t-statistic	Prob.
LNGDPPC	5.333	-3.699	0.000	5.028	3.596	0.004
LNGDPPC²	-4.945	-4.605	0.000	-5.155	-4.833	0.000
LNTOP	0.369	2.964	0.008	0.753	5.091	0.000
DCPS	0.053	4.602	0.000	0.364	3.144	0.005
URB	0.438	2.187	0.048	0.444	2.326	0.029
C	-23.415	-2.830	-0.009	-21.601	-2.723	0.013

Table 8 provides estimates from an ARDL (Autoregressive Distributed Lag) model analysing the long-run relationships between various economic and environmental variables. The focus is on two dependent variables, carbon dioxide emissions (CO_2) and ecological footprint (EFP). The findings indicate a significant positive relationship between economic growth and CO_2 emissions in the long run. As a result, economic growth increases CO_2 emissions. Concisely, a 1 percent increase in economic growth triggers CO_2 emissions by 53.33% in the long run. Also, the estimated coefficient of $LNGDPPC^2$ is found to be negative. The positive sign of LNGDPPC and the negative sign of $LNGDPPC^2$ confirm an inverted U-shaped relationship between economic growth and CO_2 emissions for Nigeria. The results support the findings of Halicioglu (2009) for Turkey, Shahbaz, Lean, and Shabbir (2012) for Pakistan and Shahbaz, Solarin, Mahmood, and Arouri (2013) for Malaysia. In addition, financial development (Domestic Credit to the Private Sector DOMR) has a positive coefficient of 0.053, which is significant (p-value 0.000). This implies that more credit to the private sector could be linked to increased CO_2 emissions, potentially through higher investment in carbon-intensive industries. This result is in line with the results of Wudil and Tsauni (2019). Moreover, trade openness (LNTOP) has a positive coefficient of 0.369, which is significant (p-value 0.008). This suggests that increased trade openness is associated with higher CO_2 emissions, possibly due to increased production and transportation activities. Also, urbanization (URB) has a positive significant coefficient of 0.438 (p-value 0.048), indicating that higher urbanization is impacting CO_2 emissions in the long run, possibly due to more efficient infrastructure and services in urban areas.

The coefficient of LNGDPPC suggests that a 1% increase in economic growth results in a 50.28% rise in the ecological footprint (EFP) in the long run, highlighting a positive relationship between economic growth and EFP. Furthermore, the negative coefficient of $LNGDPPC^2$ (-5.155) indicates that the impact of economic growth on EFP diminishes as growth continues. The combination of a positive coefficient for LNGDPPC and a negative coefficient for $LNGDPPC^2$ supports the presence of an inverted U-shaped relationship between economic growth and ecological footprint in Nigeria. This finding aligns with the conclusions of Sharif et al. (2020) and Bulut (2021). However, Financial development (Domestic Credit to the Private Sector DCPS) has a significant positive coefficient of 0.364 (p-value 0.005), suggesting that more credit to the private sector may increase ecological footprint, potentially through improved resource efficiency. These finding is in consonance with Ozturk and Acaravci (2010) for Turkey. Similarly, Trade Openness (LNTOP) has a statistically significant positive coefficient of 0.753 (p-value 0.000), indicating that trade openness increase ecological footprint. A 1 percent trade openness increase EFP by 75.30% which is in line with Grossman and Krueger (1991) and Jalil and Feridun (2011). Also, urbanization (URB) has a positive coefficient of 0.444, (p-value 0.029), implying that urbanization increased ecological footprint.

4.6. ARDL Short Run Estimates

Table 9. ARDL short run estimates.

Variable	Dependent variable (CO_2)			Dependent variable (EFP)		
	Coefficient	t-statistic	Prob.	Coefficient	t-statistic	Prob.
D(LNGDPPC)	2.138	-6.569	0.000	0.697	6.079	0.000
D($LNGDPPC^2$)	-0.846	-2.135	0.043	-0.575	-4.938	0.000
D(LNTOP)	0.224	2.416	0.024	0.289	2.915	0.007
D(DCPS)	2.421	6.610	0.000	0.239	3.903	0.000
D(URB)	0.053	6.398	0.000	0.427	3.688	0.002
ECM_{t-1}	-0.533	-5.449	0.000	-0.656	-6.359	0.000

Table 9 displays the ARDL short-run estimates for two dependent variables: CO2 and EFP. The analysis includes several independent variables. The Log of GDP per capita (LNGDPPC) has a positive and statistically significant coefficient for CO2 (2.138) and a smaller coefficient for EFP (0.697), both significant at the 1% level. The squared term of Log of GDP per capita (LNGDPPC2) shows a negative impact on both dependent variables, significant at the 5% level for CO2 (-0.846) and at the 1% level for EFP (-0.575). The Log of Trade Openness (LNTOP) has a positive influence on both CO2 and EFP, with significant coefficients (0.224 for CO2 and 0.289 for EFP) at the 5% and 1% levels, respectively. Domestic credit to the private sector (DCPS) has a positive and highly significant effect on both dependent variables, with coefficients of 2.421 for CO2 and 0.239 for EFP, significant at the 1% level. Urbanization (URB) positively impacts both CO2 and EFP, with significant coefficients (0.053 for CO2 and 0.427 for EFP) at the 1% and 5% levels, respectively. The estimated error correction term (ECMt−1) value is -0.533 indicating that CO2 emissions variations are corrected by 53.30% annually, with the system self-adjusting any imbalance back to equilibrium in approximately 4 years and 3 months. The estimate of ECMt−1 is -0.656, suggesting that variations in EFP are corrected by 65.60% each year, with any imbalance in the system automatically adjusting back to equilibrium after approximately 4 years and 3 months.

4.7. Diagnostic Tests

Table 10. Results of diagnostic tests.

Tests	F-statistic (CO_2)	F-statistic (EFP)
Serial correlation (Breusch-Godfrey Lagrange multiplier test)	0.706	0.601
Heteroscedasticity (Breusch-Pagan-Godfrey)	0.249	0.319
Specification error (Ramsey RESET test)	0.797	0.751
Stability test (CUSUM & CUSUMSQ)	Stable	Stable

The Table 10 shows the F-statistic values for each test with respect to carbon emissions (CO_2). The F-statistic is used to determine if the relationships or effects are statistically significant. Serial Correlation (0.706) F-statistic suggests that there is no evidence of serial correlation in the residuals for CO_2. Heteroscedasticity (0.249) F-statistic indicates that there is no significant heteroscedasticity in the model for CO_2. Specification Error (0.797): F-statistic implies that there is no significant evidence of specification errors for CO_2. Stability test (Stable) this means that the coefficients for CO_2 remain stable over time. Also, the Table 10 presents the F-statistic values for each test with respect to ecological footprint (EFP). Serial Correlation (0.601) F-statistic suggests that there is no evidence of serial correlation in the residuals for EFP. Heteroscedasticity (0.319) F-statistic indicates that there is no significant heteroscedasticity in the model for EFP. Specification Error (0.751) F-statistic implies that there is no significant evidence of specification errors for EFP. Stability test (Stable) this means that the coefficients for EFP also remain stable over time.

4.8. Results of Toda Yamamoto Non-Causality Test

The study used the Toda and Yamamoto (1995) method to analyze the causal relationships among Ecological footprint EFP, LGDPPC, DCPS, URB, and LTOP in Nigeria from 1991 to 2022. Before conducting the T-Y non-causality test, important tests were performed on the optimum VAR model to ensure the conditions were met.

Table 11. Results of Toda-Yamamoto causality.

Dependent variables	Independent variables	dmax+k	χ^2	P	Decision	Conclusion
EFP	LNTOP	3	8.747	0.004*	H0: Rejection	LNTOP => EFP
	LNGDP	3	0.997	0.317	H0: Acceptance	LNGDP ≠>EFP
	DCPS	3	10.307	0.001*	H0: Rejection	DCPS => EFP
	URB	3	8.087	0.004*	H0: Rejection	URB => EFP
	ALL	3	14.030	0.004*	H0: Rejection	ALL => EFP
LNTOP	LNEFP	3	0.091	0.763	H0: Acceptance	LNEFP ≠> LNTOP
	LNGDP	3	1.639	0.200	H0: Acceptance	LNGDP ≠> LNTOP
	DCPS	3	2.845	0.092***	H0: Rejection	DCPS => LNTOP
	URB	3	3.796	0.241	H0: Acceptance	URB ≠> LNTOP
	ALL	3	4.832	0.184	H0: Acceptance	ALL ≠> LNTOP
LNGDP	LNEFP	3	4.955	0.026**	H0: Rejection	LNEFP => LNGDP
	LNTOP	3	4.672	0.031**	H0: Rejection	LNTOP =>LNGDP
	DCPS	3	3.494	0.062***	H0: Rejection	DCPS => LNGDP

Dependent variables	Independent variables	dmax+k	χ^2	P	Decision	Conclusion
	URB	3	3.563	0.083***	H0: Rejection	URB => LNGDP
	ALL	3	6.664	0.083***	H0: Rejection	ALL => LNGDP
DCPS	EFP	3	0.225	0.635	H0: Acceptance	LNEFP ≠> DCPS
	LNTOP	3	0.155	0.695	H0: Acceptance	LNEEC ≠> DCPS
	LNGDP	3	0.025	0.888	H0: Acceptance	LNGDP ≠> DCPS
	URB	3	0.179	0.733	H0: Acceptance	URB ≠> DCPS
	ALL	3	2.189	0.535	H0: Acceptance	ALL ≠> DCPS
URB	LNEFP	3	0.088	0.711	H0: Acceptance	LNEFP ≠> URB
	LNGDP	3	2.632	0.377	H0: Acceptance	LNGDP ≠> URB
	DCPS	3	2.879	0.055***	H0: Rejection	DCPS => URB
	LNTOP	3	2.567	0.241	H0: Acceptance	LNTOP ≠> URB
	ALL	3	3.823	0.244	H0: Acceptance	ALL ≠> URB

Note: χ^2: Chi-square value, P: Probability value *, **, and *** refer to 1%, 5%, and 10% significance levels, respectively, =>: Granger causality exists, ≠>: No granger causality.

The Table 11 presents the results Toda-Yamamoto causality tests indicate that Trade Openness (LNTOP), Financial Development (DCPS), and Urbanization (URB) have a significant Granger causality effect on the Ecological Footprint (EFP). Moreover, Economic Growth (LNGDP) is influenced significantly by both Ecological Footprint (LNEFP) and Trade Openness (LNTOP), with minor impacts from Financial Development (DCPS) and Urbanization (URB). Trade Openness is slightly influenced by Financial Development, while no significant causality is observed between Financial Development and the other variables. Urbanization exhibits minor causality with Financial Development but does not have significant effects on or from the other variables.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

This study examines the validity of the Environmental Kuznets Curve (EKC) Hypothesis in Nigeria by analyzing two environmental variables, carbon dioxide emissions and ecological footprint from 1991 to 2022. Utilising an autoregressive distributed lag (ARDL) bounds test for cointegration and Toda-Yamamoto causality approach. The study reveals a positive nexus between economic growth and carbon dioxide emissions (CO_2) and ecological footprint (EFP) in Nigeria. This indicates that as the economy expands, there is a rise in CO_2 emissions and ecological footprint. The study also shows an inverted U-shaped relationship between economic growth and CO_2 emissions, suggesting that there is a threshold beyond which further economic growth could lead to a decrease in emissions. This underscores the importance of adopting sustainable economic development strategies to mitigate environmental impacts. Additionally, the study finds that financial development, as measured by domestic credit to the private sector (DOMR), has a positive influence on CO_2 emissions and ecological footprint. This implies that increased access to credit may result in higher emissions and ecological footprint through investments in carbon-intensive industries. Furthermore, the results indicate that trade openness (LNTOP) and urbanization (URB) have a significant positive effect on CO_2 emissions and ecological footprint. The rise in trade openness and urbanization is linked to increased emissions and ecological footprint, possibly due to heightened production, transportation activities, and infrastructure development in urban areas.

Based on the findings, policymakers in Nigeria should consider the study policy recommendations to promote sustainable economic growth and reduce environmental impact. Implement green financing initiatives to encourage investments in renewable energy and sustainable projects. Furthermore, utilizing green financial products like Sukuk for funding priority infrastructure projects could boost renewable energy, environmental sustainability, and strengthen the financial sector in Nigeria. Introduce regulations and incentives to promote energy efficiency and reduce carbon emissions in industries and develop sustainable urban planning strategies to manage urbanization and reduce environmental degradation. Also, enhance environmental monitoring and reporting mechanisms to track progress towards environmental sustainability goals. Strengthen international cooperation on climate change mitigation and adaptation to address global environmental challenges.

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