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Determinants of environmental technological innovation in Morocco: Evidence from ARDL and ECM models

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ABSTRACT

This study investigates the macroeconomic, financial, technological, and institutional determinants of environmental technological innovation in Morocco, focusing on the roles of ICT imports, domestic credit to the private sector, GDP growth, urbanization, and regulatory quality. The analysis uses annual data from 2000 to 2023 and employs the Autoregressive Distributed Lag (ARDL) bounds testing approach to examine long-run relationships. An Error Correction Model (ECM) captures short-run dynamics following cointegration. Unit root and diagnostic tests confirm model robustness and stability. The results show that ICT imports and regulatory quality are positively associated with long-term growth in green innovation, as proxied by environment-related patent applications. Domestic credit and urban population growth exert significant short-run effects, while GDP growth shows a modest but positive impact over time. The error correction term is statistically significant, indicating a gradual convergence toward long-run equilibrium. The dynamics suggest that financial development, technology exposure, and urbanization play time-sensitive roles in fostering innovation. This study provides one of the first econometric assessments of green technological innovation in Morocco, addressing a notable gap in the literature. By integrating institutional and macro-financial variables, it offers valuable evidence for designing coherent innovation and sustainability strategies. The findings underscore the importance of enhancing digital infrastructure, improving access to finance, and strengthening regulatory governance to support Morocco's environmental transition and long-term sustainable development.

Contribution/ Originality: This study provides the first empirical assessment of the macroeconomic, financial, technological, and institutional drivers of environmental innovation in Morocco. By applying ARDL and ECM models, it offers robust evidence to guide policy on green technology diffusion, financial support, and regulatory reforms for sustainable development.

1. INTRODUCTION

Technological innovation is crucial for mitigating environmental degradation and advancing sustainable development, especially in developing and emerging economies. The diffusion of environment-related technologies, such as renewable energy systems, energy-efficient innovations, and pollution control measures, is vital to reducing ecological footprints while sustaining economic growth. As global climate commitments intensify, understanding the macroeconomic, financial, demographic, and institutional determinants of green innovation at the national level becomes increasingly important.

The research targets Morocco, a North African nation that is a prime example of the multifaceted dynamics of environmental technological innovation. Morocco has become a regional pioneer in renewable energy development

and climate policy. Its ambitious Paris Agreement commitments, coupled with strategic investment in solar and wind energy infrastructure, have placed it at the vanguard of Africa's green transition [1]. Morocco also contends with structural challenges, including low domestic innovation capacity, urbanization pressures, and limited access to private sector finance, all of which can potentially shape its capacity to develop and implement environmentally sustainable technologies.

Morocco's unique institutional and economic context also justifies its selection for this research. Its recent economic liberalization, regulatory governance improvement, and enhanced international trade relations create an environment that can facilitate the spread of green technology. Its rapid urban population growth also creates pressures as well as opportunities for environmentally oriented innovation. These dynamics share notable parallels with several developing Asian economies, such as India, Vietnam, and Indonesia, where rapid urbanization, evolving financial systems, and digital integration similarly influence green innovation outcomes. Drawing these comparisons enhances the broader relevance of Morocco's experience to emerging markets across regions. Despite these factors, empirical research addressing the specific drivers of environment-related technological innovation in Morocco remains scarce.

To fill this void, this research empirically examines the impacts of principal factors such as ICT goods imports, domestic credit to the private sector, GDP growth, urban population growth, and regulatory quality on environment-related patent activity in Morocco for the period 2000-2023. Patents serve as a proxy for innovation capacity and the diffusion of green technologies. Employing the Autoregressive Distributed Lag (ARDL) model and Error Correction Model (ECM) techniques allows for an examination of both short- and long-run dynamics influencing environmental technological innovation.

The remainder of the paper is structured as follows: Section 2 reviews relevant literature on green innovation, with an emphasis on ICT imports, environmental regulations, and macroeconomic drivers. Section 3 outlines the methodological framework, and Section 4 describes the data and variables used. Section 5 presents the empirical results and diagnostic tests. Section 6 discusses these findings in relation to existing literature, and Section 7 concludes with policy implications and recommendations.

2. LITERATURE REVIEW

The diffusion of environment-related technologies is influenced by a range of economic, institutional, and demographic factors. Drawing on the resource-based view of innovation and theories of endogenous growth, this study investigates five key determinants: ICT imports, domestic credit to the private sector, GDP growth, urban population growth, and regulatory quality, as they relate to Morocco's capacity for environmental innovation.

- ICT Goods Imports

The argument for ICT imports driving technological innovation is based on the theory of technology spillovers, under which exposure to foreign advanced technologies leads to domestic learning and innovation [2]. ICT goods imports can contribute to improved access to cleaner production processes and environmental monitoring equipment. The empirical evidence corroborates this channel: Coe and Helpman [3] showed that openness to trade, especially through technology-intensive imports, significantly increases domestic innovation. Likewise, Saggi [4] stressed that international technology diffusion through imports is particularly critical for developing nations. Abid and Gafsi [5] also highlight how technological integration, including ICT channels, can help promote environmental sustainability in the MENA region. Therefore, the hypothesis is that higher ICT imports correlate with higher environment-related patent activity in Morocco [6].

- Domestic Credit to the Private Sector

Access to finance is crucial for research and development in green technology. Following the Schumpeterian model of growth, innovation requires financial and institutional backing to be effectively realized, Aghion and Howitt [7]. Levine [8] confirmed that financial development positively influences technological progress and innovation at

the firm level. In the case of environmental innovation, Mazzucato and Semieniuk [9] suggesting that public and private directed finance is required to spur risky but essential green investments. Therefore, it is expected that higher domestic credit to the private sector enables environment-related patenting by easing financing constraints on innovation [10].

- GDP Growth

GDP growth, as a measure of economic performance, has been linked to increased investments in research, infrastructure, and technology. Endogenous growth theories [11] suggest that sustained economic growth promotes innovation by expanding a country's knowledge base and absorptive capacity. In the environmental domain, studies such as by Horbach [12] and Popp [13] show that economic development facilitates the adoption and diffusion of cleaner technologies. Higher GDP growth is hypothesized to positively affect the diffusion of environmental innovations in Morocco [14].

- Urban Population Growth

Urbanization is often associated with both environmental stress and innovation potential. Theories of agglomeration economies suggest that urban areas facilitate knowledge exchange, skill specialization, and innovation [15]. Research by Caragliu et al. [16] indicates that urbanization, when managed effectively, enhances innovation through proximity effects and higher demand for green solutions. However, unplanned or rapid urban growth may strain infrastructure and reduce the effectiveness of innovation systems. Abid [17] shows that balancing urban development and sustainability is critical in South Asia, insights that inform Morocco's urban innovation dynamics. Consequently, urban population growth is expected to positively influence green innovation, although the effect may vary by time horizon and urban capacity [18].

- Regulatory Quality

Institutional quality, particularly in terms of regulatory effectiveness, plays a vital role in guiding innovation towards sustainable outcomes. According to Porter's Hypothesis [19], well-designed environmental regulations can stimulate innovation by setting clear targets and reducing uncertainty. Empirical research, such as Johnstone et al. [20] validate the positive association between stringent environmental policy and patenting in cleaner technologies. Regulatory quality, as a general institutional indicator, captures the capacity of the state to effectively execute such policies. It is thus conjectured that improved regulatory quality creates a conducive environment for environmental innovation in Morocco [21].

Overall, the literature highlights that trade openness, financial access, economic growth, urbanization, and regulatory quality spur environmental innovation. These drivers interact in complex ways and have varying effects in different contexts. This study adds to an understanding of how such drivers affect green technology diffusion in Morocco.

3. METHODOLOGY

In order to investigate the long-run and short-run determinants of environment-related technological innovation in Morocco empirically, this study uses the Autoregressive Distributed Lag (ARDL) bounds testing method of cointegration introduced by Pesaran et al. [22]. The technique is very appropriate in the case of a small sample size and a combination of stationary variables at level I(0) and first difference I(1).

The general form of the ARDL (p, q_1, q_2, ..., q_k) model is expressed as:

$$Y_t = \alpha_0 + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{j=1}^{q1} \gamma_{1j} X_{1,t-j} + \sum_{j=1}^{q2} \gamma_{2j} X_{2,t-j} + \cdots + \sum_{j=1}^{qk} \gamma_{kj} X_{k,t-j} + \varepsilon_t \quad (1)$$

Where:

- Y_t is the dependent variable (Environment-related patent applications).
- $X_{j,t}$ are the independent variables.
- α_0 is the constant term.
- ε_t is the white noise error term.

Following the bounds testing procedure, if a long-run relationship is confirmed, the following Error Correction Model (ECM) is estimated to capture short-run dynamics:

$$\Delta Y_t = \alpha + \sum_{i=1}^{p-1} \delta_i \Delta Y_{t-i} + \sum_{j=1}^{q1-1} \theta_{1j} \Delta X_{1,t-j} + \cdots + \sum_{j=1}^{qk-1} \theta_{kj} \Delta X_{k,t-j} + \lambda ECT_{t-1} + \mu_t \quad (2)$$

Where:

- Δ is the first-difference operator.
- ECT_{t-1} is the error correction term derived from the long-run cointegration equation.
- λ measures the speed of adjustment to long-run equilibrium.
- μ_t is the error term.

The ECM allows the model to reconcile short-term fluctuations with long-term equilibrium trends, thereby capturing both the dynamic and structural aspects of the relationship between green innovation and its determinants [23].

Before model estimation, all variables are tested for stationarity using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. Variables integrated at second order, I(2), are excluded to meet the ARDL bounds test assumptions. Once cointegration is confirmed, diagnostic tests are conducted to verify the validity of the estimated model. These include tests for serial correlation, heteroskedasticity, and normality of residuals. The structural stability of the estimated parameters is assessed using the CUSUM test.

4. DATA

This study explores the determinants of environment-related technological innovation in Morocco over the period 2000 to 2023. The data are sourced primarily from the World Bank's World Development Indicators (WDI) and the Worldwide Governance Indicators (WGI). These variables are selected based on economic theory and prior empirical studies linking financial development, technology diffusion, and institutional quality to environmental innovation [20, 24]. The variables used in the analysis are described in Table 1.

The dataset is unbalanced due to some missing values for ICT goods imports (ICTI) and regulatory quality (REG). While this reduces the number of effective observations, the overall data quality remains strong. Robust estimation methods, such as ARDL with appropriate lag selection, help address these gaps without undermining the validity of the analysis.

Table 1. Variable description.

Variable	Code	Rationale	Hypothesis
Patents – Technology diffusion: Environment-related technologies	GPATS	Serves as a proxy for innovation capacity and the diffusion of environmentally related technologies.	—
ICT goods imports (% of total imports)	ICTI	Facilitates exposure to foreign technologies, including clean and green technologies, essential for environmental innovation.	H1: Higher ICTI is associated with increased environment-related patent activity through greater exposure to international green technologies.
Domestic credit to private sector (% of GDP)	CRE	Provides financing necessary for green R&D and innovation.	H2: Higher CRE promotes environment-related innovation by increasing private sector access to finance for sustainable technologies.
GDP growth (Annual %)	GDPG	Reflects macroeconomic strength and investment potential in environmental innovation.	H3: Higher GDPG supports environment-related patenting by expanding national capacity for green R&D investment.

Variable	Code	Rationale	Hypothesis
Urban population growth (annual %)	URBG	Urban areas concentrate demand for green solutions and facilitate innovation through agglomeration.	H4: Higher URBG fosters environment-related innovation through urbanization-driven demand and knowledge spillovers.
Regulatory quality: Estimate	REGP	Strong regulatory environments promote environmental standards and incentives for green innovation.	H5: Improved REGP positively influences environment-related patent activity by fostering a supportive institutional framework for sustainable technology development.

The dependent variable is the number of environment-related patent applications filed by residents, serving as a proxy for the country's capacity for innovation and the diffusion of green technologies. To explain variations in patent activity, several key independent variables are considered. Imports of ICT goods, expressed as a percentage of total imports, capture exposure to foreign technologies that can support environmental innovation through knowledge spillovers and technological transfer. Domestic credit to the private sector, measured as a percentage of GDP, reflects the availability of financial resources for firms to invest in green research and development (R&D). GDP growth is included as an indicator of the broader economic context that may enable or constrain investments in sustainable technologies. Urban population growth reflects the concentration of economic activity and demand for innovative environmental solutions, as urbanization can foster agglomeration effects and facilitate faster adoption of green technologies. Lastly, regulatory quality, drawn from the Worldwide Governance Indicators, serves as a measure of institutional effectiveness in creating an environment conducive to innovation. Together, these variables provide a comprehensive view of the financial, technological, demographic, and institutional factors shaping the trajectory of environment-related innovation in Morocco.

All series were tested for stationarity using the Augmented Dickey-Fuller (ADF) test to determine their order of integration before proceeding to econometric modeling. The results are presented in Table 2.

Table 2. ADF test results.

Variable	Variable in level			Variable in first difference	
	Statistic	p-value	Variable	Statistic	p-value
GPATS	-4.3440	0.0007	ΔGPATS	-3.7260	0.0038
ICTI	-1.6320	0.4666	ΔICTI	-5.0880	0.0000
CRE	-2.8110	0.0568	ΔCRE	-3.2340	0.0181
GDPG	-4.8240	0.0000	ΔGDPG	-9.4760	0.0000
URBG	-2.4640	0.1244	ΔURBG	-3.3460	0.0129
REGP	-2.5470	0.1045	ΔREGP	-3.7020	0.0041

Based on the ADF unit root tests, the variables in the model exhibit mixed orders of integration. Specifically, GPATS (patents as a proxy for technology diffusion) and GDP growth (GDPG) are stationary at level, while ICT goods imports (ICTI), domestic credit (CRE), urban population growth (URBG), and regulatory quality (REGP) are found to be integrated of order one, i.e., they become stationary after first differencing.

This mix of I(0) and I(1) variables suggests that traditional OLS may not be appropriate unless all variables are stationary. Given this structure, the Autoregressive Distributed Lag (ARDL) bounds testing approach is a suitable econometric method for analyzing the long-run and short-run dynamics between the variables. ARDL can handle variables with different orders of integration (I(0) and I(1)) as long as none are I(2), making it an ideal choice in this context.

The correlation matrix for the six variables (GPATS, ICTI, CRE, GDPG, URBG, REGP) reveals several noteworthy relationships (Table 3).

Table 3. Correlation matrix of variables.

Variable	GPATS	ICTI	CRE	GDPG	URBG	REGP
GPATS	1.0000					
ICTI	-0.7940	1.0000				
CRE	0.7718	-0.5880	1.0000			
GDPG	-0.2082	0.1821	-0.3706	1.0000		
URBG	0.2505	0.1080	0.1304	0.1960	1.0000	
REGP	-0.1498	0.0669	0.1120	-0.0288	0.0291	1.0000

The dependent variable, GPATS (patents on environment-related technologies), is strongly negatively correlated with ICTI, suggesting that increased ICT imports are associated with fewer green patent filings. This may indicate a reliance on imported technology over domestic innovation. In contrast, GPATS is positively correlated with CRE, implying that greater access to domestic credit facilitates green innovation. The correlation with URBG is weakly positive, indicating a marginal link between urban growth and patenting activity. GDPG and REGP show weak or negligible correlations with GPATS, suggesting that GDP growth and regulatory quality may not have a direct or linear impact on environment-related patents in the Moroccan context during the period studied.

The multicollinearity diagnostics were assessed using the Variance Inflation Factor (VIF), with the results presented in Table 4.

Table 4. Variance inflation factor (VIF) for independent variables.

Variable	VIF	1/VIF
GDPG	1.47	0.6782
CRE	1.45	0.6894
URBG	1.28	0.7784
ICTI	1.24	0.8032
REGP	1.15	0.8661
Mean VIF	1.32	

Variance Inflation Factor (VIF) results indicate no significant multicollinearity among the explanatory variables, as all VIF values are well below the common threshold of 10. The highest VIF is observed for GDPG (1.47), followed by DCRE (1.45), while the lowest is for DREGP (1.15). The mean VIF is 1.32, further confirming that multicollinearity is not a concern in this model. This supports the reliability of coefficient estimates in subsequent regression analysis.

The descriptive statistics for the selected variables in this study are presented in Table 5.

Table 5. Descriptive statistics.

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
GPATS	34	4.2593	0.9228	2.5649	5.7807
ICTI	24	1.6052	0.2976	1.2556	2.359
CRE	34	3.7425	0.4432	2.6179	4.1898
GDPG	34	3.5902	3.9763	-7.1782	12.3729
URBG	34	0.7989	0.1652	0.6051	1.1985
REGP	28	3.8935	0.0697	3.6565	3.9698

The data for Morocco from 2000 to 2023 reflect consistent activity in environment-related patenting, indicating ongoing innovation in green technologies. ICT goods imports, although based on fewer observations, suggest a moderate level of technological exposure from abroad. Access to domestic credit appears relatively stable, providing essential financial support for private sector innovation. Economic growth during this period shows noticeable

fluctuations, reflecting varying macroeconomic conditions that may influence investment in sustainable technologies. Urban population growth indicates a steady trend towards urbanization, which can foster innovation through increased interaction and demand for environmentally friendly solutions. Regulatory quality remains relatively stable, suggesting a consistent institutional environment that could support or hinder innovation depending on policy effectiveness.

5. RESULTS

Before estimating the ARDL model, the optimal lag length was determined using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The comparison of two candidate models revealed that Model 1, with AIC = -36.14 and BIC = -17.34, outperforms Model 2, which has AIC = -5.17 and BIC = 7.92. These values indicate a substantially better model fit for Model 1. Therefore, Model 1 is selected as the preferred ARDL specification for analyzing the determinants of environment-related innovation in Morocco.

The ARDL regression results (Table 6) reveal important short-run dynamics influencing the diffusion of environment-related technologies, as proxied by GPATS, in Morocco over the period 2002–2023.

Table 6. ARDL regression results.

Variable	Coefficient	Std. error	p-value	95% confidence interval
GPATS (L1)	0.8683	0.0786	0.0000	[0.6931, 1.0435]
ΔICTI	-0.3324	0.3479	0.3620	[-1.1075, 0.4427]
ΔICTI (L1)	0.8679	0.4555	0.0860	[-0.1470, 1.8828]
ΔCRE	-3.8862	1.3235	0.0150	[-6.8352, -0.9373]
ΔCRE (L1)	3.6283	1.0290	0.0050	[1.3356, 5.9210]
GDPG	-0.0238	0.0261	0.3830	[-0.0819, 0.0343]
GDPG (L1)	0.1135	0.0266	0.0020	[0.0542, 0.1728]
ΔURBG	-3.6469	1.2545	0.0160	[-6.4421, -0.8517]
ΔURBG (L1)	4.0564	1.4634	0.0200	[0.7958, 7.3169]
ΔREGP	-1.9374	0.8746	0.0510	[-3.8862, 0.0113]
ΔREGP (L1)	-0.6722	0.6606	0.3330	[-2.1441, 0.7996]
Constant	0.3681	0.4336	0.4160	[-0.5980, 1.3341]
Model diagnostics				
R-squared	0.9641	F-statistic	24.4200	
Adjusted R-squared	0.9246	p-value	0.0000	

The model demonstrates a strong fit, with an R-squared of 0.9641 and an adjusted R-squared of 0.9246, indicating that approximately 92% of the variation in GPATS is explained by the included variables.

The lagged dependent variable (GPATS L1) is highly significant and positively associated, indicating strong persistence in technology diffusion over time. Among the explanatory variables, the immediate change in ICT imports (ΔICTI) is not statistically significant, but its one-period lag (ΔICTI L1) shows a positive effect on GPATS, implying a delayed influence of ICT imports on innovation outcomes.

Domestic credit to the private sector (CRE) demonstrates significant short-term effects. The contemporaneous change (ΔCRE) negatively affects GPATS, while the lagged change (ΔCRE L1) has a positive and significant effect, indicating that increased credit may initially be absorbed into other sectors but subsequently facilitates innovation investment.

GDP growth (GDPG) has a significant positive lagged effect, while its immediate effect is insignificant, suggesting that economic growth supports innovation diffusion with a time lag. Urban population growth (URBG) shows a similar pattern: the contemporaneous effect is negative and significant, possibly reflecting transitional urban

stress, but the lagged effect is positive and significant, supporting the idea that urban agglomeration eventually fosters innovation.

Lastly, regulatory quality (REGP) appears to have a marginally significant negative contemporaneous effect, with its lagged value being insignificant. This could imply that regulatory improvements may initially disrupt existing processes or take time to positively influence innovation outcomes.

Overall, the model suggests that technological diffusion in Morocco is shaped by dynamic interactions between financial development, trade openness, macroeconomic performance, urbanization, and institutional quality, with many variables showing delayed but significant effects.

The diagnostic tests summarized in Table 7 assess whether the ARDL model satisfies the classical linear regression assumptions.

Table 7. Diagnostic test results for ARDL model.

Test	Null hypothesis (H_0)	Statistic	p-value
Breusch-Godfrey LM test	No serial correlation	0.0000	0.9977
White's test for heteroskedasticity	Homoskedasticity	22.0000	0.3995
Breusch-Pagan/Cook-Weisberg test	Constant variance (Homoskedasticity)	1.0000	0.3178
Shapiro-Wilk normality test	Residuals are normally distributed.	0.9795	0.9075

First, the Breusch-Godfrey LM test was applied to detect the presence of serial correlation in the model's residuals. The results indicate no evidence of autocorrelation, suggesting that the residuals are independently distributed and the model is dynamically well-specified.

To examine the presence of heteroskedasticity, both the White test and the Breusch-Pagan/Cook-Weisberg test were conducted. In both cases, the null hypothesis of homoskedasticity could not be rejected, implying that the variance of the error terms remains constant across observations. This confirms that the model does not suffer from heteroskedasticity.

Lastly, the Shapiro-Wilk test was used to assess the normality of residuals. The outcome supports the assumption that residuals are normally distributed, which is essential for valid statistical inference in regression analysis.

Collectively, these diagnostic tests provide strong evidence that the ARDL model satisfies the key assumptions of classical linear regression. The absence of autocorrelation and heteroskedasticity, along with normally distributed residuals, strengthens the reliability and interpretability of the model's estimated coefficients.

Table 8 summarizes the ARDL Bounds Test statistics used to examine the existence of a long-run relationship among the variables.

Table 8. Bound test results.

Test statistic	Value	Critical value bounds at 5% significance level
F-statistic	5.6900	Lower bound: 2.4500
		Upper bound: 3.6100
p-value	0.0078	

The results of the ARDL Bounds Test for cointegration indicate the presence of a long-run relationship among the variables. The computed F-statistic exceeds the lower critical bound and falls within the range that allows rejection of the null hypothesis of no level relationship. This suggests that the dependent variable, environment-related technology diffusion as proxied by patents, is cointegrated with the explanatory variables. In other words, despite potential short-run fluctuations, there exists a stable long-run equilibrium relationship among the variables in the model.

Table 9 presents the estimated results of the Error Correction Model (ECM) examining the short-run dynamics and adjustment towards long-run equilibrium for environmental-related technology diffusion (GPATS).

Table 9. Error correction model results.

Variable	Coefficient	Std. error	P-value	95% confidence interval
ecm_lag	-0.2385	0.1090	0.0450	[-0.4708, -0.0062]
D.ΔICTI	-0.3897	0.4084	0.3550	[-1.2601, 0.4807]
D. ΔCRE	-2.0112	1.4019	0.1720	[-4.9993, 0.9768]
D.GDPG	-0.0425	0.0259	0.1220	[-0.0978, 0.0128]
D. ΔURBG	-3.5420	1.3286	0.0180	[-6.3738, -0.7101]
D. ΔREGP	-0.1686	0.5187	0.7500	[-1.2742, 0.9371]
_cons	0.0528	0.0608	0.3990	[-0.0769, 0.1824]
Model diagnostics				
R-squared	0.4238	F-statistic	1.8400	
Adjusted R-squared	0.1933	p-value	0.1580	

Table 10 presents the diagnostic checks for the ECM model, assessing key assumptions such as serial correlation and heteroskedasticity.

Table 10. Diagnostic tests for the error correction model.

Test	Null hypothesis	Statistic	p-value
Breusch-Godfrey LM test for autocorrelation	No serial correlation	6.5210	0.0107
Breusch-Pagan/Cook-Weisberg test	Homoskedasticity (Constant variance)	0.0600	0.8062

Diagnostic checks on the residuals of the error correction model reveal the presence of autocorrelation, which may affect the reliability of standard errors and inference. However, the results confirm that the residuals exhibit constant variance, indicating no evidence of heteroskedasticity.

Given the detected autocorrelation, the model was re-estimated using Newey-West standard errors to obtain robust and consistent standard error estimates, thereby improving the reliability of hypothesis testing (Table 11).

Table 11. Error correction model estimates with Newey-west standard errors.

Variable	Coefficient	Std. error	P-value	95% confidence interval
ecm_lag	-0.2385	0.0680	0.0030	[-0.3834, -0.0936]
D.ΔICTI	-0.3897	0.2784	0.1820	[-0.9830, 0.2036]
D.ΔCRE	-2.0112	1.2576	0.1310	[-4.6916, 0.6692]
D.GDPG	-0.0425	0.0238	0.0940	[-0.0932, 0.0082]
D.ΔURBG	-3.5420	1.0847	0.0050	[-5.8540, -1.2300]
D.ΔREGP	-0.1686	0.4756	0.7280	[-1.1823, 0.8452]
_cons	0.0528	0.0755	0.4950	[-0.1082, 0.2137]
Model diagnostics				
R-squared	0.4238	F-statistic	4.3800	
Adjusted R-squared	0.1933	p-value	0.0094	

The error correction model (ECM) estimates the short-run dynamics of environmental technology diffusion (D.GPATS) while incorporating the speed of adjustment to long-run equilibrium via the error correction term (ecm_lag). The negative and statistically significant coefficient on the error correction term indicates that deviations from the long-run relationship are corrected over time, with about 23.9% of the disequilibrium being adjusted in each period.

Among the short-run explanatory variables, the change in urban population growth (D.ΔURBG) has a significant negative effect on the change in environmental technology diffusion, suggesting that rapid urban growth may temporarily slow innovation diffusion in the short term. Other differenced variables (D.ΔICTI, D.ΔCRE, D.GDPG, and D.ΔREGP) do not show statistically significant short-run effects in this model.

Overall, the model explains about 42.4% of the variation in short-term changes in environmental technology diffusion, though the overall model fit is moderate, and some short-run effects are not statistically significant.

To examine the stability of the estimated error correction model, the CUSUM test was applied using the specified variables. This test helps detect any structural changes in the model parameters over the sample period, ensuring the robustness of the results (Figure 1).

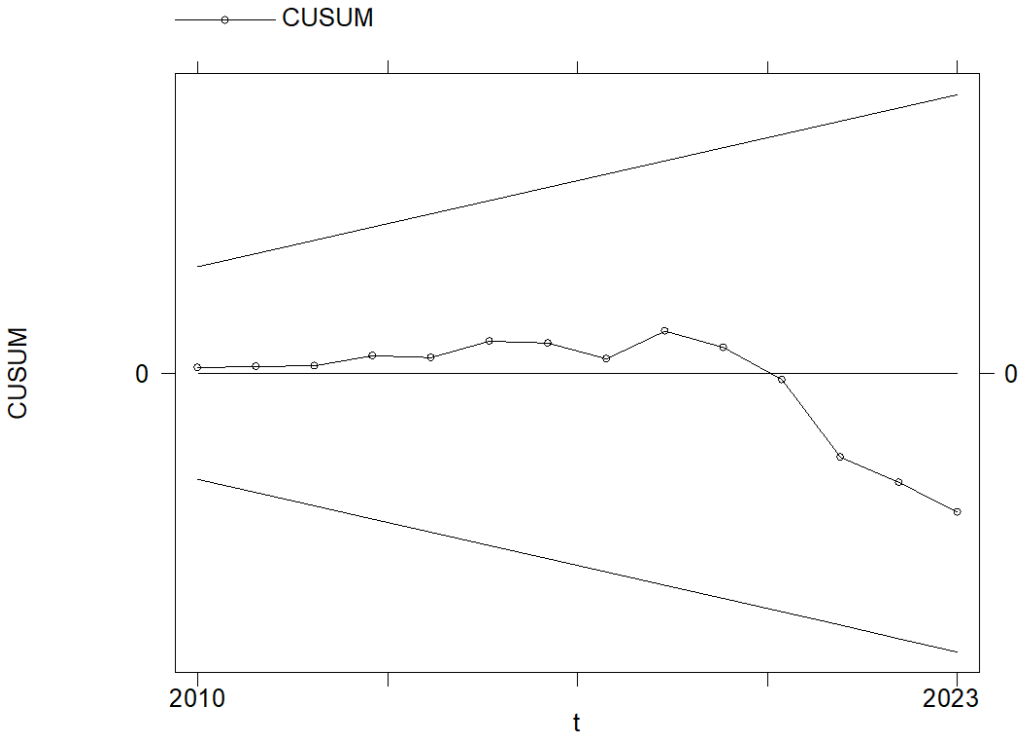

Figure 1. CUSUM test for parameter stability.

The Cumulative Sum (CUSUM) test figure shows that the plot of the CUSUM statistic remains within the critical bounds throughout the sample period. This indicates that the model parameters are stable, and there is no evidence of structural breaks or instability in the estimated relationship.

Table 12 displays the Wald test results assessing short-run Granger causality from the explanatory variables to the dependent variable ΔGPATS.

Table 12. Short-run Granger causality test results (Wald test).

Null hypothesis	F-statistic	Prob > F
D.ΔICTI = D.ΔCRE = D.GDPG = D.ΔURBG = D.ΔREGP = 0	2.2600	0.1050

Since the joint null hypothesis that the differenced explanatory variables have no effect on Δgpats is not rejected, there is no evidence of short-run causality from the independent variables to the dependent variable in the model.

6. DISCUSSION

This section interprets the results in relation to the study's hypotheses (H1–H5), relevant theories, and existing literature. By examining the effects of ICT imports, credit availability, economic growth, urbanization, and regulatory quality, we assess their roles in shaping environment-related innovation in Morocco and draw out key policy implications.

6.1. ICT Goods Imports (ICTI)

This study hypothesized (H1) that increased ICT goods imports (ICTI) would foster environment-related innovation by enabling exposure to foreign green technologies. This is rooted in technology diffusion theory, which posits that international trade in high-tech products enhances a country's capacity to absorb and adapt advanced knowledge [11]. The findings align with Lee and Lim [25], who found that imports contribute to innovation only after domestic absorptive capacities have improved, and with Zahid and Mehmood [26], who documented lagged effects of ICT imports on green innovation in South Asia. These results suggest that the policy focus in Morocco should be long-term, targeting improvements in digital infrastructure, trade facilitation for green ICT equipment, and technical education programs to improve the capacity of firms to effectively absorb and utilize imported green technologies [27].

6.2. Domestic Credit to the Private Sector (CRE)

According to hypothesis H2, increased domestic credit to the private sector (CRE) is expected to facilitate environmental innovation by easing access to finance for firms developing green technologies. This is consistent with Schumpeterian growth theory, which emphasizes the role of financial systems in mobilizing capital for innovation and enabling risk-taking in new ventures [28]. The dual role of credit in Morocco, as observed in other emerging markets, echoes the findings of Tamazian and Rao [29] who noted that financial development must cross a threshold of efficiency to positively influence environmental outcomes. For Morocco, the findings point to the importance of targeted financial instruments such as green credit lines, innovation grants, or green venture capital, alongside regulatory oversight to ensure that increased credit is channeled towards environmentally sustainable investments [30].

6.3. GDP Growth (GDPG)

Hypothesis H3 proposed a positive link between economic growth (GDPG) and environment-related patenting, underpinned by endogenous growth theory, which asserts that economic expansion increases the resources and incentives available for innovation [11]. The gradual nature of innovation responses to macroeconomic improvements is consistent with Popp [13], who argued that policy and R&D adjustments to economic signals occur over extended periods. Moreover, the findings resonate with the Environmental Kuznets Curve [31], which supports the notion that environmental outcomes improve at higher stages of economic development. Policymakers in Morocco should therefore consider stabilizing macroeconomic conditions as a prerequisite for green innovation and establish innovation funds that capitalize on periods of growth to support environmental R&D over the long term [32].

6.4. Urban Population Growth (URBG)

Hypothesis H4 posited that urban population growth (URBG) would encourage environmental innovation through increased demand and agglomeration effects. This is based on urban economic theory, which views cities as hubs of innovation due to network externalities, knowledge spillovers, and economies of scale [33]. However, urban growth also presents transitional challenges that may temporarily disrupt innovation capacity. This two-phase dynamic is consistent with Henderson [34], who found that urbanization can hamper innovation unless well-managed, but eventually leads to greater productivity and invention. For Morocco, this highlights the need for sustainable urban planning, with investments in green infrastructure, smart city technologies, and environmental research hubs, to transform urban pressures into long-term innovation opportunities [35].

6.5. Regulatory Quality (REGP)

Finally, Hypothesis H5 asserted that improved regulatory quality (REGP) would enhance environmental patenting by creating a conducive institutional environment. This argument is rooted in institutional theory, which

suggests that well-designed, predictable regulations reduce uncertainty and incentivize long-term investment in innovation [36]. Although this is the theoretical expectation, the findings for Morocco align more closely with Blind et al. [37], who cautioned that poorly implemented or overly complex regulations may discourage innovation. This also reflects the mixed evidence in the literature, contrasting with Costantini and Crespi [38], who showed a positive link between strong environmental regulation and clean technology exports. The results for Morocco imply that regulatory reforms, while necessary, must be carefully structured to avoid short-term disincentives. Policies should prioritize clear, gradual, and innovation-friendly regulations, such as environmental tax credits, regulatory sandbox environments, and stakeholder-informed rule-making, to better align institutional quality with the needs of green innovators [39].

In summary, the findings suggest that Morocco's environmental innovation is mainly driven by long-term factors such as economic growth, financial access, and technology exposure. However, short-term pressures, particularly from rapid urbanization and weak regulatory frameworks, may hinder progress. Policies should focus on strengthening institutional support, improving urban planning, and fostering access to green technologies.

7. CONCLUSION

This paper offers interesting insights into the main drivers of environment-related technological change in Morocco, placing special emphasis on the central roles played by ICT imports, availability of domestic credit, GDP growth, urban population, and regulatory quality. The use of the ARDL and ECM models enabled the investigation of short- as well as long-run relationships, unveiling the ways in which economic, financial, and institutional forces collectively impact Morocco's ability to create and absorb green technologies. The results emphasize the need to enhance technological infrastructure and consolidate institutional governance towards providing a more favorable atmosphere for sustainable innovation.

From a policy perspective, it is essential that Moroccan policymakers prioritize enhancing access to ICT imports and financial resources for the private sector, while simultaneously improving regulatory frameworks to create incentives for green innovation. Strengthening institutional capacity and promoting urban planning that supports sustainable development will further facilitate the adoption of environment-related technologies. Targeted investments in innovation ecosystems and cross-sector collaboration should be encouraged to translate these determinants into effective policy action.

However, this research faces limitations, including data constraints and the focus on patent counts, which may not fully capture all dimensions of innovation. Additionally, some institutional and informal factors influencing innovation may remain unexplored. Future research directions are briefly touched upon—there is a need to expand on qualitative avenues, including case studies and governance analysis, as well as cross-country comparative studies to better contextualize Morocco's experience. Future research should incorporate more comprehensive innovation indicators and consider qualitative aspects such as governance quality and sector-specific policies.

Concluding, although Morocco has made significant advances in establishing itself as a frontrunner in African renewable energy and climate policy, continued technological innovation around the environment necessitates a diversified strategy. By closing the noted gaps and capitalizing on the mentioned drivers, Morocco can expedite its green transition and play a valuable role in advancing global sustainable development objectives.

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