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Do technological innovation, financial development, education, and institutional quality contribute to environmental sustainability? Evidence from COSTA RICA

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Abstract

This study explores how technological innovation, financial development, education, and institutional quality impact CO_2 emissions between 1995 and 2021 in Costa Rica, one of the developing nations that have found ways to balance economic development with sustainable measures. We apply the Autoregressive Distributed Lag (ARDL) model and the Error Correction Model (ECM) to analyze the short-run and long-run relationships between the variables. Time-series data are analyzed to determine the direction and magnitude of these relationships. The results indicate that financial development positively correlates with CO_2 emissions in the long run, while technological innovation reduces environmental degradation. Short-run results show that institutional quality initially worsens emissions, while financial development and education contribute to mitigating CO_2 emissions. The findings underscore the need for policy aimed at balancing financial growth and environmental responsibility. Institutional quality and technological progress are central to achieving long-run sustainability. Policymakers ought to prioritize the implementation of sustainable investment methodologies, augment institutional frameworks, and advocate for innovation-oriented environmental policies. The adoption of these measures will be crucial for the mitigation of CO_2 emissions while concurrently facilitating sustained economic advancement.

Keywords: CO_2 Emissions, Education, Environmental sustainability, Financial development, Institutional quality, Technological innovation.

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1. Introduction

Climate change is now among the most pressing world concerns, and carbon dioxide (CO_2) emissions are a prominent contributor to environmental degradation. As countries seek economic growth, the harmony between development and the environment has gained significant attention among policy and research circles [1]. Costa Rica is a remarkable case study considering its embrace of sustainability, ambitious environmental policies, and steps toward carbon neutrality. Although it is a developing country, Costa Rica has managed to reconcile economic development with environmental conservation. For instance, statistics showed that in 2022, almost 99.78% of the nation's electricity was generated using renewable energy, with about 74% derived from hydropower, 13% from geothermal energy, and 11% from wind power [2].

In this study, we examine the role of technological innovation, economic growth, education, and institutional quality in shaping Costa Rican CO_2 emissions. Together, these factors are crucial in building a country's ability to achieve sustainable development with the added goal of avoiding environmental degradation. Innovation is essential in driving green technologies and enhancing energy efficiency, resulting in reduced emissions [3]. Financial growth affects green infrastructure and renewable energy investments; yet it can also lead to emissions through the growth of industry and higher energy use [4]. Education raises awareness of the environment and promotes sustainable behavior, resulting in lower emissions in the long term [5]. In addition, institutional quality guarantees the effectiveness of environmental policies and regulations, dictating a country's ability to control emissions in a sustainable way [6].

Given Costa Rica's sustainability leadership, it is essential to understand the roles of these variables in shaping CO_2 emissions so that policymakers can better position themselves to promote economic growth and conservation. Empirical evidence is used in this research to examine the dynamic interactions between innovation, financial development, education, and institutional quality, and to offer insights for sustainable policymaking.

The rest of this paper will be organized as follows: Section 2 focuses on the theoretical background by examining relevant economic and environmental theories and reviews the relevant literature on the impact of independent variables on CO_2 emissions. Section 3 describes the data and the methodology. Section 4 presents and discusses empirical results. Finally, Section 5 concludes the paper.

2. Background and Literature Review

2.1. Background Theories

Financial Development, Institutional Quality, Education, and Technological Innovation form a virtuous cycle of development. They are the key drivers of economic progress, social stability, and environmental sustainability. The study of the effect of these variables on Environmental degradation is rooted in several economic and environmental theories.

2.1.1. Environmental Kuznets Curve (EKC) theory

The EKC theory, proposed by Grossman and Krueger [7], suggests that economic growth initially leads to environmental harm. However, this degradation eventually diminishes as economies mature and adopt sustainable practices. When a country's income levels are low, its attention is on growing the income levels without paying attention to the impact on environmental quality. So the income growth is characterized by increased pollution. The environmental degradation starts to decline at some point as the country launches to achieve sustainable growth, thanks to development finance, which accelerates the adoption of clean technologies and green policies [8, 9]. Following Ozturk et al. [10] in the second phase of development, the increase in investment in renewable energy and green financing enhances the quality of the environment.

2.1.2. Endogenous Growth Theory

Romer [11] and Lucas Jr [12] advanced Endogenous Growth Theory, which underscores the role of innovation, education, and financial development in economic growth and pollution degradation. The theory suggests that Technological innovation drives long-term economic growth by reducing environmental harm through the adoption of clean energy and production methods. On the other hand, financial development oriented to sustainable goals is ensured by institutional quality control through enforcing environmental regulations [13].

2.1.3. Institutional Economics Theory

Institutional economics Theory, as discussed by North [14], highlights the role of institutions in shaping economic and promoting environmental sustainability. According to this theory, institutional quality encourages long-term investments in green infrastructure by enforcing environmental regulations and property rights [15]. Moreover, strong institutions ensure policy stability, which decreases risks and boosts sustainable economic practices.

2.1.4. Theory of Ecological Modernization

Developed by Mol and Spaargaren [16], the ecological modernization theory promotes that innovation and institutional reforms can orient economies toward sustainability. This theory suggests that Technological innovation can separate economic growth from environmental harm, resulting in an eco-friendly industrialization [17]. Besides, education can help in the transition to low-carbon economies. York and Rosa [18] indicate that education plays a crucial role in promoting green business practices and consumer behavior.

While economic growth alone may initially contribute to environmental harm, strong institutions, financial development, green finance, education, and technological progress can shift economies toward sustainability by reducing environmental pollution.

2.2. Literature Review

2.2.1. Education and Environmental Degradation

In this research, we study the crucial role of education in preventing environmental harm by developing sustainable practices. In this context, the study of Aytun and Akin [19] highlighted a causality relationship between Education and CO_2 emissions in Chile and Poland, countries with the highest education and income levels. Furthermore, Xin et al. [20] show a significant negative effect of education, measured by the average years of schooling, on carbon emissions in China. Using the FMOLS model and the data for 20 OECD countries over the period 1997-2019, Özbay and Duyar [21] demonstrated that lower-level education significantly increases CO_2 emission; however, they found a negative relationship between higher-level education and CO_2 emission. Also, in Saudi Arabia, Alkhateeb et al. [22] found that secondary education reduces environmental degradation. So, education can be used as a tool for developing green or energy-efficient technologies.

2.2.2. Financial Development and Environmental Degradation

While several studies have analyzed the effect of financial development, proxied by Foreign Direct Investment (FDI), on CO_2 emissions, results have been diverse. Certain studies found that CO_2 emissions are positively correlated with FDI inflow [23, 24]. However, other studies, such as Bilalli et al. [25] and Mahmood [26] showed no impact of FDI on environmental pollution. On the other hand, using the ARDL Approach, in a small emerging economy, the results of Abbasi and Riaz [27] revealed that financial development initially increases CO_2 emissions; however, after reaching a limit, FDI mitigates environmental pollution by promoting green technological transfer.

2.2.3. Technological Innovation and Environmental Degradation

Abundant literature suggests that Technological Innovation enhances CO_2 emissions as it is considered the catalyst of economic activities and energy consumption. Mahmood et al. [28] in their study about the MENA countries affirmed that the level of innovation is insufficient to generate green technologies, so the clean environment could not be achieved. In contrast, Bai et al. [29] demonstrated a negative relationship between innovation and carbon emissions in China from 2000 to 2017. Using spatial econometric models, Chen and Lee [30] affirmed that globally technological innovation does not damage CO_2 emissions in 96 countries. Nevertheless, they found that in high-income, high-technology, and high-CO_2 emission countries, technological innovation significantly decreases CO_2 emissions in neighboring countries.

2.2.4. Institutional Quality and Environmental Degradation

The effect of institutional quality on CO_2 emissions across countries is divergent. Salman et al. [31] demonstrated that robust economic institutions play a crucial role in promoting a sustainable environment by implementing policies and carbon reduction efforts across Thailand, Indonesia, and South Korea. A similar conclusion was detected by Mukhtarov et al. [32] in Canada. They used data from 1996 to 2021 and the FMOLS Method to show that higher institutional quality, measured by lower corruption index, can more effectively implement and enforce environmental policies to ensure an eco-friendly environment. However, in OECD countries, Dam et al. [33] found that the impact of institutional quality on environmental degradation is positive and significant in the long run.

3. Materials and Methods

3.1. Data Source and Description of Variables

This study examines the relationship between Environmental degradation, Financial Development, Institutional Quality, Education and Technological Innovation in Costa Rica. The temporal scope of our data is from 1995 to 2021, thus enabling a full and extensive review.

More information about the data and the sources used may be found in the informative Table 1 shown below.

Table 1.
Description of the variables.

Variable	Symbol	Measurement units	Data sources
Environmental degradation	LCO2	CO_2 emissions (metric tons per capita)	World Development Indicators
Financial Development	LFDI	Foreign direct investment, net inflows (% of GDP)	World Development Indicators
Institutional Quality	QUALITY	Government effectiveness index (-2.5 weak; 2.5 strong)	World Development Indicators
Education	LEDU	School enrolment, secondary (% gross)	World Development Indicators
Technological Innovation	LTI	Number of patent applications	World Development Indicators

LCO2, the dependent variable, as a proxy of Environmental degradation, CO_2 emissions at metric tons per capita. Key independent variables include LFDI, reflecting financial development is net inflows as a share of GDP; QUALITY measures Institutional Quality as a Government effectiveness index; LEDU reflects education level and LTI reflects Technological Innovation as a number of patent applications.

3.2. ARDL and ECM Estimation Models

Understanding the long-term impact within the econometric framework is important for making assessments of the lasting influence of the variables, and such will enable policy decisions to be made for the long term [34]. The impact of Financial Development, Institutional Quality, Education and Technological Innovation on Environmental degradation in Costa Rica has been studied using the ARDL-ECM framework in this present research. The Autoregressive Distributed Lag Error Correction Model (ARDL-ECM) was chosen due to its adaptability and dependability in managing datasets and their interrelations. This methodology is regarded as highly effective for addressing datasets characterized by mixed stationarity, whether at the level or first differences, thereby mitigating the complications associated with unit root pretesting [35].

The study employed the ARDL approach and bound testing cointegration method, as introduced by Pesaran et al. [36], to analyse both long-term and short-term associations and dynamic interactions among the variables [37]. This methodology facilitates adaptability in the lag structure of the variables and yields an enhanced alignment with the empirical data. Furthermore, it elucidates, via the Error Correction Model, the velocity at which the system reverts to its long-term equilibrium subsequent to transient disturbances. The model utilized for this study is specified in Equation 1.

$$LCO2_t = \alpha_0 + \alpha_1 LFDI_t + \alpha_2 QUALITY_t + \alpha_3 LEDU_t + \alpha_4 LTI_t + \varepsilon_t \qquad (1)$$

Where L denotes the logarithm transformation, CO_2 refers to CO_2 emissions, FDI refers to foreign direct investment, QUALITY indicates institutional quality, EDU refers to education, LTI indicates technological innovation, and ε_t indicates the error term.

Equation 2 outlines the ARDL regression model utilized in this study.

$$\begin{aligned} \Delta LCO2_t = {} & \alpha_0 + \sum_{k=1}^{n} \alpha_1 \Delta LCO2_{t-k} + \sum_{k=1}^{n} \alpha_2 \Delta LFDI_{t-k} + \sum_{k=1}^{n} QUALITY + \sum_{k=1}^{n} \alpha_4 \Delta LEDU_{t-k} + \sum_{k=1}^{n} \alpha_5 \Delta LTI_{t-k} \\ & + \lambda_1 LCO2_{t-1} + \lambda_2 LFDI_{t-1} + \lambda_3 QUALITY_{t-1} + \lambda_4 LEDU_{t-1} + \lambda_5 LTI_{t-1} + \varepsilon_t \end{aligned} \qquad (2)$$

Where Δ represents the first difference, α_1 through α_5 are the short-run coefficients, and λ_1 through λ_5 are the long-run coefficients.

4. Results and Discussion

4.1. Descriptive Statistics

Table 2 presents the descriptive statistics of the variables.

Table 2.
Descriptive statistics.

	Obs.	Mean	max	min	Std. Dev.
LCO2	27	0.187	0.259	0.112	0.040
LFDI	27	0.703	0.921	0.464	0.120
QUALITY	23	0.285	0.474	0.031	0.103
LEDU	27	1.945	2.150	1.697	0.144
LTI	27	2.566	2.902	1.875	0.276

The descriptive statistics indicate the varying distributions for the variables. LCO2 has a mean of 0.187 with a range of 0.112 to 0.259, with a low standard deviation of 0.040 and therefore low variability. LFDI has a high mean of 0.703 with a standard deviation of 0.120 and, therefore, a moderate spread of 0.464 to 0.921. QUALITY has the smallest mean (0.285) and the highest relative variation (Std. Dev. = 0.103), varying between 0.031 and 0.474, reflecting differences in institutional quality. LEDU and LTI have the highest means (1.945 and 2.566, respectively), with LEDU varying between 1.697 and 2.150 and LTI between 1.875 and 2.902. LTI also has the highest standard deviation (0.276), reflecting more heterogeneity in technological levels across observations.

4.2. Unit Root Test

The unit root tests constitute an essential component of the analytical framework utilized in time series analysis, which, during their application, address several critical issues. These tests ascertain the presence of stationarity or non-stationarity within a time series, thereby informing the selection of appropriate modeling techniques and mitigating the risk of spurious regression results. Indeed, through the application of unit root tests, researchers can gain insights into the long-term dynamics of economic variables, enhance forecasting accuracy, and establish a foundation for conducting cointegration analyses. The results from the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test for unit roots are presented in Table 3.

Table 3.
The results of the unit root test.

Variable	ADF		PP		Remarks
	Level	1st Diff.	Level	1st Diff.	
	Prob.	**Prob.**	**Prob.**	**Prob.**	
LCO2	0.7160	0.0005***	0.8228	0.0006***	I(1)
LFDI	0.6588	0.0566*	0.4054	0.0005***	I(1)
QUALITY	0.5744	0.0281**	0.4717	0.0023***	I(1)
LEDU	0.6122	0.0000***	0.5136	0.0000***	I(1)
LTI	0.8705	0.0007***	0.7429	0.0000***	I(1)

Note: *,**, and *** indicate 10%, 5% and 1% significance levels, respectively.

As represented in Table 3, both ADF and PP tests have led to a common result that is stationarity after first differencing for the variables under study, such as LCO2, LFDI, QUALITY, LEDU, and LTI. This sets up a basis of having variables that are integrated at I(1), an appropriate order required by the variables when applying an Autoregressive Distributed Lag model.

4.3. Determining The Optimal Lag Structure in the ARDL Model

Table 4 demonstrates the lag order selection criteria acquired from the unrestricted VAR. The optimal lag structure of the ARDL model is selected with the Akaike Information Criterion (AIC). According to this, both the dependent variable (LCO2) and the fixed regressors included in the model have a maximum of two lags.

Table 4.
Lag selection.

Lag	LL	LR	FPE	AIC	HQIC	SBIC
0	129.684		6.63e-13	-13.854	-13.820	-13.606
1	193.689	85.340	9.92e-15	-18.188	-17.983	-16.704
2	243.920	39.068*	1.42e-15*	-20.991*	-20.616*	-18.271*

Note: * indicates lag order selected by the criteria.

The AIC criteria for the top 20 ARDL models are depicted in Figure 1. The outcome demonstrates that the optimal lags chosen for ARDL estimation are (2, 2, 1, 2, 0).

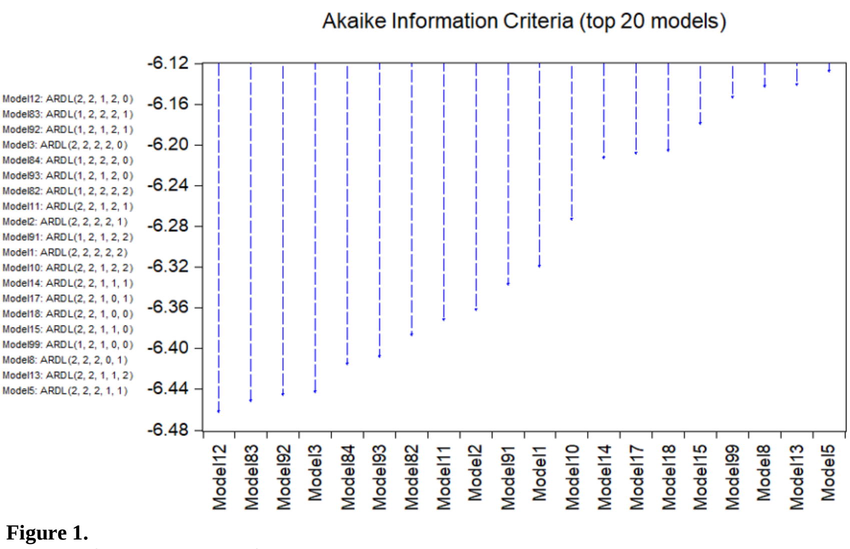

Figure 1.
Akaike Information Criteria for the Top 20 ARDL Models.

4.4. ARDL Bound Test

To assess the coefficients, a bounds test was performed, as presented in Table 5. This assessment possesses the capability to ascertain the existence of a long-term association among the variables, regardless of their integration order.

Table 5.
Bound test for cointegration analysis.

Test statistic	Value	Significance level	I(0)	I(1)
F-statistic	15.770	10%	2.45	3.52
K	4	5%	2.86	4.01
		1%	3.74	5.06

From above, the computed F-statistic, 15.77, is greater than the critical lower and upper bound values at all the usual levels of significance (1%, 5%, and 10%). The findings that demonstrate considerable robustness provide compelling support for the rejection of the null hypothesis regarding the absence of cointegration. It is reasonable to deduce that a substantial long-term equilibrium relationship exists among the variables under consideration.

4.5. Long-run Analysis of the ARDL Model

The long-run findings of the ARDL model are given in Table 6.

Table 6.
Estimated long-run coefficients of the model.

Dependent variable: LCO2				
Variable	**Coeff.**	**Std. Err.**	**t-stat.**	**Prob.**
LFDI	0.741**	0.174	2.810	0.026
QUALITY	-0.065	0.046	-0.410	0.201
LEDU	0.300	0.160	1.880	0.103
LTI	-0.462*	0.211	-2.190	0.065
C	0.224**	0.077	2.9200	0.043

Note: *,** and *** indicate 10%, 5% and 1% significance levels, respectively.

From the ARDL model, the estimated long-run coefficients reveal that LFDI and LTI have significant effects on LEF, but QUALITY and LEDU do not. In particular, a 1% rise in financial development (LFDI) increases LCO2 by 0.74%, while a 1% rise in technological innovation (LTI) reduces LCO2 by 0.46%. These findings imply that FDI-enhancing policies may favourably influence LCO2, but TI has a negative impact. However, institutional quality and education do not affect CO_2 emissions in the long run.

4.6. Short-run Dynamics of the Model

The findings of the error correction term are given in Table 7.

Table 7.
ECM regression.

Dependent variable: LCO2				
Variable	**Coeff.**	**Std. Err.**	**t-stat.**	**Prob.**
D(LCO2(-1))	0.185	0.149	1.24	0.256
D(LFDI)	-0.164***	0.451	-3.64	0.008
D(LFDI(-1))	-0.261***	0.044	-5.98	0.001
D(QUALITY)	0.105***	0.027	3.83	0.006
D(LEDU)	-0.535**	0.217	-2.47	0.043
D (LEDU(-1))	-0.531**	0.167	-3.18	0.015
CointEq(-1)	-0.644***	0.174	-3.69	0.008
R-Square	0.959			
AdjustedR^2	0.8945			

Note: ** and *** indicate 5% and 1% significance levels, respectively.

As shown in Table 7, the ECM regression estimates reveal the short-run dynamics that affect LCO2. The coefficient on D(LFDI) is -0.164 and 1% significant ($p = 0.008$) and indicates that foreign direct investment is a short-run negative force behind CO2 emissions. The lagged variable, D(LFDI(-1)), possesses an even larger negative coefficient (-0.261, $p = 0.001$), supporting this relationship over time. D(QUALITY) is significantly and positively correlated (0.105, $p = 0.006$), suggesting that increasing institutional quality leads to greater emissions in the short run. Both D(LEDU) and its lagged version (D(LEDU(-1))) are both significant and negative (-0.535, $p = 0.043$ and -0.531, $p = 0.015$, respectively), suggesting that improving education leads to decreased emissions. The error correction term (CointEq(-1)) is -0.644 and is significant at ($p = 0.008$), proving the presence of a stable long-run relationship with around 64.4% of errors corrected each time period. Good fit of the model is represented by high R-squared (0.9590) and Adjusted R-squared (0.8945) as it accounts for a majority of CO_2 emission variability.

4.7. Diagnostic Tests

The estimators derived from the Autoregressive Distributed Lag (ARDL) model are deemed dependable solely in the absence of heteroscedasticity and serial correlation. Consequently, a series of diagnostic assessments are conducted to ascertain the existence of prevalent issues such as autocorrelation, heteroskedasticity, residual normality, and model stability. Specifically, the Breusch-Godfrey serial correlation LM test, Cameron & Trivedi's Decomposition of IM Test, Jarque-Bera normality test, Ramsey RESET Test, and recursive CUSUM test were applied, as elucidated in Table 8. These findings indicate that the model does not suffer from heteroscedasticity or serial correlation, as evidenced by F-statistics and Chi-square p-values exceeding 0.05. The Jarque-Bera statistic of 0.35, with a corresponding p-value of 0.84, confirms that the residuals follow a normal distribution. The RESET test results further validate the correct model specification. Overall, the diagnostic tests support the statistical significance and reliability of the ARDL model.

Table 8.
Diagnostic tests for the ARDL approach.

Diagnostic test	Coeff.	Prob.	Outcomes
Breusch-Godfrey Serial Correlation LM Test	2.022	0.155	No serial correlation exists
Cameron & Trivedi's Decomposition of IM Test	19.00	0.392	No heteroscedasticity exists
Jarque-Bera	0.349	0.840	Residuals are normally distributed
Ramsey RESET Test	0.480	0.715	Model is correctly specified

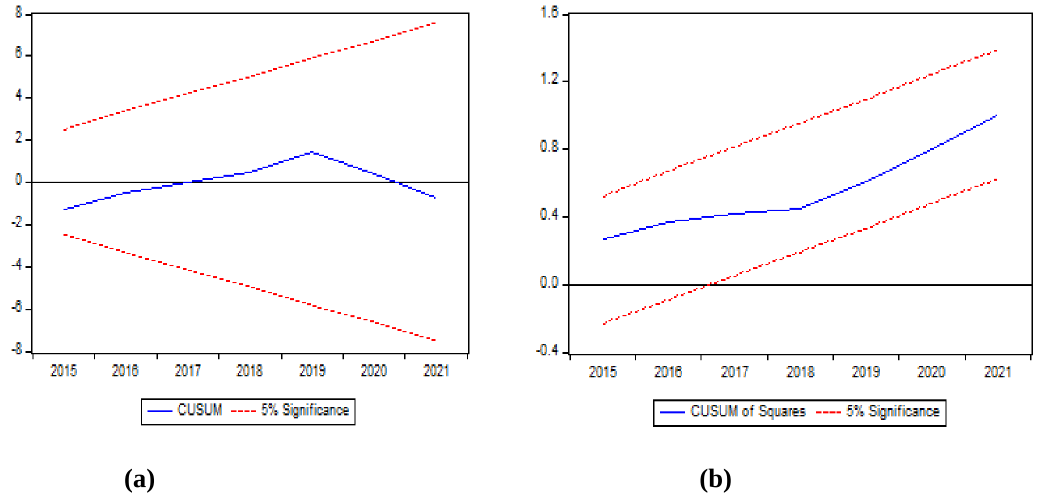

Figure 2.
Results of CUSUM test (a) and CUSUM squared test (b).

The long-term stability of the model was further corroborated through the implementation of the CUSUM test and the CUSUM squared test, as illustrated in Figure 2a-b. The graphical representations of both the CUSUM and CUSUM squared tests remain within critical limits, indicating model stability. These findings confirm the model's consistency over the study period, reinforcing its suitability for analyzing causality and long-term relationships.

4.8. Discussion

The results in Table 6 show a significant positive log-run relationship between carbon emissions and financial development, measured by LFDI, which means that foreign inflows of investment increase environmental degradation in Costa Rica. Our findings concur with Abbasi and Riaz [27], who concluded that financial development initially rises with emissions but afterwards encourages environmental sustainability. Our result shows that higher FDI promotes economic growth, industrialization, and urbanization, leading to higher energy consumption and emissions. Costa Rica's environmental sustainability policy, with its strong emphasis on renewable energy, reforestation, and carbon neutrality goals, aims to mitigate these effects. The country has invested considerable capital in clean energy, with renewable sources generating over 99% of electricity, and implemented tough environmental policies to balance financial development with sustainable growth. As long as the policies continue, Costa Rica can finally break the link between carbon emissions and financial development.

CO_2 emissions have a significant inverted relationship with technological innovation. This finding indicates how the development of technology enables fewer carbon emissions. On one hand, our findings provide substantial support for the endogenous growth theory, which emphasizes the significance of technological advancement in mitigating environmental degradation; on the other hand, these outcomes are consistent with the findings of Chen and Lee [30] in high-income countries. The country's huge investment in clean energy reduces its dependence on non-renewable resources. Raising the energy efficiency of smart grids, electric vehicles, and other emerging technologies keeps lowering emissions. The environmental policies that are stringent along with fiscal incentives, motivate companies across sectors to implement environment-friendly technologies. Due to this, Costa Rica's focus on technology enables it to have sustainable economic development while minimizing its impact on the environment.

CO_2 emissions do not appear to have a relationship with institutional quality and education. Institutional quality has a negative, insignificant effect on CO_2 emissions, but education has a positive, insignificant effect.

The results in Table 7 show that an increase in the institutional quality (QUALITY) exerts a short-term increase in CO_2 emissions, which means that institutional quality contributes to environmental degradation. Our findings contradict those of Salman et al. [31] and Mukhtarov et al. [32]. The short-run jump in CO_2 emissions due to enhanced institutional quality in Costa Rica means that higher governance initially generates economic growth, industrialization, and higher energy consumption. Higher investments and projects are drawn into better institutions, and these are of temporary environmental concern. Rule changes may also contribute to more emissions before introducing cleaner technologies. Foreign direct investment into dirty sectors can also bring about this short-run effect. However, in the longer run, superior institutional quality should make environmental policy more effective, promote green technology, and reduce CO_2 emissions over time.

The data in Table 7 indicate that the current and the previous year's improvements in financial development negatively influence Costa Rica's CO_2 emissions in the short term, which contradicts EKC's assumption that economic growth always increases pollution before a turning point. This result shows that more financial resources facilitate sustainable investment and cleaner technology. With increasing financial growth, industries and firms can adopt energy-saving measures, invest in clean energy, and follow green standards, which leads to reduced emissions. Moreover, the presence of green finance and public incentives can also accelerate low-carbon transformation. The impact of last year demonstrates a continued effect, where economic growth continues to drive environmental gains in the long term. The trend demonstrates Costa Rica's commitment to maintaining economic growth aligned with sustainability through stable financial growth.

Education follows a pattern similar to that of financial development. Their current and the previous year's levels negatively influence Costa Rica's CO_2 emissions in the short term. This finding aligns with the ecological modernization theory, suggesting that education facilitates economic transitions toward sustainability, and is consistent with the results of Aytun and Akin [19] and Xin et al. [20]. The negative short-run impact suggests that further education results in environmental awareness, technological advancement, as well as environmental sustainability. Educated individuals are likely to maintain green lifestyles, promote green policies, and develop research that facilitates clean energy and efficiency. Additionally, a well-trained labor force forces industries to deploy sustainable technologies and reduce the consumption of fossil fuel. Last year's impact implies a cumulative one, where constant education can build long-term environmental responsibility. It is a trend that reflects the strength of education in driving sustainability and reducing carbon emissions through knowledge and innovation.

5. Conclusion

This study investigates the impact of financial development, institutional quality, education, and technological innovation on environmental degradation in Costa Rica during the period between 1995 and 2021 within the ARDL-ECM framework. The results obtained indicate that, in the long run, financial development increases ecological deterioration, but technological innovation plays a significant role in curbing environmental degradation. However, in the short term, institutional quality appears to worsen the environmental measure, while financial development and education levels have a negative relationship with environmental degradation.

The evidence implies that Costa Rica can implement policies to balance economic development and environmental sustainability by encouraging green investment and low-carbon technology. Institutional quality can be insulated from its short-run negative effects on economic growth by building institutional frameworks such that growth aligns with environmental legislation.

Additionally, further reducing ecological decline is possible through an increase in education programs dedicated to sustainability and environmental consciousness. Encouraging technological innovation through incentives and research grants will enhance long-term environmental conservation. In most cases, policies need to integrate financial growth, governance improvement, education, and innovation to achieve sustainable development and minimize environmental degradation.

Despite producing valuable findings, this study has some limitations. These ought to be seen as chances for more research on this subject in the future. Subsequent research could explore sector-specific impacts of financial development and innovation on CO_2 emissions to provide more policy-relevant evidence for sectors like agriculture, energy, and manufacturing.

Comparing with other nations in Latin America could further the understanding of financial development and sustainability in Latin America. Second, evaluating the effectiveness of climate policies in Costa Rica and examining microeconomic activity at firm and household levels would tell us more about the interdependence between ecological sustainability and economic development. These avenues would facilitate improved policy advice and a better comprehension of the dynamics between development and ecological sustainability.

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