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RESEARCH ARTICLE

Mitigating human-induced emissions in Argentina: role of renewables, income, globalization, and financial development

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Abstract

Achieving environmental sustainability has become a global initiative while addressing climate change and its effects. However, the role of energy production and consumption in economic development remains critical amidst environmental pollution. Thus, the need for innovation and clean energy alternatives is critical while pursuing sustainable development. This country-specific study focuses on Argentina, where economic growth trajectory is embedded with high CO_2 emissions. This study assesses the long-term and causal impact of financial development and renewables on environmental pollution while accounting for the role of economic development and globalization using yearly data spanning 1980 to 2017. A battery of econometric methods is applied to underscore the interaction between the parameters of interest. The findings of Maki and ARDL tests of cointegration alongside Kripfganz and Schneider critical approximation *p-values* affirm long-run equilibrium interaction between variables. The outcomes of autoregressive distributed lag, fully modified, and dynamic ordinary least squares demonstrate that while economic expansion dampens environmental quality—globalization and renewables improve the environment. This finding suggests pollution-driven economic growth trajectory in Argentina with high dependence on fossil fuels. Besides, the gradual shift causality test finds evidence of one-way causality from renewable energy consumption, economic growth, and globalization to CO_2 emissions. Argentina's pathway in achieving sustainable development requires gradual and inclusive economic shift towards green growth.

Keywords CO_2 emissions · Environmental sustainability · Economic growth · Financial development · Renewable energy · Argentina

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Introduction

Environmental issues including climate change and its long-term effects are widespread—especially among industrialized and emerging economies. Both human (anthropogenic) and natural economic expansion practices triggered these environmental issues. Argentina's CO_2 emissions per capita in 2019 were 4.42 tons of CO_2 per capita (BP, 2021). Argentina is ranked 31st and 3rd biggest economy in the world and Latin America, respectively, with GDP amounting to US$ 445.445 billion in 2019 (World Bank, 2020). Argentina signed the COP21 agreement in 2016 and agreed to mitigate CO_2 emissions substantially with its pledges and targets presented in Table 1. Argentina was the largest dry gas producer in 2016 and the fourth biggest producer of other liquids and petroleum in South America. In 2015, natural gas, which is extensively utilized in manufacturing, residential sectors, and electricity generation accounted for 52% of total primary energy utilization. Oil is the main fuel utilized in the transport industry, accounting for 36% of overall primary energy demand; however, hydropower is the 3rd largest primary source of energy. A lower proportion of the nation's overall energy use to generate electricity can be traced to the utilization of coal, hydroelectric power, and nuclear, whereas other renewable options are utilized in the production of biofuels for transportation.

Economic expansion is reliant on energy production and consumption—due to its role in improving income generation and development, stimulating employment, and accelerating productivity. Likewise, literature on energy economics shows economic growth and energy use are the two major factors with long-term impact on climate change. For instance, Kirikkaleli et al. (2020), Ayobamiji and Demet (2020), Adebayo and Kirikkaleli (2021), Olanrewaju et al. (2021), Odugbesan and Rjoub (2020), and Akinsola and Adebayo (2021) establish energy usage and economic growth as the main cause of environmental degradation across countries and regions. Previous studies [Adebayo (2021), Adedoyin et al. (2020a), Adedoyin et al. (2020b), Dogan et al. (2020), and Alola et al. (2019)] establish conventional energy sources as critical to increasing CO_2 levels which in turn decrease environmental sustainability. This stance is reinforced by the optimistic association between consumption of fossil fuels and economic growth—which implies that GDP growth contributes to higher utilization of energy and higher CO_2 emissions, respectively (Asongu et al. 2020; Umar et al. 2020; Adebayo et al. 2021; Dogan et al. 2020). The dependence on fossil fuels has caused significant environmental harm, triggering the necessity for green energy innovations and a switch to environmentally friendly and sustainable options (renewables) that can guarantee energy efficiency (Owusu and Asumadu, 2016; Sarkodie and Owusu, 2021; Sharif et al. 2019; Ramzan et al. 2021; Azam et al., 2019; Sun et al. 2021). This stance is buttressed by the studies of Kalmaz and Adebayo (2021), Bekun et al. (2019), Adedoyin et al. (2021), and Kirikkaleli and Adebayo (2020) that disclose the role of green energy in mitigating environmental degradation. The key policy for maintaining a sustainable environment is to implement a decarbonization plan in line with the Intergovernmental Panel on Climate Change (IPCC, 2011)—which includes replacing fossil fuels with renewable energy sources.

Moreover, several studies have highlighted the significant role of financial development (FD) in attaining environmental quality. These studies used measures of FD in modeling the connection between growth, environment, and energy (see Odugbesan and Adebayo 2020; Kirikkaleli and Adebayo 2020; Charfeddine and Khediri 2016). Effective and efficient financial sector stimulates environmental sustainability by providing cheap loans for environmentally sustainable projects, supplying businesses with renewable technology, and offering incentives for firms that conform to environmental regulations and rules (Iorember et al. 2020). By increasing the stock of capital accessible for investment in sustainable energy resources intended to decrease CO_2 emissions, financial development can influence the efficiency of the ecosystem. Financial development, as established by the supply-

Table 1 Main pledge and targets of Argentina

	Ratified	Yes
Paris agreement	2030 Unconditional target(s)	483 MtCO2e by 2030 (SAR GWP) [422 MtCO2e by 2030 excl. LULUCF (AR4 GWP) [81% above levels of 1990 by 2030 excl LULUCF] [32% above levels of 2020 by 2030, LULUCF]
	2030 Conditional target(s)	369 MtCO2e by 2030 (SAR GWP) [322 MtCO2e by 2030 excl. LULUCF (AR4 GWP)] [39% above levels 1990 by 2030, excl. LULUCF] [1% above levels of 2010 by 2030, excl. LULUCF]
	Coverage	Economy-wide, incl. LULUCF
Long-term goals	Long-term goals	None

Source: Our World in Data. https://buff.ly/331B6XE leading hypothesis, can also impact environmental sustainability via its positive effects on economic growth (Iorember et al. 2021). Besides, more energy consumption is needed for higher economic development; hence, energy and carbon-intensive economic pathway leads to CO_2 emissions. Consequently, this has become an active concern to consider the role of financial development in the growth-energy-environment connection.

Globalization is a global phenomenon that impacts human lives politically and socially (Bekun et al. 2021)—with its positive effects more pronounced than negative impacts—especially in reducing poverty and income disparity in developing nations. Recently, several scholars have assessed the association between environmental degradation and globalization; however, outcomes are mixed, making it difficult to determine the exact effect of globalization on environmental degradation. For instance, studies like Kirikkaleli et al. (2020), Koengkan et al. (2020), and Rahman (2020) established the role of globalization in escalating CO_2 emissions, which in turn decreases environmental quality. In contrast, other studies (Saint Akadiri et al. 2020; Asongu et al. 2020; Umar et al. 2020; Haseeb et al. 2018; Zaidi et al. 2019) found the effect of globalization in mitigating CO_2 emission sc., improves environmental quality. This infers that globalization may eliminate tariffs and taxation and free up financial development and trade, which may stimulate economic growth (Kirikkaleli et al. 2020). Nonetheless, economic expansion may reduce environmental sustainability (Adedoyin et al. 2020a, b).

The varying environmental effects of renewable energy, globalization, financial, and economic development require more scientific studies—owing to the mixed results of prior studies and lack of research consensus. The choice of Argentina as a case study is because of its ranking as third-biggest emitter in Latin America behind Mexico and Brazil, and limited jurisdictional and empirical studies on the theme. Thus, this research provides valuable policy suggestions on mitigating CO_2 emissions in Argentina. This study evaluates the interaction and causal impacts of globalization, renewables, and economic development on Argentina's environmental sustainability.

The primary additions of this research include (i) the introduction of financial development index into the framework for Argentina and utilization of green energy resources rather than traditional energy utilization in existing studies (see Zhang et al. 2021; Dogan et al. 2020; Kirikkaleli et al. 2020; Adebayo, 2021; Olanrewaju et al. 2021). The incorporation of financial development index in the research of energy–growth–globalization–environment association is a significant addition to existing studies, particularly in Argentina; (ii) due to potential breaks in series, employing the conventional cointegration test will yield misleading outcomes. Therefore, this study adopts Maki's cointegration test to capture cointegration among the series in the presence of five breaks. Besides, this study utilizes Bounds test with Kripfganz and Schneider (2018) critical values for model robustness and validation. The advantage of this approach is the consideration of both T-statistic and F-statistics in deciding the cointegration between the parameters; (iii) the long-run association between CO_2 emissions and regressors are captured using the ARDL, FMOLS, and DOLS; (iv) unlike prior studies (Ayobamiji and Kalmaz, 2020; Kirikkaleli et al. 2020; Rahman 2020; Adedoyin et al. 2021) based on time-domain causality test, this study employs the gradual shift causality test that controls for the effect of structural break in exploring the causal linkage between sampled variables.

Table 2 shows the summary of related studies. Subsequent sections of this study include data and methodology presented in Section 3. The findings and discussions are highlighted in Section 3, whereas Section 4 presents conclusion and policy directions.

Materials and method

Data

In this research, the 8th, 9th, 13th, 15th, and 17th Sustainable Development Goals (SDGs) of the United Nations lay the foundation for selecting variables. Our data series comprises CO_2 emissions (CO_2), economic growth (GDP), globalization (GLO), renewable energy (REN), and financial development (FD).

CO_2 emissions: SDG 13 seeks to enhance atmospheric and habitat quality by lowering GHG emissions to optimal levels, thus illustrating the unparallel danger of global warming to human lives due to upsurge in CO_2 emissions.

Economic growth: Decent employment and productivity with aim of encouraging the vast unemployed to build work and entrepreneurship. SDG 8 seeks to guarantee that all employees that are qualified have full employment and good jobs.

Globalization: The aim of SDG 17 is to enhance global cooperation in all related areas and to utilize tactical alliances to achieve sustainability objectives. The overall aim will result in open access to technology and information for sustainable growth and development.

Renewable energy: SDG 17 seeks to improve capacity and update technologies including renewable energy sources—which is a vital objective to foster both growth and clean environment.

Financial development: Industrialization cannot occur without innovation and technology, whereas growth cannot take place without industrialization. SDG 9 aims at achieving sustainable development through the positive effects of financial development. This aims to enhance sustainability targets

Table 2 Summary of related studies

Investigator(s)	Period	Country	Variables	Method(s)	Outcomes
Magazzino, (2016)	1970–2006	Italy	CO_2, GDP, EN	TY Granger	GDP↔CO_2 EN↔CO_2
Dogan and Aslan (2017)	1995–2011	EU and candidate countries	CO_2, GDP, TOR	Panel FMOLS, the DOLS, causality	GDP➔ CO_2 (-) EN➔CO_2 (-) TOR➔ CO_2 (-)
Magazzino, (2017)	1960–2013	19 APEC countries	CO_2, GDP, EN	VAR	EN≠GDP
Zaidi et al. (2019)	1990–2016,	APEC countries	CO_2, GDP, GDP^2, FD, GLO	CUP-BC, CUP-FM,DH causality	GDP^2➔ CO_2 (-) GLO➔CO_2 (-) FD➔CO_2 (-) GLO➔CO_2
Haseeb et al. (2018)	1995–2014	BRICS countries	CO_2, GDP, EN, URB, FD	FMOLS, DSUR, DH causality	GDP^2➔ CO_2 (-) GLO➔CO_2 (-) URB➔CO_2 (-) FD➔CO_2 (+) EN➔CO_2 (+) EN↔CO_2 FD↔CO_2 GLO↔CO_2
Saint Akadiri et al. (2019)	1973–2014	South Africa	EFP GDP, EN,	ARDL, Granger causality	GDP➔ EFP (+) EN➔ EFP (+)
Alola et al. (2019)	1997–2014	Europe	EFP GDP, REN, EN, FR	PMG-ARDL	GDP➔ CO_2 (+) REN➔CO_2 (-) EN➔ CO_2 (+)
Bekun et al. (2019)	1996–2014	16-EU countries	CO_2, GDP, REN, EN, RENT	PMG-ARDL	GDP➔ CO_2 (+) REN➔CO_2 (-) EN➔ CO_2 (+) RENT➔ CO_2 (+)
Le and Ozturk, (2020)	1990–2014	7 Emerging Market and Developing Economies (EMDEs)	CO_2, GDP, GLO, FD	CCEMG, AMG, and DCCE	FD➔ CO_2 (+) GDP➔CO_2 (+) GLO➔ CO_2 (+)
Dogan et al. (2020)	1980–2014	BRICST Nations	CO_2, GDP, GDP^2, EN	Panel ARDL	EN➔ CO_2 (+) GDP^2➔CO_2
Kirikkaleli et al. (2020)	1980–2016	Turkey	EFP, GDP, GLO, TO	FMOLS, DOLS, dual adjustment	GDP➔ EFP (+) GLO➔ EFP (+) TO➔EFP(-)
Asongu et al. (2020)	1980–2014	Africa	CO_2, GDP, ELE, URB, EN	ARDL-PMG, D-H causality	EN➔ CO_2 (+) GDP➔CO_2 (+) URB➔CO_2 URB↔CO_2 GDP↔CO_2
Khan and Ozturk (2020)	1980–2014	17 countries from Asia	CO_2, GDP, FDI, TO	FMOLS	FDI➔ CO_2 (+) FDI↔CO_2
Adebayo et al. (2020)	1980–2018	MINT Nations	CO_2, GDP, URB, TO, EN	ARDL, panel causality	GDP ≠ CO_2 EN➔ CO_2 (+) URB CO_2 (+) TO➔CO_2 (+) URB➔CO_2 TO➔CO_2
Odugbesan and Adebayo (2020)	1980–2016	Nigeria	CO_2, GDP, FDI, FD	ARDL, NARDL	FD^P➔ CO_2 (-) FD^n≠ CO_2 FDi^P➔ CO_2 (-)
Adebayo & Odugbesan, (2020)	1971–2016	South-Africa	CO_2, GDP, URB, FD	ARDL, FMOLS, DOLS, CCR, wavelet	GDP➔CO_2 (+) FD➔CO_2 (+) URB➔CO_2 (-)
Olanrewaju et al. (2021)	1971–2016	Thailand	CO_2, GDP, EN, GCF, FD	ARDL, FMOLS, DOLS, CCR, wavelet	GDP➔ CO_2 (+) GCF➔ CO_2 (+) EN➔ CO_2 (+)

Table 2 (continued)

Investigator(s)	Period	Country	Variables	Method(s)	Outcomes
					FN$\rightarrow$ CO_2 (+) URB$\rightarrow$ CO_2
Adedoyin et al. (2020a)	1990–2014	BRICS economies	CO_2, GDP, CR, CC	PMG-ARDL	GDP$\rightarrow$$CO_2$ (+) CC$\rightarrow$$CO_2$ (+) CR $\neq$ CO_2
Zhang et al. (2021)	1970–2016	Malaysia	CO_2, GDP, URB, TO, GCF	Maki cointegration, ARDL, wavelet, gradual shift causality	GDP$\rightarrow$ CO_2 (+) URB$\rightarrow$ CO_2 (+) GCF$\rightarrow$ CO_2 (+) URB$\rightarrow$ CO_2 URB$\rightarrow$ CO_2
Ahmed et al. (2021)	1980–2017	Japan	EFP, GDP, GLO, FD	ARDL	$GLO^+$$\rightarrow$ EFP (-) $GLO^-$$\rightarrow$ EFP (-) FD$\rightarrow$EFP(+)
Ullah et al. (2020)	1980–2018	Pakistan	CO_2, GDP, URB, HC, IND	ARDL, NARDL	GDP$\rightarrow$ CO_2 (+) HC$\rightarrow$ CO_2 (+)
Usman et al. (2021)	1990-2017	15 highest emitting countries	EFP GDP,FD,REN, NON	Panel ARDL	$GLO^+$$\rightarrow$ EFP (-) $REN^-$$\rightarrow$ EFP (-) FD$\rightarrow$EFP(-)
Alam et al. (2020)	1996–2013	30 OECD Nations	CO_2, GDP, SM, R&D, FDI	Panel ARDL	GDP$\rightarrow$ CO_2 (+) R&D$\rightarrow$ CO_2 (+) FDI$\rightarrow$ CO_2 (+) SM$\rightarrow$ CO_2 (+)
Anser et al. (2021)	1990-2015.	top ten carbon emitter nations	CO_2, GDP, GDP^2, POP, EN	PMG-ARDL	GDP$\rightarrow$ CO_2 (+) $GDP^2$$\rightarrow$ CO_2 (-) POP$\rightarrow$ CO_2 (+) EN$\rightarrow$ CO_2 (+)
Assi et al. (2021)	1998–2018.	ASEAN +3 economies	CO_2, GDP, REN, FD	panel ARDL, D-H causality	FD$\neq$ REN $CO_2$$\rightarrow$ REN (-)
Adebayo (2021)	1981–2016	Indonesia	CO_2, GDP^2, GDP, TO, EN	ARDL, wavelet	GDP$\rightarrow$ CO_2 (+) $GDP^2$$\rightarrow$ CO_2 (-) EN$\rightarrow$ CO_2 (+) TO$\rightarrow$ CO_2 (-)

Notes: *GDP* gross domestic production, *CO_2* carbon emissions, *EN* energy use, *TO* trade openness, *FD* financial development, *GLO* globalization, *CC* coal consumption, *CR* coal rent, *URB* urbanization, *R&D* research and development, *GCF* gross capital formation, *EFP* ecological footprint, *HC* human capital, *REN* renewable energy, *SM* stock market, *FDI* foreign direct investment, *TOR* tourism

through technological innovations including growing efficient resources and achieving energy efficiency.

Based on this, we assess the impact of financial development and renewable energy on environmental degradation by accounting for the role of GDP and globalization in Argentina using yearly data from 1980 and 2017. This study utilizes the following economic function:

$$CO_2 = f(GDP, FD, REN, GLO) \tag{1}$$

In Eq. 1, CO_2 denotes carbon emissions, FD signifies financial development index, GLO stands for globalization, and REN illustrates renewable energy.

The unit of measurement, description, and source of data are presented in Table 3. Figure 1 depicts the flow chart of the econometric procedure used in this study.

Theoretical rationale and specification of model

In line with Adebayo and Odugbesan (2020) for South Africa and Kirikkaleli et al. (2020) for Turkey, the specification of the model can be expressed as:

$$CO_{2t} = \beta_1 GDP_t + \beta_2 FD_t + \beta_3 REN_t + \beta_4 GLO_t + \varepsilon_t \tag{2}$$

In Eq. 1, CO_2, FD, REN, GDP, and GLO depict environmental degradation, financial development, renewable energy, economic growth, and globalization, respectively. Also, t illustrates the period of study (1980–2017); β_1, β_2, β_3, β_4, and β_5 are parameters while ε is the error term.

Constant expansion of the economy has contributed to an upsurge in GDP, leading to higher energy demand, which contributes more to emissions (Kirikkaleli et al. 2020;

Adebayo, 2021; Olanrewaju et al. 2021). Thus, GDP is projected to increase CO_2 emissions $\left(\beta_1 = \frac{\delta CO_2}{\delta GDP} > 0\right)$. Financial development is expected to negatively impact CO_2 emissions (Kirikkaleli and Adebayo 2020; Charfeddine and Khediri 2016). Thus, an increase in financial development would also increase environmental degradation, i.e., $\left(\beta_2 = \frac{\delta CO_2}{\delta FD} < 0\right)$ otherwise $\left(\beta_2 = \frac{\delta CO_2}{\delta FD} > 0\right)$ if not eco-friendly. Following Kirikkaleli and Adebayo (2020) and Kirikkaleli et al. (2020), we incorporate renewable energy into the model. Renewable energy is anticipated to decrease CO2 emissions (Kirikkaleli and Adebayo 2021). Thus, the expected sign of REN coefficient is negative $\left(\beta_3 = \frac{\delta CO_2}{\delta REN} < 0\right)$. It is predicted that the interaction between globalization and CO_2 emissions is negative (Asongu et al. 2020; Kirikkaleli et al. 2020). Thus, a rise in GLO would decrease CO_2 emissions $\left(\beta_4 = \frac{\delta CO_2}{\delta GLO} < 0\right)$ otherwise $\left(\beta_4 = \frac{\delta CO_2}{\delta GLO} > 0\right)$ if globalization is not eco-friendly.

Methodology

Unit root tests

Using non-stationary data for model estimation will produce spurious regression, hence affects statistical inferences (Granger et al. 1974). To investigate the stationarity properties of sampled series, this study employs ADF and PP unit root tests.

The equation of ADF is expressed as:

$$\Delta Y_t = \beta_1 Y_{t-1} + \sum_{i-1}^{p} b_1 \Delta Y_{t-1} + \epsilon_t \tag{3}$$

Equation 4 explains the PP unit root expressed as:

$$\Delta Y_t = \beta_0 + \beta_1 t + \beta_2 Y_{t-1} + \epsilon_t \tag{4}$$

where Δ denotes the first difference, Y_t denotes the target variable used, t denotes the time trend of the variable, p denotes lags used, and ε represents error term. PP unit root is a modified version of ADF because the residual of the serial correlation and heteroscedasticity were been taken into but PP employs statistical methods that are non-parametric to solve the heteroscedasticity and serial correlation problem. This study used the Zivot and Andrews (2002) unit root test in detecting a single structural break and stationarity features of the parameters.

$$\text{Model A}: \quad \Delta \mathrm{y} = \sigma + \widehat{u} y_{t-1} + \beta \mathrm{t} + \gamma \mathrm{DU}_t + \textstyle\sum_{j=i}^{t} d_j \Delta y_{t-j} + \varepsilon_t \tag{5}$$

$$\text{Model B}: \quad \Delta \mathrm{y} = \sigma + \widehat{u} y_{t-1} + \beta \mathrm{t} + \mathrm{DT}_t + \textstyle\sum_{j=i}^{t} d_j \Delta y_{t-j} + \varepsilon_t \tag{6}$$

$$\text{Model C}: \Delta \mathrm{y} = \sigma + \widehat{u} y_{t-1} + \beta \mathrm{t} + \mathrm{DT}_t + \gamma \mathrm{DU}_t + \textstyle\sum_{j=i}^{t} d_j \Delta y_{t-j} + \varepsilon_t \tag{7}$$

where Tb is the possible breakpoint, and r is the upper limit of the lag length of the explanatory variables. Also, $DU_t = 1$ and DT_t will be equivalent to $t - T_b$ if $t > T_b$ and it will be 0 if otherwise

$$\mathrm{DUt} = \begin{cases} 1 \ldots\ldots\ldots\ldots \mathit{if}\ t > TB \\ 0 \ldots\ldots\ldots. \mathit{otherwise} \end{cases} \quad \text{and} \quad \mathrm{DUt} = \begin{cases} t{-}TB \ldots . \mathit{if}\ t > TB \\ 0 \ldots\ldots\ldots. \mathit{otherwise} \end{cases} \tag{8}$$

Maki cointegration test

Bearing in mind the structural break(s) in series, the current paper applied Maki cointegration test to explore the cointegration features between CO_2, REN, GDP, FD, and GLO in Argentina. We applied this test in contrast to both Hatemi-j's (2008) and Gregory and Hansen's (1996) cointegration tests, which can capture two and more potential break dates. The Maki cointegration test can capture cointegration in series with almost five breaks simultaneously. The four regression models of Maki (2012) are illustrated as:

Level shift

$$Y_t = \rho + \sum_{i=1}^{k} \rho_i D_{i,t} + \theta^{\iota} Z_t + \varepsilon_t \tag{9}$$

Level shift with trend

$$Y_t = \rho + \sum_{i=1}^{k} \rho_i D_{i,t} + \theta^{\iota} Z_t + \sum_{i=1}^{k} \theta^{\iota} Z_t D_{i,t} + \varepsilon_t \tag{10}$$

Regime shifts

$$Y_t = \rho + \sum_{i=1}^{k} \rho_i D_{i,t} + \theta^{\iota} Z_t + \sigma t + \sum_{i=1}^{k} \theta^{\iota} Z_t D_{i,t} + \varepsilon_t \tag{11}$$

Trend and regime shifts

$$Y_t = \rho + \sum_{i=1}^{k} \rho_i D_{i,t} + \theta^{\iota} Z_t + \sigma t + \sum_{i=1}^{k} \sigma^{\iota} D_{i,t} + \sum_{i=1}^{k} \theta^{\iota} Z_t D_{i,t} + \varepsilon_t \tag{12}$$

In Eqs. 9, 10, 11, and 12, t stands for time. Y_t and Z_t depict dependent and independent variables, while the error term is depicted by ε_t.

ARDL approach

Bounds testing based on autoregressive distribution lag (ARDL) is used to capture the long-run association between

Table 3 Variables, units, and sources

Variable	Description	Units	Sources
CO_2	Environmental degradation	Metric tons per capita	BP
GDP	Economic growth	GDP per capita constant $US, 2010	WDI
FDI	Financial development index	A broad measure for financial development by taking into account its efficiency, accessibility, and depth	IMF
REN	Renewable energy consumption	% of total final energy consumption	BP
GLO	Economic globalization	Index based on FDI, trade, and portfolio investment	Gygli et al., (2019): Revised KOF Globalization Index

the dependent and independent variables (Pesaran and Timmermann 2005). The benefits of the ARDL bounds model over other traditional cointegration techniques are the following: (i) it can be used when there is mixed integration order; (ii) it incorporates both short and long-run coefficients concurrently; (iii) it perfectly fits small sample size (BetonKalmaz and Adebayo 2020); (iv) accommodate different lag-length (Mwamba et al. 2021; Olanrewaju et al. 2021); and (v) autocorrelation problem is removed. The estimated F-statistic is compared to the lower and upper bound critical values. When the calculated F-statistics is below the critical value, the null hypothesis can not be rejected; however, the null hypothesis is rejected when the estimated F-statistics is greater—which shows evidence of long-run relationship among variables. Equation 13 explains the ARDL bounds model, expressed as:

$$\begin{aligned}\Delta CO_{2t} = {} & C_0 + \beta_1 CO_{2t-1} + \beta_2 GDP_{t-1} + \beta_3 FD_{t-1} \\ & + \beta_4 REN_{t-1} + \beta_5 GLO_{t-1} + \sum_{i=1}^{t} \pi_{1,I} \Delta C0_{2t-i} \\ & + \sum_{i=1}^{t} \pi_{2,I} \Delta GDP_{t-i} + \sum_{i=1}^{t} \pi_{3,I} \Delta FD_{t-i} \\ & + \sum_{i=1}^{t} \pi_{4,I} \Delta REN_{t-i} + \sum_{i=1}^{t} \theta_5 \Delta REN_{t-i} + \varepsilon_t \qquad (13)\end{aligned}$$

where Δ is the first difference operator of the variables. The first part of equation (10) estimates the long-run coefficients whereas the second part estimates the short-run coefficients of the variables. The speed at which the short-run disequilibrium adjusts to its long-run equilibrium path is determined by the error correction mechanism (ECM). The ECM equation is based on:

$$\begin{aligned}\Delta CO_{2t} = {} & \psi_0 + \sum_{i=0}^{p} \theta_{1,i} \Delta C0_{2t-i} + \sum_{i=0}^{q} \theta_{2,1} \Delta GDP_{t-i} \\ & + \sum_{i=0}^{q} \theta_{3,i} \Delta FD_{t-i} + \sum_{i=0}^{q} \theta_4 \Delta REN_{t-i} \\ & + \sum_{i=0}^{q} \theta_{5,i} \Delta GLO_{t-i} + \omega ECT_{t-1} + \varepsilon_t \qquad (14)\end{aligned}$$

where the adjustment speed to the long-run equilibrium level is captured by the error correction term (ECT). The short-run parameters are given by φ_1, θ_1, θ_2, θ_3, θ_4, and θ_5. The choice of this method is based on its numerous advantages. Among these advantages, it can be applied whether the variables are I(0), I(1), or integrated fractionally. More so, the performance of this test in small sample size is better compared to other cointegration tests. To determine cointegration among variables, Pesaran and Timmermann (2005) proposed an F-test. The null hypothesis for cointegration test is that H_o: $\alpha_0 = \alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0$, whereas H_1: $\alpha_0 \neq \alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5 = 0$ represents the alternative hypothesis.

FMOLS and DOLS

If the long-run relationship is established among the variables, the need to estimate the long-run coefficients for the various

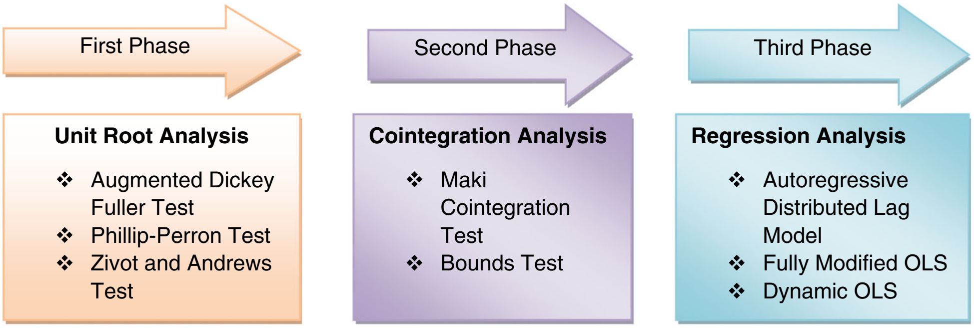


Fig. 1 A graphical flow of analysis

variables is germane. For this purpose, the fully modified ordinary least square (FMOLS) of Phillips and Hansen (1990) and the dynamic ordinary least square (DOLS) were used. Therefore, long-term elasticity with FMOLS and DOLS estimators is used in this study. The FMOLS estimator is depicted by Eq. 15 as:

$$CO_{2t} = \vartheta_0 + \vartheta_1 GDP_t + \vartheta_2 FD_t + \vartheta_3 REN_t + \vartheta_4 GLO_t + \sum_{i=q}^{q} \beta_1 \Delta GDP_{t-i} + \sum_{i=q}^{q} \beta_2 \Delta FD_{t-i} + \sum_{i=q}^{q} \beta_3 \Delta REN_{t-i} + \sum_{i=q}^{q} \beta_3 \Delta GLO_{t-i} + \varepsilon_t \tag{15}$$

The FMOLS estimator has the advantage of correcting autoregression and endogeneity problems, as well as error emerging from sample bias (Narayan & Narayan, 2005).

The dynamic ordinary least squares (DOLS) estimation test is utilized to ascertain the magnitude of long-run equilibrium. The advantages of DOLS include the following: (i) it can be estimated irrespective of the order of integration of series, but the dependent variable is expected to be integrated of order one and (ii) it eliminates serial correlation issues arising from the model estimation and other internalities (Esteve and Requena 2006). The DOLS long-run equation is illustrated in Eq. 16 as:

$$CO_{2t} = \vartheta_0 + \vartheta_1 GDP_t + \vartheta_2 FD_t + \vartheta_3 REN_t + \vartheta_4 GLO_t + \sum_{i=q}^{q} \beta_1 \Delta GDP_{t-i} + \sum_{i=q}^{q} \beta_2 \Delta FD_{t-i} + \sum_{i=q}^{q} \beta_3 \Delta REN_{t-i} + \sum_{i=q}^{q} \beta_3 \Delta GLO_{t-i} + \varepsilon_t \tag{16}$$

Here, q represents the optimum lag level suggested by Schwarz information criterion.

Table 4 Descriptive statistics

Statistics	CO_2	GDP	EG	FD	REN
Mean	3.9646	8403.0	42.552	0.3089	1.822667
Median	3.8453	7975.5	41.931	0.3204	1.935492
Maximum	4.7182	10883.	53.604	0.4267	3.1599187
Minimum	3.3096	6245.7	33.832	0.1894	0.1500846
Std. Dev.	0.4690	1412.8	6.3524	0.0641	2.295481
Skewness	0.3903	0.4678	0.1881	-0.3362	0.114931
Kurtosis	1.6161	1.8360	1.6326	2.12182	3.548128
Jarque-Bera	3.9968	3.5313	3.1847	1.936	0.559361
Probability	0.1355	0.1710	0.2034	0.3796	0.756025
Observations	38	38	38	38	38

Table 5 ADF and PP unit root results

	ADF		PP	
	I(0)	I(1)	I(0)	I(1)
CO_2	−3.081	−5.279*	−2.977	−9.409*
EG	−1.632	−5.147*	−1.632	−5.146*
FD	−2.028	−4.533*	−2.418	−9.634*
GDP	−2.798	−4.698*	−2.754	−4.644*
REN	−2.651	−5.694*	−2.740	−6.120*

Note: * stands for 1% significance level. PP and ADF denotes Phillip-Perron and Augmented Dickey fuller tests correspondingly

Gradual shift causality

The gradual-shift model developed by Toda and Yamamoto (1995) depends on vector autoregressive (VAR) built by Sims (1980). The optimal lag length, $p + d_{max}$ is added to the lag of d_{max}, determined by the maximum-order of integration of the series in the VAR model. However, the outcome of the VAR model can produce inaccurate and inconsistent results because structural shifts are ignored (Enders and Lee 2012; Enders and Jones 2016). We utilized the Fourier Toda-Yamamoto causality test developed by Nazlioglu et al. (2016) to capture structural shifts in Granger causality analysis—including gradual and smooth shift termed the "gradual shift causality test." Fourier approximation comprises single-frequency (SF) and cumulative-frequencies (CF). Thus, by adding the TY-VAR analysis and Fourier approximation, the modified Wald test statistic (MWALT) is generated. Assuming the coefficients of the intercept is constant over time, the VAR model can be modified as:

$$y_t = \sigma(t) + \beta_1 y_{t-1} + \ldots + \beta_{p+dmax} y_{t-(p+dmax)} + \varepsilon_t \tag{17}$$

where y_t denotes CO_2, GDP, CC, GLO, and FD; σ denotes intercept; β denotes coefficient matrices; ε denotes the error term; t denotes time function. To capture the structural change, the Fourier expansion is introduced and explained in Eq. 18.

Table 6 ZA (intercept and trend)

	t-statistic	BD	t-statistic	BD
CO_2	−3.978	1994	−6.645*	2009
EG	−2.778	1999	−6.403*	1990
FD	−3.978	1994	−7.602*	1989
GDP	−3.458	1990	−5.804**	2008
REN	−3.149	2002	−5.748**	1995

Note: * and ** represent 1% and 5% significance level. BD denotes break date

Table 7 Maki (2012) outcomes

	T-statistics	Critical values	
Model		5%	BD
Trend and regime shifts			
CO_2=f(GDP, REN, FD, EG)	−7.967*	−6.911	1995
CO_2=f(GDP, REN, FD, EG)	−8.555 *	−7.638	1995, 1988
CO_2=f(GDP, REN, FD, EG)	−8.555 *	−8.254	1995, 1988, 2004
CO_2=f(GDP, REN, FD, EG)	−10.096*	−8.871	1995, 1988, 2004, 2010
CO_2=f(GDP, REN, FD, EG)	−10.096*	−9.482	1995, 1988, 2004, 2010, 1985

Note: * represents 1% significance level. BD stands for the break date

$$\sigma(t) = \sigma_0 + \sum_{k=1}^{n} \gamma_{1k} \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} \gamma_{2k} \cos\left(\frac{2\pi kt}{T}\right) \tag{18}$$

where γ_{1k} and γ_{2k} measures the frequency amplitude and displacement respectively; n denotes the number of frequency.

Substituting Eq. (18) into Eq. (17), the structural shift is considered by defining Fourier Toda-Yamamoto causality with cumulative frequencies (CF), expressed as:

$$y_t = \sigma_0 + \sum_{k=1}^{n} \gamma_{1k} \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} \gamma_{2k} \cos\left(\frac{2\pi kt}{T}\right) + \beta_1 y_{t-1} + \ldots + \beta_{p+dmax} y_{t-(p+dmax)} + \varepsilon_t \tag{19}$$

where k denotes approximation frequency. The single-frequency components are defined in Eq. 20 as:

$$\sigma(t) = \sigma_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) \tag{20}$$

The Fourier Toda-Yamamoto causality with single frequencies (SF) is illustrated in Eq. (21) as:

$$y_t = \sigma_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + \beta_1 y_{t-1} + \ldots + \beta_{p+d} y_{t-(p+d)} + \varepsilon_t \tag{21}$$

Here, the Wald statistic can be used for testing the null hypothesis that non-causality is zero (H_0: $\beta_1 = \beta\ \ = 0$).

Findings and discussion

The description of the sample following the empirical results is presented in Table 4. The outcome of the Jarque-Bera test shows parameters conform to the normality assumption since the probability fails to reject the null hypothesis of normal distribution. The unit root features of the series presented in Tables 5 and 6 show the order of integration of CO_2, GDP, REN, EG, and FD is I(1) process. Moreover, we apply both Maki (2012) and bounds test cointegration tests to explore the long-run equilibrium interaction among time series variables presented in Tables 7 and 8, respectively. The results of the Maki (2012) cointegration in Table 7 reveal long-run association between CO_2 emissions, financial development, globalization, renewable energy consumption, and economic growth. To ensure robustness of Maki (2012) cointegration test, we applied bounds test. The bounds test depicted in Table 8 confirms evidence of long-run association among the economic variables. Therefore, both Maki and bounds tests affirm cointegration among the parameters—indicative that the independent variables converge to the dependent variable. In other words, the combination of CO_2, GDP, REN, EG, and FD is significant in the long-run.

After confirming the cointegration among the parameters, we utilized ARDL test to capture the association between CO_2 emissions and regressors in both long-run and short-run presented in Table 9. Appropriate lag selection is essential when applying the ARDL. Thus, we utilized the AIC criteria proposed by Akaike (1987). As stated in Udemba et al. (2021) and Zhang e al. (2021), AIC is preferred for lag selection due

Table 8 Bound test with Kripfganz and Schneider critical and P-values

	F-statistics		6.76		T-statistics		−5.98
	10%		5%		1%		PV
F-statistics CV	2.204	3.320	2.615	3.891	3.572	5.112	0.00*
T-statistics CV	−2.495	−3.798	−2.843	−4.207	−3.54	−5.021	0.00*

Note: Note * represents 1% significance level, and PV denotes probability value. Both F-stat and T-stat are greater than critical values

Table 9 ARDL results

Regressors	Coefficient	t-statistic	Prob
Long-run outcomes			
GDP	0.4614*	4.7558	0.0001
EG	−0.1944**	2.3458	0.0411
FD	0.0409	1.2134	0.2368
REN	−0.1260**	−3.2309	0.0036
BD(GDP)$_{2008}$	0.0282***	1.9733	0.0601
BD(EG)$_{1990}$	−0.0149	−1.1076	0.2790
BD(FD)$_{1989}$	0.0111	0.8357	0.4115
BD(REN)$_{1995}$	−0.0082	−0.5146	0.6115
Short-run outcomes			
GDP	0.0282*	3.2637	0.0033
EG	−0.1944*	−3.6336	0.0013
FD	0.0226	1.6037	0.1219
REN	−0.0149***	−1.9212	0.0667
ECT(-)	−0.5744*	−10.346	0.0000
R^2	0.96		
Adj R^2	0.95		
Post-estimation tests			
χ2 ARCH	0.98 (0.30)		
χ2 RESET	0.27 (0.78)		
χ2 Normality	0.92 (0.63)		
χ2 LM	1.09 (0.80)		
CUSUM	Stable at 5% significance level		
CUSUM of Sq	Stable at 5% significance level		

Note: *, **, and *** stand for 1%, 5%, and 10% significance level, respectively. BD represents break date

to its superior characteristics. The model's goodness-of-fit is depicted by the R^2 (0.98) and Adj R^2 (0.97), respectively. The results of the R^2 and Adj R^2 illustrate 98% and 97% variations in CO_2 can be explained by GDP, REN, FD, and GLO, while the remaining percentage can be attributed to error. The speed of adjustment is observed to facilitate long-term convergence between the parameters with significant negative error correction (ECT) coefficient. The outcome of the ECT is −0.70, which illustrates evidence of cointegration among the parameters, and further signifies the capability of CO_2 to witness 70% speed of adjustment to verify the alignment to equilibrium in the long-run due to the effect of GDP, REN, FD, and GLO.

We observe in Table 9 that economic growth exerts positive impact on CO_2 emissions—which implies economic expansion in Argentina deteriorates environmental quality. Thus, keeping all indicators constant, 1% increase in GDP growth increases CO_2 by 0.48%. The probable reason behind this is that Argentina has been experiencing accelerated growth. Numerous studies document the positive link between economic growth and energy use. Meaning that economic growth increases with increasing levels of energy consumption, hence increasing CO_2 emissions—which deteriorates environmental quality (Kalmaz and Adebayo 2021). This outcome concurs with Kirikkaleli et al. (2020) for Turkey, Olanrewaju et al. (2021) for Thailand, Adebayo and Odugbesan for South Africa, and Zhang et al. (2021) for Malaysia.

There is insignificant linkage between financial development and CO_2 emissions. The reason for this insignificant linkage is that in emerging nations such as Argentina where structural transition of the financial sector is at an early stage, financial development may not improve environmental

Table 10 FMOLS and DOLS results

	FMOLS			DOLS		
Variable	Coefficient	t-statistic	Prob.	Coefficient	t-statistic	Prob.
GDP	0.4376*	8.3522	0.0000	0.4614*	4.8981	0.0001
EG	−0.0423**	−2.1352	0.0436	−0.0409**	−2.2498	0.04223
FD	0.1878	1.07333	0.20011	0.1944	1.2236	0.30358
REN	−0.1119*	−5.0931	0.0000	−0.1260*	−3.3273	0.0028
BD(GDP)$_{2008}$	0.0279*	3.6171	0.0014	0.0282*	2.0324	0.0533
BD(EG)$_{1990}$	0.0075	1.0540	0.3028	0.0149	1.1408	0.2652
BD(FD)$_{1989}$	−0.0149	−2.0576	0.0511	−0.0111	−0.8607	0.3979
BD(REN)$_{1995}$	−0.0092	−1.0666	0.2972	−0.0082	−0.5300	0.6010
R^2	0.96			0.96		
Adj R^2	0.95			0.95		
S.E. of regression	0.0122			0.0123		

Note: * and ** stand for 1% and 5% significance level, respectively. BD represents break date

Table 11 Gradual shift causality test

Causality Path	Wald-stat	No of Fourier	P-value	Decision
CO_2→ GDP	9.0366	3	0.2500	Do not reject Ho
GDP → CO_2	23.922*	3	0.0011	Reject Ho
CO_2→ FD	7.8616	3	0.3449	Do not reject Ho
FD→ CO_2	4.6718	3	0.6999	Do not reject Ho
CO_2→ EG	3.0876	1	0.8767	Do not reject Ho
EG → CO_2	12.365***	1	0.0891	Reject Ho
CO_2→REN	10.356	2	0.1692	Do not reject Ho
REN → CO_2	15.252**	2	0.0329	Reject Ho

Note: *, **, and *** stand for 1%, 5%, and 10% significance level, respectively

quality. This outcome corresponds with prior studies (Bekhet et al. 2017; Sekali and Bouzahzah 2019; Salahuddin et al. 2018) that found insignificant interconnection between financial development and CO_2 emissions.

However, if fossil fuel energy consumption is substituted with renewables, environmental quality increases. This argument is reflected in our findings from the effect of renewables on CO_2 emissions. Our results show renewable energy consumption decreases environmental degradation in Argentina with a negative link between renewable energy utilization and CO_2 emissions. The results reveal 1% increase in renewable energy utilization decreases CO_2 emissions by 0.14%. This indicates the need to improve the energy consumption structure from conventional energy sources to renewables. This is consistent with the findings presented in Kirikkaleli and Adebayo, (2020) and Dogan and Seker (2016), confirming the stimulating role of renewables on environmental sustainability.

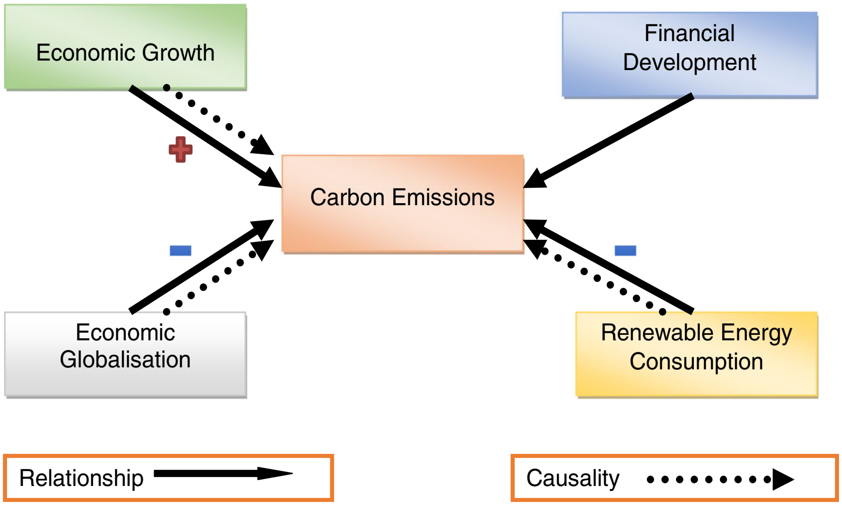
Evidence of negative linkage between globalization and CO_2 emissions illustrates that nations with higher globalization level/openness observe less environmental degradation. Therefore, keeping other indicators constant, 1% increase in globalization decreases CO_2 emissions by 0.19%. In each case, the technique effect is at work, as globalization introduces innovative goods and new techniques for production that enhance new activity. Globalization can boost economic expansion while minimizing environmental degradation (Zaidi et al. 2019). As businesses compete on a global scale, they strengthen their quality and service levels to stay competitive, which tends to solve environmental challenges in developing countries. This is consistent with the findings of Zaidi et al. (2019) and Shahbaz et al. (2013) who established negative and significant globalization-CO_2 emissions interconnection but contradicts the results of Kirikkaleli et al. (2020), Koengkan et al. (2020), and Rahman (2020) who found a positive role of globalization in environmental deterioration.

Regarding the effects of identified structural breaks, the results show that the break date (i.e., 2008) for economic growth is significant in explaining CO_2 emissions–economic growth relationship. The significance of the 2008 structural break can be attributed to the global financial crisis that affected the global economy.

The various post-estimation tests conducted are presented in Table 9. The results of the normality, serial correlation, Ramsey, and heteroscedasticity tests show that the model is well specified, normally distributed with no serial correlation and heteroscedasticity effects. The CUSUM and CUSUMSQ plots correspondingly exemplify the stability of the model parameters.

To affirm the ARDL long-run outcomes, we applied FMOLS and DOLS long-run estimators to capture the long-run interaction between CO_2 emissions and the regressors

Fig. 2 Graphical findings



(GDP, FD, REN, and GLO). The results of FMOLS and DOLS as presented in Table 10, showing both renewable and globalization, improve environmental quality, whereas economic growth impedes environmental quality in Argentina. These outcomes support the findings from the ARDL long-run estimation.

Finally, we utilized the gradual shift causality test to capture the causal impact of financial development, renewable energy consumption, globalization, and economic growth on CO_2 emissions in Argentina between 1980 and 2017. The findings of the causality test presented in Table 11 show (a) unidirectional causality from economic growth to CO_2 emissions. This illustrates that GDP is an important predictor of CO_2 emissions: (b) one-way causality from globalization to CO_2 emissions. This infers that globalization is a significant factor in predicting CO_2 emissions: (c) one-way causality from renewable energy consumption to CO_2 emissions—implying renewable energy consumption can predict CO_2 emissions. As a policy implication, the evidence of unidirectional causality highlights that economic growth-induced pollution is worthy of caution for environmental stakeholders. See Fig. 2 for causality scheme.

Conclusion and policy directions

The constant need for energy production and consumption energy driven mostly by fossil fuels threatens the environment. This research explored the linkage between CO_2 emissions and financial development in Argentina, while accounting for renewable energy utilization and economic development from 1980 to 2017. We utilized broad-based financial development index to accurately cover financial development, which measures access, efficiency, and financial depth contrary to conventional metrics. To achieve the hypothesized relationship between these variables, we applied a battery of second-generational econometric techniques comprising ARDL bounds test to cointegration in conjunction with Kripfganz and Schneider critical approximation p-values and Maki cointegration tests. We further leveraged the ARDL, FMOLS, DOLS regression estimators, and gradual shift based on Fourier approximation for testing causality. The empirical results show renewable energy mitigates environmental degradation by reducing CO_2 emissions. Thus, renewables are useful in mitigating CO_2 emissions in Argentina. Achieving environmental quality requires the transformation of current energy policies to encourage green and energy-efficient technologies. Moreover, this study demonstrates a negative relationship between globalization and emissions, showing the importance of global partnership on environmental sustainability. Openness to markets and new types of trading partners will help improve environmental quality. Environmental degradation can decline by creating opportunities and flexibility for renewable technology imports, as well as clear laws and regulations for environmental protection. Argentina can also deepen relations with its international trading partners to alleviate poverty, raise the number of new work opportunities, and boost imports and exports. Unsurprisingly, financial development does not mitigate CO_2 emissions in Argentina. Thus, the structural transition of the financial sector in emerging nations at the early stage may not improve environmental quality. This proposes the need to expand the financial base particularly public-private partnerships in clean and sustainable energy consumption to foster clean energy (SDG-7) and clean environment (SDG-13). Besides, economic growth decreases environmental degradation by increasing CO_2 emissions. This suggests that policymakers in Argentina could formulate policies that increase economic growth while improving environmental sustainability. Thus, there is a need to arrive at a balance between Argentina's energy mix, environmental strategies, and macroeconomic objectives by designing robust energy conservative policies. This will foster sustainable economic growth without compromising energy-cut. Thus, a paradigm shift to renewables such as photovoltaic, hydro energy, wind, and thermal energy could be pursued.

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Many thanks in advance look forward to your favorable response.

Availability of data and materials The data for this present study are sourced from the World Development Indicators (https://data.worldbank.org/). The current data specific data can be made available upon request but all available and downloadable at the earlier mentioned database and weblink.

List of Nomenclature

CO_2	Carbon dioxide
ARDL	Autoregressive distributed lag
BP	British petroleum
GDP	Gross domestic production
CO_2	Carbon emissions
EN	Energy use
TO	Trade openness
FD	Financial development
GLO	Globalization
CC	Coal consumption
CR	Coal rent
URB	Urbanization
R&D	Research and development
GCF	Gross capital formation
EFP	Ecological footprint
HC	Human capital
REN	Renewable energy

SM	Stock market
FDI	Foreign direct investment
TOR	Tourism

Author contribution The first author (Dr Tomiwa Sunday Adebayo) was responsible for the conceptual construction of the study's idea. The second author (Dr. Gbenga Daniel Akinsola) handled the literature section while the third author (Dr. Festus Victor Bekun) managed the data gathering and manuscript editing. Dr. Oseyenbhin Sunday Osemeahon managed the draft and SA Sarkodie, Ph.D. responsible for proofreading and supervision.

Declarations

Ethical approval Authors mentioned in the manuscript have agreed for authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.

Consent to participate Note applicable.

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